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Computer aided operation cost prediction of complex technical systems with reserve and improved components

Keywords

complex technical system, operation process optimization, operation cost analysis, improved system

Abstract

There is presented the computer program based on methods and algorithms for prediction of the operation cost of the complex technical system in variable operation conditions. The program allows to determine of the costs of the non-repairable and repairable improved complex technical systems before and after their operation processes optimization. The procedure of the computer program use and its application to operation cost analysis of the exemplary complex technical system.

1. Theoretical backgrounds

The following output characteristics of the complex technical system operation costs during the system operation time θ, $\theta \geq 0$, are determined after applying the computer program:

- the total operation cost of the non-repairable system with non-improved components

$$C^{(0)}(\theta) \cong \sum_{b=1}^{\nu} p_b \sum_{i=1}^{n} c_i^{(0)}(\theta, b),$$

where p_b, $b = 1,2,...,\nu$, are transient probabilities defined by (2.4) in [2];

- the total operation cost of the non-repairable system with a hot single reservation of components

$$C^{(1)}(\theta) \cong 2\sum_{b=1}^{\nu} p_b \sum_{i=1}^{n} c_i^{(1)}(\theta, b),$$

where p_b, $b = 1,2,...,\nu$, are transient probabilities defined by (2.4) in [2];

- the total operation cost of the non-repairable system with a cold single reservation of components

$$C^{(2)}(\theta) \cong \sum_{b=1}^{\nu} p_b \sum_{i=1}^{n} [c_i^{(2)}(\theta, b) + \overline{c}_i^{(2)}(\theta, b)],$$

where p_b, $b = 1,2,...,\nu$, are transient probabilities defined by (2.4) in [2];

- the total operation cost of the non-repairable system with improved components by reduction their rates of departures from the reliability state subsets is

$$C^{(3)}(\theta, \rho(r)) \cong \sum_{b=1}^{\nu} p_b \sum_{i=1}^{n} c_i^{(3)}(\theta, \rho(r), b),$$

where p_b, $b = 1,2,...,\nu$, are transient probabilities defined by (2.4) in [2];

- the total operation cost of the repairable system with ignored renovation time with non-improved components

$$C_{ig}^{(0)}(\theta) \cong \sum_{b=1}^{\nu} p_b \sum_{i=1}^{n} c_i^{(0)}(\theta, b) + c_{ig}^{(0)} H^{(0)}(\theta, r),$$

where p_b, $b = 1,2,...,\nu$, are transient probabilities defined by (2.4) in [2] and $H^{(0)}(\theta,r) = H(\theta,r)$ is the mean value of the number of exceeding by the system the critical reliability state r during the operation time $\theta,$ that according to (4.4) from [2] is given by

$$H^{(0)}(\theta,r)=\frac{\theta}{\mu^{(0)}(r)},\quad r\in\{1,2,...,z\},$$

where and $\mu^{(0)}(r)$ is the mean value of the unconditional system lifetime in the reliability state subset $\{u,u+1,...,z\}$ of the non-repairable system with non-improved components given by (3.6)-(3.7) in [2] for $u=r$;

- the total operation cost of the repairable system with ignored renovation time with a hot single reservation of components is

$$C_{ig}^{(1)}(\theta)\cong 2\sum_{b=1}^{\nu}p_b\sum_{i=1}^{n}c_i^{(1)}(\theta,b)+c_{ig}^{(1)}H^{(1)}(\theta,r)$$

$$+\,c_{ig}^{(2)}H^{(2)}(\theta,r),$$

where $p_b,\ \ b=1,2,...,\nu,$ are transient probabilities defined by (2.4) in [1] and $H^{(1)}(\theta,r)$ is the mean value of the number of exceeding by the system the critical reliability state r during the operation time $\theta,$ that according to (5.4) from [1] is given by

$$H^{(1)}(\theta,r)=\frac{\theta}{\mu^{(1)}(r)},\ r\in\{1,2,...,z\},$$

where and $\mu^{(1)}(r)$ is the mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components hot single reservation given in [1];

- the total operation cost of the repairable system with ignored renovation time with a cold single reservation of components is

$$C_{ig}^{(2)}(\theta)\cong\sum_{b=1}^{\nu}p_b\sum_{i=1}^{n}[c_i^{(2)}(\theta,b)+\bar{c}_i^{(2)}(\theta,b)]$$

where $p_b,\ \ b=1,2,...,\nu,$ are transient probabilities defined by (2.4) in [1] and $H^{(2)}(\theta,r)$ is the mean value of the number of exceeding by the system the critical reliability state r during the operation time $\theta,$ that according to (5.4) from [1] is given by

$$H^{(2)}(\theta,r)=\frac{\theta}{\mu^{(2)}(r)},\ r\in\{1,2,...,z\},$$

where and $\mu^{(2)}(r)$ is the mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components cold single reservation given in [1];

- the total operation cost of the repairable system with ignored renovation time with components improved by reduction their rates of departures is

$$C_{ig}^{(3)}(\theta,\rho(r))\cong\sum_{b=1}^{\nu}p_b\sum_{i=1}^{n}c_i^{(3)}(\theta,\rho(r),b)$$

$$+\,c_{ig}^{(3)}H^{(3)}(\theta,r),$$

where $p_b,\ \ b=1,2,...,\nu,$ are transient probabilities defined by (2.4) in [2] and $H^{(3)}(\theta,r)$ is the mean value of the number of exceeding by the system the critical reliability state r during the operation time $\theta,$ that according to (5.4) from [1] is given by

$$H^{(3)}(\theta,r)=\frac{\theta}{\mu^{(3)}(r)},\ r\in\{1,2,...,z\},$$

where and $\mu^{(3)}(r)$ is the mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components improved by the reduction of their rates of departures from the reliability state subsets given in [1];

- the total operation cost of the repairable system with non-ignored renovation time with non-improved components

$$C_{nig}^{(0)}(\theta)\cong\sum_{b=1}^{\nu}p_b\sum_{i=1}^{n}c_i^{(0)}(\theta,b)+c_{nig}^{(0)}\overline{\overline{H}}^{(0)}(\theta,r)\,,$$

where $p_b,\ \ b=1,2,...,\nu,$ are transient probabilities defined by (2.4) in [2] and $\overline{\overline{H}}^{(0)}(\theta,r)=\overline{\overline{H}}(\theta,r)$ is the mean value of the number of renovations of the system during the operation time $\theta,$ that according to (4.12) [2] is given by

$$\overline{\overline{H}}^{(0)}(\theta,r)=\frac{\theta}{\mu^{(0)}(r)+\mu_0(r)},\ r\in\{1,2,...,z\},$$

where and $\mu^{(0)}(r)$ is the mean value of the unconditional system lifetime in the reliability state subset $\{u,u+1,...,z\}$ of the non-repairable system with non-improved components given by (3.6)-(3.7) in [2] for $u=r$;

