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Testing the integrated package of tools supporting decision making on identification, prediction and optimization of complex technical systems operation, reliability and safety Part 7 IS&RDSS Application – Exemplary system operation and reliability new strategy

Keywords

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Abstract

The paper presents the collection of the results concerned with the exemplary system operation, reliability, availability, maintenance and cost analysis, modelling, prediction and optimization coming from the Integrated Safety and Reliability Decision Support System - IS&RDSS application performed in its six previous parts. On the basis of the collected operation and reliability parameters and characteristics of the exemplary system before and after its operation process optimization, there is suggested its operation and reliability new strategy.

13. Input parameters and characteristics for the exemplary system operation and reliability new strategy

In this section, we collect the results concerned with the exemplary system operation, reliability, availability, maintenance and cost analysis, modelling, prediction and optimization coming from the IS&RDSS application in the previous parts [2]-[6] performed according to its scheme-algorithm included in [1].

13.1. System operation process parameters and characteristics before and after its optimization

From Section 3 [2], we have the following values of the exemplary system operation process parameters before its optimization:

- the conditional mean sojourn times of the system operation process at the particular operation states

$$M_{12} = 192,\ M_{13} = 480,\ M_{14} = 200,$$
$$M_{21} = 96,\ M_{23} = 81,\ M_{24} = 55,$$
$$M_{31} = 870,\ M_{32} = 480,\ M_{34} = 300,$$
$$M_{41} = 325,\ M_{42} = 510,\ M_{43} = 438. \qquad (314)$$

From Section 8 [4], we have the following values of the exemplary system operation process parameters after its optimization:

- the optimal conditional mean sojourn times of the system operation process at the particular operation states

$$\dot{M}_{12} = 200,\ \dot{M}_{13} = 500,\ \dot{M}_{14} \cong 1024,$$
$$\dot{M}_{21} = 100,\ \dot{M}_{23} = 100,\ \dot{M}_{24} \cong 480,$$

$$\dot{M}_{31} = 900,\ \dot{M}_{32} = 500,\ \dot{M}_{34} \cong 419,$$
$$\dot{M}_{41} = 300,\ \dot{M}_{42} = 500,\ \dot{M}_{43} \cong 487. \quad (315)$$

From Section 5 [3], we have the following values of the exemplary system operation process characteristics before its optimization:

- the unconditional mean sojourn times of the system operation process at the particular operation states

$$M_1 = 287.84,\ M_2 = 71.00,$$
$$M_3 = 397.20,\ M_4 = 399.60; \quad (316)$$

- the transient probabilities of the system operation process at the particular operation states

$$p_1 = 0.214,\ p_2 = 0.038,$$
$$p_3 = 0.293,\ p_4 = 0.455; \quad (317)$$

- the total sojourn times of the system operation process at the particular operation states during the operation time $\theta = 1$ year = 365 days

$$E[\hat{\theta}_1] = 78.1,\ E[\hat{\theta}_2] = 13.9,$$
$$E[\hat{\theta}_3] = 106.9,\ E[\hat{\theta}_4] = 166.1. \quad (318)$$

From Section 8 [4], we have the following values of the exemplary system operation process characteristics after its optimization:

- the optimal unconditional mean sojourn times of the system at the particular operation states

$$\dot{M}_1 \cong 675,\ \dot{M}_2 \cong 290,$$
$$\dot{M}_3 \cong 490,\ \dot{M}_4 = 400; \quad (319)$$

- the optimal transient probabilities of the system operation process at the particular operational states

$$\dot{p}_1 = 0.341,\ \dot{p}_2 = 0.105,$$
$$\dot{p}_3 = 0.245,\ \dot{p}_4 = 0.309; \quad (320)$$

- the optimal total sojourn times of the system operation process at the particular operation states during the operation time $\theta = 1$ year = 365 days

$$\dot{E}[\hat{\theta}_1] = 125.5,\ \dot{E}[\hat{\theta}_2] = 38.3,$$
$$\dot{E}[\hat{\theta}_3] = 89.4,\ \dot{E}[\hat{\theta}_4] = 112.8. \quad (321)$$

13.2. System reliability characteristics before and after its operation process optimization

From Section 6 [3], we have the following values of the exemplary system reliability characteristics before its operation process optimization:
- the expected values of the system unconditional lifetimes respectively in the reliability state subsets $\{1,2,3\}$, $\{2,3\}$, $\{3\}$

$$\mu(1) = 378.51,\ \mu(2) = 357.68,$$
$$\mu(3) = 341.51, \quad (322)$$

- the mean values of the unconditional lifetimes respectively in the particular reliability states 1, 2, 3

$$\bar{\mu}(1) = 20.83,\ \bar{\mu}(2) = 16.17,$$
$$\bar{\mu}(3) = 341.51. \quad (323)$$