- the total operation cost of the repairable system with non-ignored renovation time with a hot single reservation of components

$$C_{nig}^{(1)}(\theta) \cong 2\sum_{b=1}^{\nu} p_b \sum_{i=1}^{n} c_i^{(1)}(\theta,b) + c_{nig}^{(1)} \overline{\overline{H}}^{(1)}(\theta,r),$$

where p_b, $b=1,2,...,\nu$, are transient probabilities defined by (2.4) and $\overline{\overline{H}}^{(1)}(\theta,r)$ is the mean value of the number of renovations of the system during the operation time θ, that according to (5.12) from [1]

$$\overline{\overline{H}}^{(1)}(\theta,r) = \frac{\theta}{\mu^{(1)}(r)+\mu_0(r)},\ r\in\{1,2,...,z\},$$

here and $\mu^{(1)}(r)$ is the mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components hot single reservation given in [1];

- the total operation cost of the repairable system with non-ignored renovation time with a cold single reservation of components

$$C_{nig}^{(2)}(\theta) \cong \sum_{b=1}^{\nu} p_b \sum_{i=1}^{n} [c_i^{(2)}(\theta,b) + \overline{c}_i^{(2)}(\theta,b)]$$

$$+ c_{nig}^{(2)} \overline{\overline{H}}^{(2)}(\theta,r),$$

where p_b, $b=1,2,...,\nu$, are transient probabilities defined by (2.4) and $\overline{\overline{H}}^{(2)}(\theta,r)$ is the mean value of the number of renovations of the system during the operation time θ, that according to (5.12) from [1]

$$\overline{\overline{H}}^{(2)}(\theta,r) = \frac{\theta}{\mu^{(2)}(r)+\mu_0(r)},\ r\in\{1,2,...,z\},$$

where and $\mu^{(2)}(r)$ is the mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components cold single reservation given in [1];

- the total operation cost of the repairable system with non-ignored renovation time with improved components by reduction the rates of departures in the reliability state subsets

$$C_{nig}^{(3)}(\theta,\rho(r)) \cong \sum_{b=1}^{\nu} p_b \sum_{i=1}^{n} c_i^{(3)}(\theta,\rho(r),b)$$

$$+ c_{nig}^{(3)} \overline{\overline{H}}^{(3)}(\theta,r),$$

where p_b, $b=1,2,...,\nu$, are transient probabilities defined by (2.4) and $\overline{\overline{H}}^{(3)}(\theta,r)$ is the mean value of the number of renovations of the system during the operation time θ, that according to (5.12) from [1]

$$\overline{\overline{H}}^{(3)}(\theta,r) = \frac{\theta}{\mu^{(3)}(r)+\mu_0(r)},\ r\in\{1,2,...,z\},$$

where and $\mu^{(3)}(r)$ is the mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components improved by the reduction of their rates of departures from the reliability state subsets given in [1];

- the total optimal operation cost of the non-repairable system with non-improved components after their operation processes optimization

$$\dot{C}^{(0)}(\theta) \cong \sum_{b=1}^{\nu} \dot{p}_b \sum_{i=1}^{n} c_i^{(0)}(\theta,b),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [2];

- the total optimal cost of the non-repairable system with a hot single reservation of components after their operation processes optimization

$$\dot{C}^{(1)}(\theta) \cong 2\sum_{b=1}^{\nu} \dot{p}_b \sum_{i=1}^{n} c_i^{(1)}(\theta,b),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [2];

- the total optimal operation cost of the non-repairable system with a cold single reservation of components after their operation processes optimization

$$\dot{C}^{(2)}(\theta) \cong \sum_{b=1}^{\nu} \dot{p}_b \sum_{i=1}^{n} [c_i^{(2)}(\theta,b) + \overline{c}_i^{(2)}(\theta,b)],$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [2];

- the total optimal operation cost of the non-repairable system with improved components by reduction their rates of departures from the reliability state subsets after their operation processes optimization

$$\dot{C}^{(3)}(\theta,\rho(r)) \cong \sum_{b=1}^{\nu} \dot{p}_b \sum_{i=1}^{n} c_i^{(3)}(\theta,\rho(r),b),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [2];

- the total optimal operation cost of the repaired system with ignored renovation time with non-improved components after their operation processes optimization

$$\dot{C}_{ig}^{(0)}(\theta) \cong \sum_{b=1}^{\nu} \dot{p}_b \sum_{i=1}^{n} c_i^{(0)}(\theta,b) + c_{ig}^{(0)} \dot{H}^{(0)}(\theta,r),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [2] and $\dot{H}^{(0)}(\theta,r) = \dot{H}(\theta,r)$ is the mean value of the optimal number of exceeding by the system the critical reliability state r during the operation time θ, that according to (5.28) from [1] is given by

$$\dot{H}^{(0)}(\theta,r) = \frac{\theta}{\dot{\mu}^{(0)}(r)},\ r \in \{1,2,...,z\},$$

where and $\dot{\mu}^{(0)}(r)$ is the optimal mean value of the unconditional system lifetime in the reliability state subset $\{u,u+1,...,z\}$ of the non-repairable system with non-improved components given by (5.17)-(5.18) in [2] for $u=r$;

- the total optimal operation cost of the repaired system with ignored renovation time with a hot single reservation of components after their operation processes optimization

$$\dot{C}_{ig}^{(1)}(\theta) \cong 2\sum_{b=1}^{\nu} \dot{p}_b \sum_{i=1}^{n} c_i^{(1)}(\theta,b) + c_{ig}^{(1)} \dot{H}^{(1)}(\theta,r),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in Task 7.5 and $\dot{H}^{(1)}(\theta,r)$ is the mean value of the optimal number of exceeding by the system the critical reliability state r during the operation time θ, that according to (5.28) from [2] is given by 0

$$\dot{H}^{(1)}(\theta,r) = \frac{\theta}{\dot{\mu}^{(1)}(r)},\ r \in \{1,2,...,z\},$$

where and $\dot{\mu}^{(1)}(r)$ is the optimal mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components hot single reservation given in [1];