- the moment when the system risk function exceeds a permitted level

$$\tau = 70.08. \quad (324)$$

From Sections 8 and 9 [4], we have the following values of the exemplary system reliability parameters and characteristics after its operation process optimization:
- the optimal expected values of the system unconditional lifetimes respectively in the reliability state subsets $\{1,2,3\}$, $\{2,3\}$, $\{3\}$

$$\dot{\mu}(1) = 422.94,\ \dot{\mu}(2) = 410.20,$$
$$\dot{\mu}(3) = 392.25, \quad (325)$$

- the optimal mean values of the unconditional lifetimes respectively in the particular reliability states 1, 2, 3

$$\dot{\bar{\mu}}(1) = 12.74,\ \dot{\bar{\mu}}(2) = 17.95,$$
$$\dot{\mu}(3) = 392.25, \quad (326)$$

- the optimal moment when the system risk function exceeds a permitted level

$$\dot{\tau} = 80. \quad (327)$$

13.3. System renewal and availability characteristics before and after operation process optimization

From Section 7 [3], we have the following values of the exemplary system renewal and availability characteristics before its operation process optimization:
- the expected value of the number of exceeding by the system with ignored time of renovation the reliability critical state during 1 year = 365 days

$$H(365,2) = 1.022, \quad (328)$$

- the expected value of the number of renovations of the system with non-ignored time of renovation during 1 year = 365 days

$$\overline{\overline{H}}(365,2) = 0.985, \quad (329)$$

- the steady availability coefficient of the system

$$A(t,2) = 0.97. \quad (330)$$

From Section 10 [4], we have the following values of the exemplary system renewal and availability characteristics after its operation process optimization:
- the optimal expected value of the number of exceeding by the system with ignored time of renovation the reliability critical state during 1 year = 365 days

$$\dot{H}(365,2) = 0.887, \quad (331)$$

- the optimal expected value of the number of renovations of the system with non-ignored time of renovation during 1 year = 365 days

$$\dot{\overline{\overline{H}}}(365,2) = 0.867, \quad (332)$$

- the optimal steady availability coefficient of the system

$$A(t,2) = 0.98. \quad (333)$$

13.4. Improved system reliability characteristics

From Section 11 [5], we have the following values of the exemplary system reliability characteristics with improved components:
- the expected values of the system unconditional lifetimes respectively in the reliability state subsets $\{1,2,3\}$, $\{2,3\}$, $\{3\}$

$$\mu^{(1)}(1) = 750.86, \ \mu^{(1)}(2) = 712.01,$$
$$\mu^{(1)}(3) = 678.19, \quad (334)$$

$$\mu^{(2)}(1) = 1031.05, \ \mu^{(2)}(2) = 977.87,$$
$$\mu^{(2)}(3) = 931.17, \quad (335)$$

$$\mu^{(3)}(1) = 428.03, \ \mu^{(3)}(2) = 404.89,$$
$$\mu^{(3)}(3) = 386.80, \quad (336)$$

- the mean values of the unconditional lifetimes respectively in the particular reliability states 1, 2, 3

$$\overline{\mu}^{(1)}(1) = 38.85, \ \overline{\mu}^{(1)}(2) = 33.08,$$
$$\overline{\mu}^{(1)}(3) = 678.19, \quad (337)$$

$$\overline{\mu}^{(2)}(1) = 53.18, \ \overline{\mu}^{(2)}(2) = 64.7,$$
$$\overline{\mu}^{(2)}(3) = 931.17, \quad (338)$$

$$\overline{\mu}^{(3)}(1) = 23.14, \ \overline{\mu}^{(3)}(2) = 18.9,$$
$$\overline{\mu}^{(3)}(3) = 386.80. \quad (339)$$