- the total optimal operation cost of the repairable system with ignored renovation time with a cold single reservation of components after their operation processes optimization

$$\dot{C}_{ig}^{(2)}(\theta) \cong \sum_{b=1}^{\nu} \dot{p}_b \sum_{i=1}^{n} [c_i^{(2)}(\theta,b) + \bar{c}_i^{(2)}(\theta,b)]$$
$$+ c_{ig}^{(2)} \dot{H}^{(2)}(\theta,r),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [1] and $\dot{H}^{(2)}(\theta,r)$ is the mean value of the optimal number of exceeding by the system the critical reliability state r during the operation time θ, that according to (5.28) from [2] is given by

$$\dot{H}^{(2)}(\theta,r) = \frac{\theta}{\dot{\mu}^{(2)}(r)},\ r \in \{1,2,...,z\},$$

where and $\dot{\mu}^{(2)}(r)$ is the optimal mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components cold single reservation given in [1];

- the total optimal operation cost of the repairable system with ignored renovation time with improved components by reduction the rates of departures after their operation processes optimization

$$\dot{C}_{ig}^{(3)}(\theta,\rho(r)) \cong \sum_{b=1}^{\nu} \dot{p}_b \sum_{i=1}^{n} c_i^{(3)}(\theta,\rho(r),b)$$
$$+ c_{ig}^{(3)} \dot{H}^{(3)}(\theta,r),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [1] and $\dot{H}^{(3)}(\theta,r)$ is the mean value of the optimal number of exceeding by the system the critical reliability state r during the time θ, that according to (5.28) from [2] is given by

$$\dot{H}^{(3)}(\theta,r)=\frac{\theta}{\dot{\mu}^{(3)}(r)},\ r\in\{1,2,...,z\},$$

where and $\dot{\mu}^{(3)}(r)$ is the optimal mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components improved by the reduction of their rates of departures from the reliability state subsets given in [1];

- the total optimal operation cost of the repairable system with non-ignored renovation time with non-improved components after their operation processes optimization

$$\dot{C}_{nig}^{(0)}(\theta)\cong\sum_{b=1}^{\nu}\dot{p}_b\sum_{i=1}^{n}c_i^{(0)}(\theta,b)+c_{nig}^{(0)}\dot{\overline{\overline{H}}}^{(0)}(\theta,r),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [1] and $\dot{\overline{\overline{H}}}^{(0)}(\theta,r)=\dot{\overline{\overline{H}}}(\theta,r)$ is the mean value of the optimal number of renovations of the system during the time θ, that according to (5.36) from [2] is given by

$$\dot{\overline{\overline{H}}}^{(0)}(\theta,r)=\frac{\theta}{\dot{\mu}^{(0)}(r)+\mu_0(r)},\ r\in\{1,2,...,z\},$$

where and $\dot{\mu}^{(0)}(r)$ is the optimal mean value of the unconditional system lifetime in the reliability state subset $\{u,u+1,...,z\}$ of the non-repairable system with non-improved components given by (5.17)-(5.18) in [2] for $u=r$;

- the total optimal operation cost of the repairable system with non-ignored renovation time with a hot single reservation of components after their operation processes optimization

$$\dot{C}_{nig}^{(1)}(\theta)\cong 2\sum_{b=1}^{\nu}\dot{p}_b\sum_{i=1}^{n}c_i^{(1)}(\theta,b)+c_{nig}^{(1)}\dot{\overline{\overline{H}}}^{(1)}(\theta,r),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [2] and $\dot{\overline{\overline{H}}}^{(1)}(\theta,r)$ is the mean value of the optimal number of renovations of the system during the time θ, that according to (5.36) from [2] is given by

$$\dot{\overline{\overline{H}}}^{(1)}(\theta,r)=\frac{\theta}{\dot{\mu}^{(1)}(r)+\mu_0(r)},\ r\in\{1,2,...,z\},$$

where and $\dot{\mu}^{(1)}(r)$ is the optimal mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components hot single reservation given in [1];

- the total optimal operation cost of the repairable system with non-ignored renovation time with a cold single reservation of components after their operation processes optimization

$$\dot{C}_{nig}^{(2)}(\theta)\cong\sum_{b=1}^{\nu}\dot{p}_b\sum_{i=1}^{n}[c_i^{(2)}(\theta,b)+\overline{c}_i^{(2)}(\theta,b)]$$

$$+c_{nig}^{(2)}\dot{\overline{\overline{H}}}^{(2)}(\theta,r),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [1] and $\dot{\overline{\overline{H}}}^{(2)}(\theta,r)$ is the mean value of the optimal number of renovations of the system during the time θ, that according to (5.36) from [2] is given by

$$\dot{\overline{\overline{H}}}^{(2)}(\theta,r)=\frac{\theta}{\dot{\mu}^{(2)}(r)+\mu_0(r)},\ r\in\{1,2,...,z\},$$

where and $\dot{\mu}^{(2)}(r)$ is the optimal mean value of the unconditional system lifetime in the reliability state subset $\{r,r+1,...,z\}$ of the non-repairable system with its components cold single reservation given in [1];

- the total optimal operation cost of the repairable system with non-ignored renovation time with improved components by reduction the rates of departures in the reliability state subsets after their operation processes optimization

$$\dot{C}_{nig}^{(3)}(\theta,\rho(r))\cong\sum_{b=1}^{\nu}\dot{p}_b\sum_{i=1}^{n}c_i^{(3)}(\theta,\rho(r),b)$$

$$+c_{nig}^{(3)}\dot{\overline{\overline{H}}}^{(3)}(\theta,r),$$

where $\dot{p}_b$, $b=1,2,...,\nu$, are optimal transient probabilities defined by (5.16) in [2] and $\dot{\overline{\overline{H}}}^{(3)}(\theta,r)$ is the mean value of the optimal number of renovations of the system during the operation time θ, that according to (5.36) from [2] is given by

$$\dot{\overline{\overline{H}}}^{(3)}(\theta,r)=\frac{\theta}{\dot{\mu}^{(3)}(r)+\mu_0(r)},\ r\in\{1,2,...,z\},$$

where and $\dot{\mu}^{(3)}(r)$ is the optimal mean value of the unconditional system lifetime in the reliability state subset $\{r, r+1, ..., z\}$ of the non-repairable system with its components improved by the reduction of their rates of departures from the reliability state subsets given in [1].
The output results of the computer application defined by these formulas allow us to compare the operation costs of the non-repairable and repaired non-improved and improved systems with ignored and non-ignored times of renovations in variable operation conditions before and after the optimization of their operation processes.

2. Description of the computer program capabilities

To make the estimation of the operation cost of the complex technical system with reserve and improved components in variable operation conditions its operation process the computer program is reading in following input parameters (*Figure 1, Figure 2, Figure 3*):
- the time of the system operation process duration θ,
- the number of the operation states of the system operation process ν ,
- the transient probabilities in particular operation states before the system operation process optimization p_1, p_2, …, p_ν,
- the transient probabilities in particular operation states after the system operation process optimization $\dot{p}_1$, $\dot{p}_2$, …, $\dot{p}_\nu$,

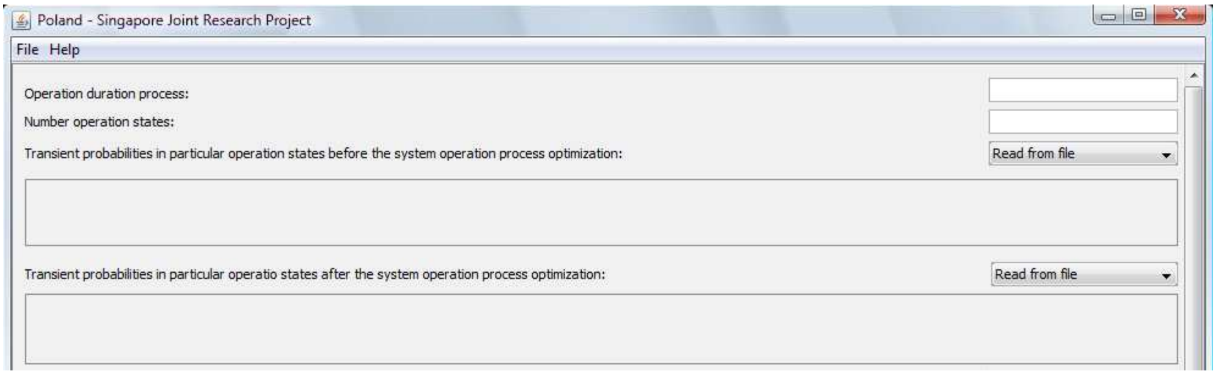

Figure 1. The program window– the input parameters

- the total number of the system components n,

- the system and components critical reliability state r,

- the mean value of the unconditional lifetime of the non-repairable system with non-improved components in the reliability states subset not worse than the system critical reliability state r before its operation process optimization $\mu^{(0)}(r)$,

- the mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state r of the non-repairable system with its components hot single reservation before its operation process optimization $\mu^{(1)}(r)$,

- the mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state r of the non-repairable system with its components cold single reservation before its operation process optimization $\mu^{(2)}(r)$,

- the mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state r of the non-repairable system with its components improved by the reduction of their rates of departures from the reliability state subsets before its operation process optimization $\mu^{(3)}(r)$,

- the optimal mean value of the unconditional lifetime of the non-repairable system with non-improved components in the reliability states subset not worse than the system critical reliability state r after its operation process optimization $\dot{\mu}^{(0)}(r)$,

- the optimal mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state r of the non-repairable system with its components hot single reservation after its operation process optimization $\dot{\mu}^{(1)}(r)$,

- the optimal mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state r of the non-repairable system with its components cold single reservation after its operation process optimization $\dot{\mu}^{(2)}(r)$,

- the optimal mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state r of the non-repairable system with its components improved by the reduction of their rates of departures from the reliability state subsets after its operation process optimization $\dot{\mu}^{(3)}(r)$,

- in the case of a repairable system with non-ignored renovation time the mean value of the system renovation time $\mu_0(r)$,

Figure 2. The program window – the input parameters

i) for a non-repairable system:

- the matrix of the operation costs $c_i^{(0)}(\theta,b)$, $i=1,2,...,n$, $b=1,2,...,v$, of the system single basic components E_i, $i=1,2,...,n$, with non-improved components in (or at) the operation state z_b, $b=1,2,...,v$, during the system operation time θ

$$[c_i^{(0)}(\theta,b)]_{n\times v} = \begin{bmatrix} c_1^{(0)}(\theta,1)\, c_1^{(0)}(\theta,2) \ldots c_1^{(0)}(\theta,v) \\ c_2^{(0)}(\theta,1)\, c_2^{(0)}(\theta,2) \ldots c_2^{(0)}(\theta,v) \\ \ldots \\ c_n^{(0)}(\theta,1)\, c_n^{(0)}(\theta,2) \ldots c_n^{(0)}(\theta,v) \end{bmatrix},$$

- the matrix of the operation costs $c_i^{(1)}(\theta,b)$, $i=1,2,...,n$, $b=1,2,...,v$, of the system single basic components E_i, $i=1,2,...,n$, with a hot single reservation of components in the operation state z_b, $b=1,2,...,v$, during the system operation time θ

$$[c_i^{(1)}(\theta,b)]_{n\times v} = \begin{bmatrix} c_1^{(1)}(\theta,1)\, c_1^{(1)}(\theta,2) \ldots c_1^{(1)}(\theta,v) \\ c_2^{(1)}(\theta,1)\, c_2^{(1)}(\theta,2) \ldots c_2^{(1)}(\theta,v) \\ \ldots \\ c_n^{(1)}(\theta,1)\, c_n^{(1)}(\theta,2) \ldots c_n^{(1)}(\theta,v) \end{bmatrix},$$

- the matrix of the operation costs $c_i^{(2)}(\theta,b)$, $i=1,2,...,n$, $b=1,2,...,v$, of the system single basic components E_i, $i=1,2,...,n$, with a cold single reservation of components in the operation state z_b, $b=1,2,...,v$, during the system operation time θ

$$[c_i^{(2)}(\theta,b)]_{n\times v} = \begin{bmatrix} c_1^{(2)}(\theta,1)\, c_1^{(2)}(\theta,2) \ldots c_1^{(2)}(\theta,v) \\ c_2^{(2)}(\theta,1)\, c_2^{(2)}(\theta,2) \ldots c_2^{(2)}(\theta,v) \\ \ldots \\ c_n^{(2)}(\theta,1)\, c_n^{(2)}(\theta,2) \ldots c_n^{(2)}(\theta,v) \end{bmatrix},$$