- the moment when the system risk function exceeds a permitted level

$$\tau^{(1)} = 272.68, \quad (340)$$

$$\tau^{(2)} = 381.88, \quad (341)$$

$$\tau^{(3)} = 77.77. \quad (342)$$

13.5. Improved system renewal and availability characteristics

From Section 11 [5], we have the following values of the exemplary system renewal and availability characteristics with improved components:
- the expected value of the number of exceeding by the system with ignored time of renovation the reliability critical state during 1 year = 365 days

$$H^{(1)}(365,2) = 0.511, \quad (343)$$

$$H^{(2)}(365,2) = 0.365, \quad (344)$$

$$H^{(3)}(365,2) = 0.913, \quad (345)$$

- the expected value of the number of renovations of the system with non-ignored time of renovation during 1 year = 365 days

$$\bar{\bar{H}}^{(1)}(365,2) \cong 0.5037, \quad (346)$$

$$\bar{\bar{H}}^{(2)}(365,2) \cong 0.369, \quad (347)$$

$$\bar{\bar{H}}^{(3)}(365,2) \cong 0.879, \quad (348)$$

- the steady availability coefficient of the system

$$A^{(1)}(t,2) \cong 0.986, \quad (349)$$

$$A^{(2)}(t,2) \cong 0.988, \quad (350)$$

$$A^{(3)}(t,2) \cong 0.976. \quad (351)$$

13.6. Results of system operation cost analysis before and after its operation process optimization

From Section 12 [6], we have the following values of the exemplary system operation cost characteristics before its operation process optimization:
- the total operation cost of the non-failed exemplary system during the operation time θ = 1 year

$$C(1) \cong 1206 \text{ PLN}, \quad (352)$$

- the total operation cost of the repairable exemplary system with ignored its renovation time during the operation time θ = 1 year

$$C_{ig}(1) \cong 1208.8 \text{ PLN}, \quad (353)$$

- the total operation cost of the repairable exemplary system with non-ignored its renovation time during the operation time θ = 1 year

$$C_{nig}(1) \cong 1210.05 \text{ PLN}. \quad (354)$$

From Section 13, we have the following values of the exemplary system operation cost characteristics after its operation process optimization:
- the optimal total operation cost of the non-failed exemplary system during the operation time θ = 1 year

$$\dot{C}(1) \cong 1064.2 \text{ PLN}, \quad (355)$$

- the optimal total operation cost of the repairable exemplary system with ignored its renovation time during the operation time θ = 1 year

$$\dot{C}_{ig}(1) \cong 1066.6 \text{ PLN}, \quad (356)$$

- the optimal total operation cost of the repairable exemplary system with non-ignored its renovation time during the operation time θ = 1 year

$$\dot{C}_{nig}(\theta) \cong 1067.8 \text{ PLN}. \quad (357)$$

13.7. Results of the non-improved and improved system operation cost analysis before and after its operation process optimization

From Section 12 [6], we have the following values of the improved exemplary system operation cost characteristics before its operation process optimization:
- the total operation cost of the non-failed exemplary system during the operation time θ = 1000 days

$$C^{(0)}(1000) \cong 12\,060 \text{ PLN}, \quad (358)$$

$$C^{(1)}(1000) \cong 24\,120 \text{ PLN}, \quad (359)$$

$$C^{(2)}(1000) \cong 18\,090 \text{ PLN}, \quad (360)$$

$$C^{(3)}(1000) \cong 18\,090 \text{ PLN}. \quad (361)$$

- the total operation cost of the repairable exemplary system with ignored its renovation time during the operation time θ = 1000 days

$$C_{ig}^{(0)}(1000) \cong 12\,200 \text{ PLN} \quad (362)$$

$$C_{ig}^{(1)}(1000) \cong 24\,260 \text{ PLN} \quad (363)$$

$$C_{ig}^{(2)}(1000) \cong 18\,166.5 \text{ PLN} \quad (364)$$

$$C_{ig}^{(3)}(1000) \cong 18\,460.5 \text{ PLN} \quad (365)$$

- the total operation cost of the renewed exemplary system with ignored its renovation time during the operation time θ = 1000 days

$$C_{nig}^{(0)}(1000) \cong 13\,420 \text{ PLN} \quad (366)$$

$$C_{nig}^{(1)}(\theta) \cong = 25\,510 \text{ PLN}, \quad (367)$$

$$C_{nig}^{(2)}(\theta) \cong 18\,847.50 \text{ PLN} \quad (368)$$

$$C_{nig}^{(3)}(1000, \rho(2)) \cong 21\,705 \text{ PLN} \quad (369)$$

From Section 12 [6], we have the values of the following improved exemplary system operation cost characteristics after its operation process optimization:
- the optimal total operation cost of the non-failed exemplary system during the operation time θ = 1 year