- the matrix of the operation costs $\overline{c}_i^{(2)}(\theta,b)$, $i=1,2,...,n$, $b=1,2,...,v$, of the system single reserve components E_i, $i=1,2,...,n$, with a cold single reservation of components in the operation state z_b, $b=1,2,...,v$, during the system operation time θ

$$\overline{c}_i^{(2)}[(\theta,b)]_{n\times v} = \begin{bmatrix} \overline{c}_1^{(2)}(\theta,1)\, \overline{c}_1^{(2)}(\theta,2) \ldots \overline{c}_1^{(2)}(\theta,v) \\ \overline{c}_2^{(2)}(\theta,1)\, \overline{c}_2^{(2)}(\theta,2) \ldots \overline{c}_2^{(2)}(\theta,v) \\ \ldots \\ \overline{c}_n^{(2)}(\theta,1)\, \overline{c}_n^{(2)}(\theta,2) \ldots \overline{c}_n^{(2)}(\theta,v) \end{bmatrix},$$

- the matrix of the operation costs $c_i^{(3)}(\theta,\rho(r),b)$, $i=1,2,...,n$, $b=1,2,...,v$, of the system single basic components E_i, $i=1,2,...,n$, with improved components in the operation state z_b, $b=1,2,...,v$, during the system operation time θ

$$[c_i^{(3)}(\theta,b)]_{n\times v} = \begin{bmatrix} c_1^{(3)}(\theta,1)\, c_1^{(3)}(\theta,2) \ldots c_1^{(3)}(\theta,v) \\ c_2^{(3)}(\theta,1)\, c_2^{(3)}(\theta,2) \ldots c_2^{(3)}(\theta,v) \\ \ldots \\ c_n^{(3)}(\theta,1)\, c_n^{(3)}(\theta,2) \ldots c_n^{(3)}(\theta,v) \end{bmatrix},$$

ii) for a repairable system with ignored renovation time:

- the cost of the singular renovation of the repairable system with ignored renovation time with non-improved components is $c_{ig}^{(0)}$,

- the cost of the singular renovation of the repairable system with ignored renovation time with a hot single reservation of components is $c_{ig}^{(1)}$,

- the cost of the singular renovation of the repairable system with ignored renovation time with a cold single reservation of components is $c_{ig}^{(2)}$,

- the cost of the singular renovation of the repairable system with ignored renovation time with improved components by reduction the rates of departures from the reliability state subsets $c_{ig}^{(3)}$,

iii) for a repairable system with non-ignored renovation time:

- the cost of the singular renovation of the repairable system with non-ignored renovation time with non-improved components is $c_{nig}^{(0)}$,

- the cost of the singular renovation of the repairable system with non-ignored renovation time with a hot single reservation of components is $c_{nig}^{(1)}$,

- the cost of the singular renovation of the repairable system with non-ignored renovation time with a cold single reservation of components is $c_{nig}^{(2)}$,

- the cost of the singular renovation of the repairable system with non-ignored renovation time with improved components by reduction the rates of departures from the reliability state subsets $c_{nig}^{(3)}$.

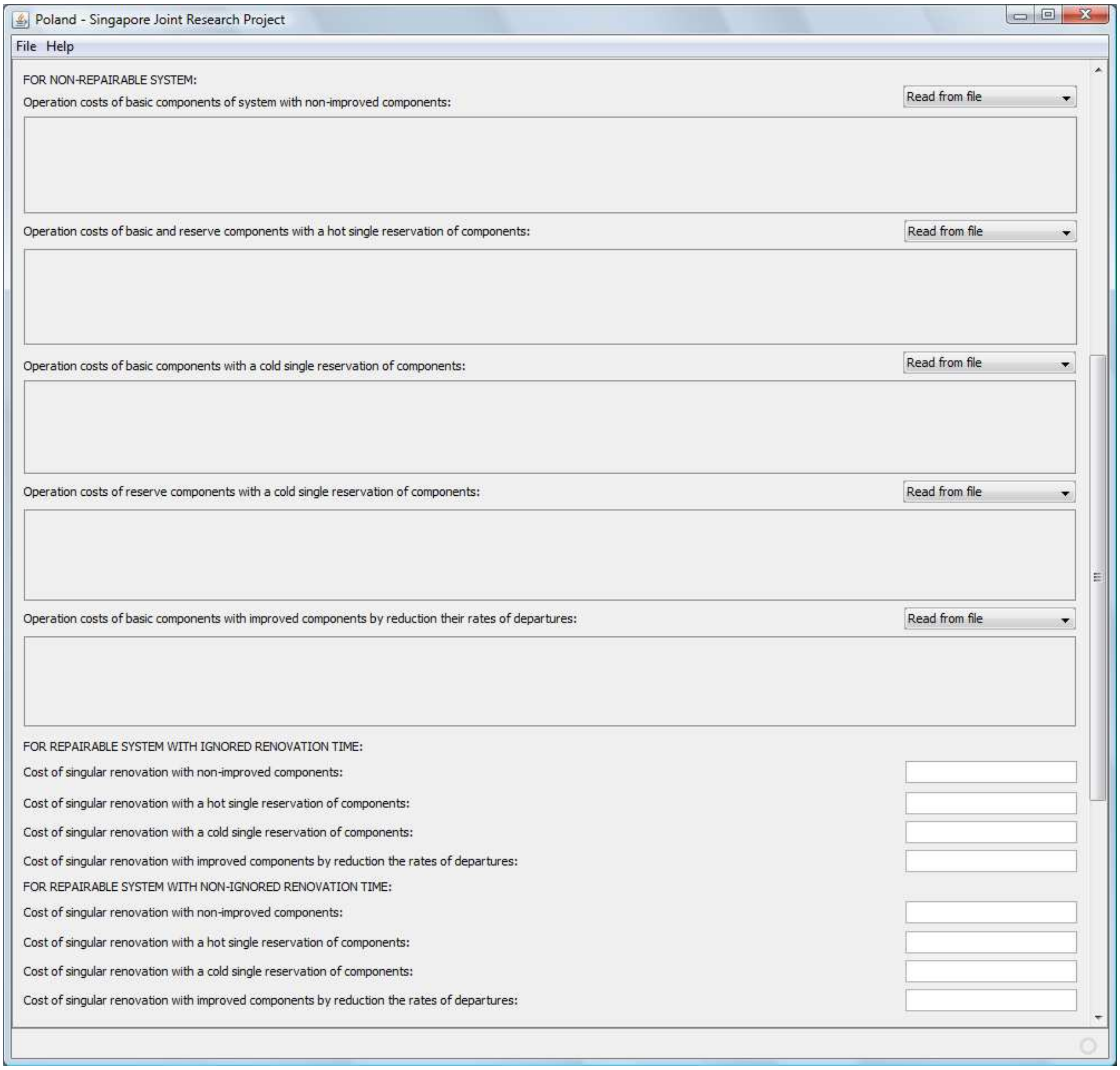

Figure 3. The program window – the input parameters

After pressing the button "Count costs", the computer program is estimating operation costs of the complex technical systems. The results are shown on the screen in the widow „OUTPUT" (*Figure 4*).