$$\dot{C}^{(0)}(1000) \cong 10\,642 \text{ PLN}, \quad (370)$$

$$\dot{C}^{(1)}(1000) \cong 21\,284 \text{ PLN}, \quad (371)$$

$$\dot{C}^{(2)}(1000) \cong 15\,963 \text{ PLN}, \quad (372)$$

$$\dot{C}^{(3)}(1000) \cong 15\,963 \text{ PLN}, \quad (373)$$

- the optimal total operation cost of the repairable exemplary system with ignored its renovation time during the operation time θ = 1000 days

$$\dot{C}_{ig}^{(0)}(1000) \cong 10\,764 \text{ PLN}, \quad (374)$$

$$\dot{C}_{ig}^{(1)}(1000) \cong 21\,412 \text{ PLN}, \quad (375)$$

$$\dot{C}_{ig}^{(2)}(1000) \cong 16\,032.75 \text{ PLN}, \quad (376)$$

$$\dot{C}_{ig}^{(3)}(1000) \cong 16\,285.5 \text{ PLN}, \quad (377)$$

- the optimal total operation cost of the renewed exemplary system with ignored its renovation time during the operation time θ = 1000 days

$$\dot{C}_{nig}^{(0)}(1000) \cong 11\,832 \text{ PLN}, \quad (378)$$

$$\dot{C}_{nig}^{(1)}(1000) \cong 22\,544 \text{ PLN}, \quad (379)$$

$$\dot{C}_{nig}^{(2)}(1000) \cong 16\,660.50 \text{ PLN}, \quad (380)$$

$$\dot{C}_{nig}^{(3)}(1000, \rho(2)) \cong 19\,123 \text{ PLN}. \quad (381)$$

13.8. Results of system corrective and preventive maintenance policy optimization

In Section 12 [6], we fixed that there is no optimal value $\dot{\eta}$ of the exemplary system preventive maintenance period η that maximize the value of its availability coefficient. The values of the system preventive maintenance period η and the values of the availability coefficient of the exemplary system that are given in *Table 4* justify that the system availability coefficient is an increasing function of the preventive maintenance period.

In Section 12 [6], we fixed that there is no optimal value $\dot{\varsigma}$ of the exemplary system age ς at which the system preventive renovation is performed that minimize the system renovation cost. The values of the system age ς at which the system preventive renovation is performed and the exemplary values of the renovation cost of the oil pipeline system are given in *Table 5* justify that the exemplary system renovation cost is an decreasing function of the system age at which the system preventive renovation is performed.

14. The exemplary system operation and reliability new strategy

On the basis of the collected operation and reliability parameters and characteristics of the exemplary system before and after its operation process optimization collected in Section 13, its operation and reliability new strategy is suggested.

14.1. Analysis of system operation, reliability and operation cost characteristics and maintenance optimization results

The comparison of the selected system characteristics before the system operation process optimization given by (316)-(318) for the system operation process, by (322)-(324) for the system reliability, by (328)-(330) for the system renewal and availability and by (352)-(354) for the system cost analysis with their values after the system operation process optimization respectively given by (319)-(321), (325)-(327), (331)-(333) and by (355)-(357) justifies the sensibility of the performed system operation process optimization.

The results of the system corrective and preventive optimization did not give the value of the preventive maintenance period that maximize the system availability coefficient. The value of the system availability coefficient is increasing while the preventive maintenance period is increasing.

14.2. Suggestions on new strategy of system operation process organizing

From the performed in Section 13.2.1 analysis of the results of the system operation process optimization it can be suggested to organize the system operation process in the way that causes the replacing (or the approaching/convergence to) the conditional mean sojourn times M_{bl} of the system at the particular operation states before the optimization defined by (314) by their optimal values $\dot{M}_{bl}$ after the optimization defined by (315). The fulfilling this suggestion of the operation process parameters changing is not easy in practice.

It seems to be practically a bit easier way the changing the operation process characteristics. The reorganizing the operation process that results in replacing (or the approaching/convergence to) the unconditional mean sojourn times M_b of the system in the particular operation states before the optimization defined by (316) by their optimal values $\dot{M}_b$ after the optimization defined by (319) is one of the next suggestions.

The easiest way of the system operation process reorganizing is that leading to the replacing (or the approaching/convergence to) the total sojourn times $E[\hat{\theta}_b]$ of the system operation process in particular operation states during the operation time $\theta = 1$ year before the optimization defined by (318) by their optimal values $\dot{E}[\hat{\theta}_b]$ after the optimization defined by (321).

14.3. Suggestions on new strategy of system maintenance policy

From the analysis of the results of the system corrective and preventive optimization it can only be suggested that in order to keep high availability of the system the value of the preventive maintenance period should not be too small.

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