Figure 4. The program window – the output parameters

3. Prediction of the operation cost of the exemplary complex technical system

The considered exemplary complex technical system S 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 $E_{ij}^{(1)}$, $i = 1,2$, $j = 1,2,3,$ with the structure presented in *Figure 5*.

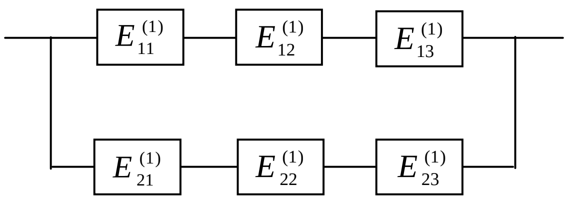

Figure 5. The scheme of the system S_1 structure

The subsystem S_2 is composed of four series subsystems, each of them composed of 2 components, denoted respectively by $E_{ij}^{(2)}$, $i = 1,2,3,4$ $j = 1,2,$ with the structure presented in *Figure 6*

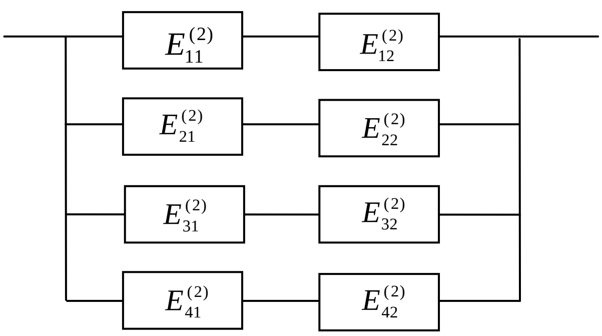

Figure 6. The scheme of the system S_2 structure

The subsystems S_1, S_2, illustrated in *Figures 5 - 6* are forming a series structure presented in *Figure 7*.

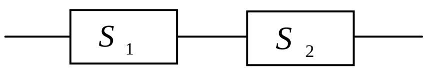

Figure 7. General scheme of the system S

To make the estimation of the operation cost of the considered exemplary complex technical system the computer program is reading in:

- the time of the system operation process duration $\theta = 1000$ days,

- the number of the system operation process states $\nu = 4$;

- the following as its four operation states:
  - an operation state z_1 – the system is composed of the subsystem S_1, with the scheme showed in *Figure 5*, 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 6* 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 7* that are series-parallel system with the schemes given in *Figures 5-6*,
  - an operation state z_4 – the system is composed of the subsystem S_1 and S_2, with the scheme showed in *Figure 7*, while the subsystem S_1 is a series-parallel system with the scheme given in *Figure 5* and the subsystem S_2 is a series-“2 out of 4” system;

- the transient probabilities p_b in particular operation states z_b, $b = 1,2,...,4,$ before the system operation process optimization

$$p_1 = 0.214, \ p_2 = 0.038, \ p_3 = 0.293, \ p_4 = 0.455,$$

- the transient probabilities $\dot{p}_b$ in particular operation states z_b, $b = 1,2,...,4,$ after the system operation process optimization

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

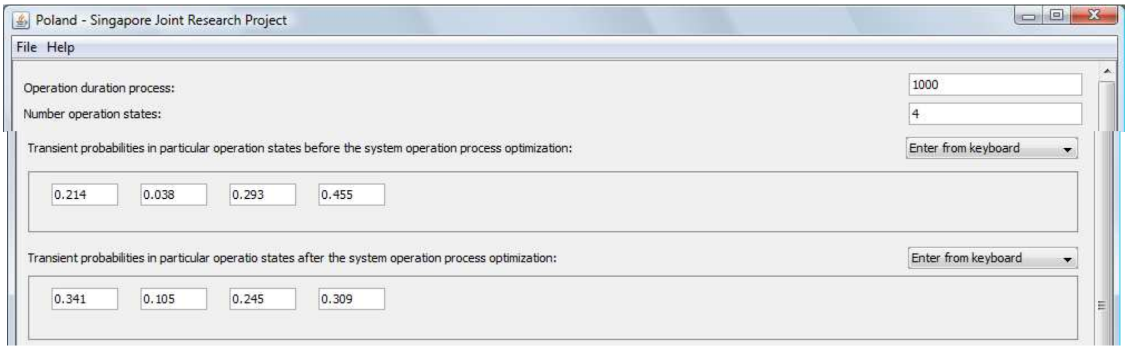

Figure 8. The program window – the input parameters of the system S

i) in the cases of a non-repairable and a repairable system

- the total number of the system components $n = 14$,
- the system and components critical reliability state is $r = 2$,

- the mean value of the unconditional lifetime of the non-repairable system with non-improved components in the reliability states subset not worse than the system critical reliability state 2 before its operation process optimization $\mu^{(0)}(2) \cong 357.68$,

- the mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state 2 of the non-repairable system with its components hot single reservation before its operation process optimization $\mu^{(1)}(2) \cong 712.01$,

- the mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state 2 of the non-repairable system with its components cold single reservation before its operation process optimization $\mu^{(2)}(2) \cong 977.87$,

- the mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state 2 of the non-repairable system with its components improved by the reduction of their rates of departures from the reliability state subsets before its operation process optimization $\mu^{(3)}(2) \cong 404.89$,

- the optimal mean value of the unconditional lifetime of the non-repairable system with non-improved components in the reliability states subset not worse than the system critical reliability state 2 after its operation process optimization $\dot{\mu}^{(0)}(2) = 410.2$,

- the optimal mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state r of the non-repairable system with its components hot single reservation after its operation process optimization $\dot{\mu}^{(1)}(2) = 781.33$,

- the optimal mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state 2 of the non-repairable system with its components cold single reservation after its operation process optimization $\dot{\mu}^{(2)}(2) = 1\,070.01$,

- the optimal mean value of the unconditional lifetime in the reliability states subset not worse than the system critical reliability state 2 of the non-repairable system with its components improved by the reduction of their rates of departures from the reliability state subsets after its operation process optimization $\dot{\mu}^{(3)}(2) = 464.47$;

ii) in the case of a repairable system with non-ignored renovation time

- the mean value of the system renovation time $\mu_0(2) = 10$.

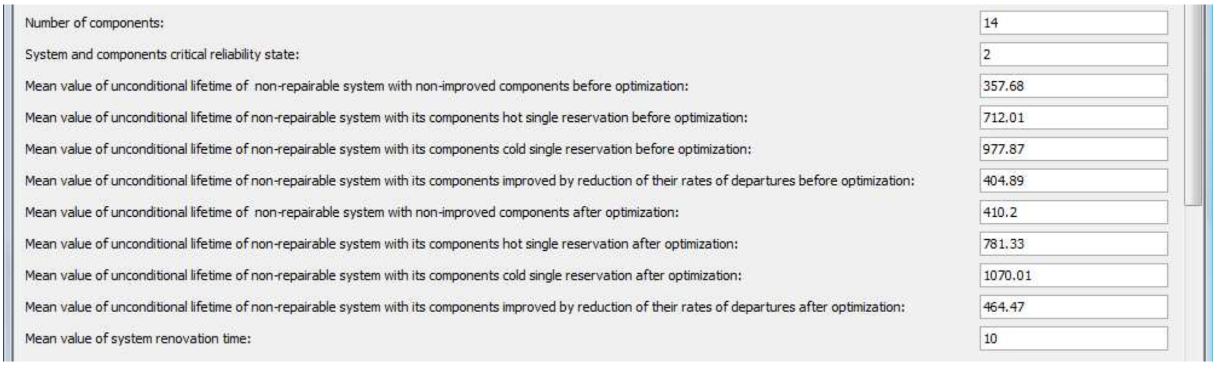

Figure 9. The program window – the input parameters of the system S

i) for a non-repairable system:

- the operation costs of basic components of the system with non-improved components in the operation state z_b, $b = 1,2,.3,4$, during the system operation time θ:

$$c_i^{(0)}(1000, b) = 1000, \quad i = 1,2,...,14;$$

- the operation costs of basic and reserve components of the system with a hot single reservation of components in the operation state z_b, $b = 1,2,...,v$, during the system operation time θ:

$$c_i^{(1)}(1000, b) = 1000, \quad i = 1,2,...,14;$$

- the operation costs of basic components of the system with a cold single reservation of components in the operation state z_b, $b = 1,2,.3,4$, during the system operation time θ:

$$c_i^{(2)}(1000, b) = 1000, \quad i = 1,2,...,14;$$

and the operation costs of reserve components of this system in the operation state z_b, $b = 1,2,.3,4$, during the system operation time θ

$$\bar{c}_i^{(2)}(1000, b) = 500, \quad i = 1,2,...,14;$$

- the operation costs of basic system components of the system with improved components by reduction their rates of departures from the reliability state subsets in the operation state z_b, $b = 1,2,.3,4$, during the system operation time θ

$$c_i^{(3)}(1000, \rho(2), b) = 1500, \quad i = 1,2,...,14;$$

ii) for a repairable system with ignored renovation time:

- the cost of the singular renovation of the repairable system with ignored renovation time with non-improved components is $c_{ig}^{(0)} = 50$;

- the cost of the singular renovation of the repairable system with ignored renovation time with a hot single reservation of components is $c_{ig}^{(1)} = 100$;

- the cost of the singular renovation of the repairable system with ignored renovation time with a cold single reservation of components is $c_{ig}^{(2)} = 75$;

- the cost of the singular renovation of the repairable system with ignored renovation time with improved components by reduction the rates of departures from the reliability state subsets $c_{ig}^{(3)} = 150$;

iii) for a repairable system with non-ignored renovation time:

- the cost of the singular renovation of the repairable system with non-ignored renovation time with non-improved components is $c_{nig}^{(0)} = 500$;

- the cost of the singular renovation of the repairable system with non-ignored renovation time with a hot single reservation of components is $c_{nig}^{(1)} = 1000$;

- the cost of the singular renovation of the repairable system with non-ignored renovation time with a cold single reservation of components is $c_{nig}^{(2)} = 750$;

- the cost of the singular renovation of the repairable system with non-ignored renovation time with improved components by reduction the rates of departures from the reliability state subsets $c_{nig}^{(3)} = 1500$.

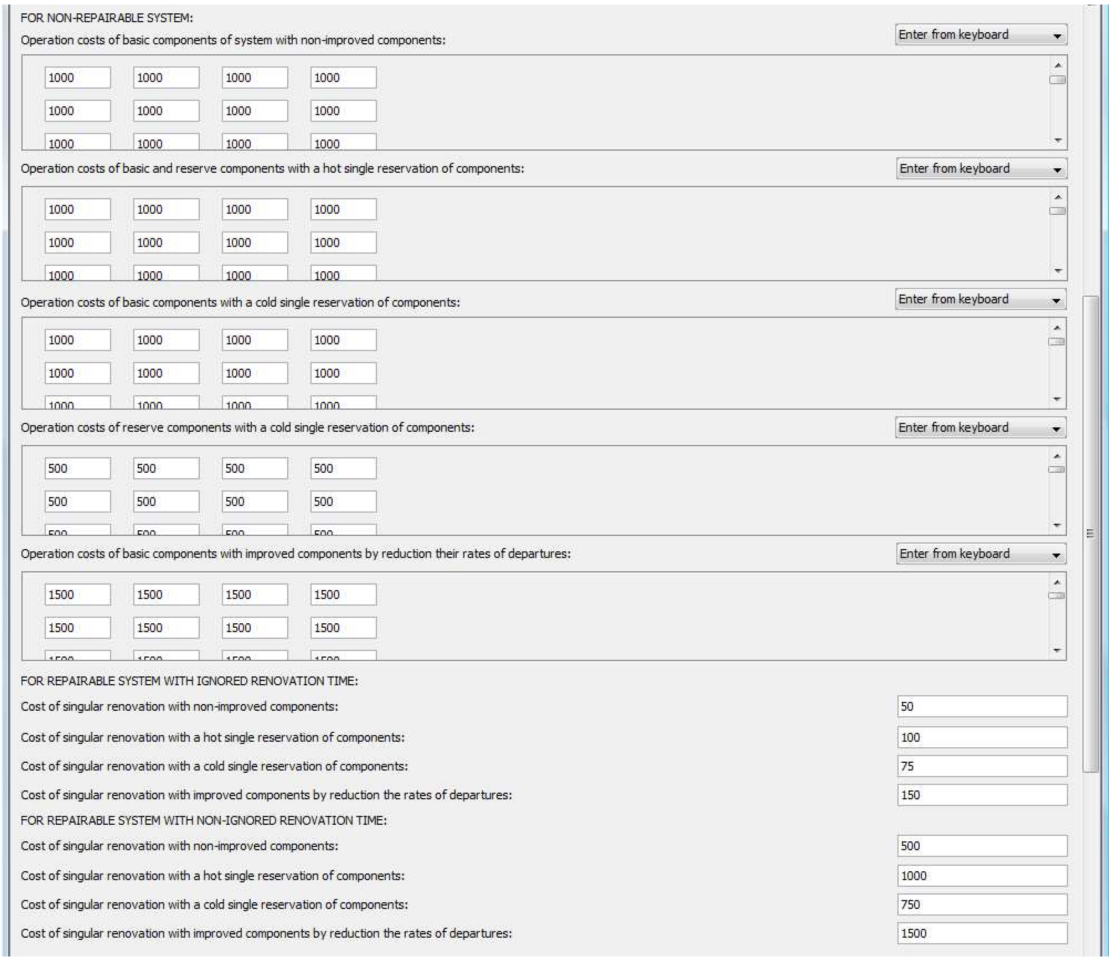

Figure 9. The program window – the input parameters of the system *S*

After pressing the button "Count costs", the computer program is estimating operation costs.

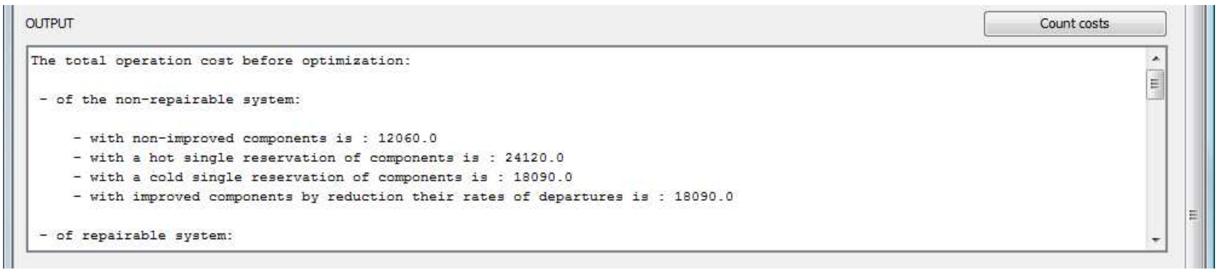

Figure 10. The program window – the output parameters of the system *S*

The total operation cost before optimization:

- of the non-repairable system:
with non-improved components is : 12060.0

- with a hot single reservation of components is : 24120.0,
- with a cold single reservation of components is : 18090.0
- with improved components by reduction their rates of departures is : 18090.0

- of repairable system:
- with ignored renovation time:

- with non-improved components is : 12199.789756206665
- with a hot single reservation of components is : 24260.447465625482
- with a cold single reservation of components is : 18166.697311503573
- with improved components by reduction their rates of departures is : 18460.470992121318

- with non-ignored renovation time:

- with non-improved components is : 13419.87815491732
- with a hot single reservation of components is : 25505.022368111244
- with a cold single reservation of components is : 18849.20920768927
- with improved components by reduction their rates of departures is : 21705.41613439707

The total operation cost after optimization:
- of the non-repairable system:

- with non-improved components is : 10642.0
- with a hot single reservation of components is : 21284.0
- with a cold single reservation of components is : 15963.0
- with improved components by reduction their rates of departures is : 15963.0

- of repairable system:
- with ignored renovation time:

- with non-improved components is : 10763.891760117016
- with a hot single reservation of components is : 21411.98689414204
- with a cold single reservation of components is : 16033.092802871
- with improved components by reduction their rates of departures is : 16285.948737270437

- with non-ignored renovation time:

- with non-improved components is : 11831.909566872917
- time with a hot single reservation of components is : 22547.695297789796
- with a cold single reservation of components is : 16657.43801446283
- with improved components by reduction their rates of departures is : 19124.422218475353.

4. Conclusion

The computer program for the prediction of the improved complex technical systems operation costs is based on the methods and algorithms from [1]. The computer program is the supplement to the training course directed to industry included in [2] where it is used for predicting the characteristics of the operation costs of complex technical systems with quantitative and qualitative redundancy. It can also be used as the supporting tool in the Integrated Safety and Reliability Support System - IS&RSS [3] for various maritime and coastal transport transportation systems operation costs analysis.

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References

[1] Blokus-Roszkowska, A., Guze, S., Kołowrocki, K., Kwiatuszewska-Sarnecka, B., Milczek, B. & Soszyńska, J. (2009). Methods of complex technical systems reliability, availability and safety improvement. Task 7.4 in WP7: Integrated package of solutions for complex industrial systems and processes safety and reliability optimization. Poland-Singapore Joint Project. MSHE Decision No. 63/N-Singapore/2007/0. Gdynia Maritime University, 2009.

[2] 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. Report. Poland-Singapore Joint Research Project, Gdynia Maritime University.

[3] Blokus-Roszkowska, A., Guze, S., Kołowrocki, K. & Soszyńska, J. (2010). Operation cost

analysis of complex technical systems with reserve and improved components - Training course addressed to industry, Task 11.13 in WP 11: Education, Training, Results Dissemination and Implementation. Report. Poland-Singapore Joint Research Project, Gdynia Maritime University.

[4] Kołowrocki, K. & Soszyńska, J. (2010). Integrated Safety and Reliability Support System – IS&RSS, Tasks 10.0-10.16 in WP 10: Education, Training, Results Dissemination and Implementation. Report. Poland-Singapore Joint Research Project, Gdynia Maritime University.