MODELLING ENVIRONMENT AND INFRASTRUCTURE OF SHIPYARD TRANSPORTATION SYSTEMS AND PROCESSES

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ABSTRACT

In the paper an analytical model of port transportation systems environment and infrastructure influence on their operation processes is constructed and presented in an example of shipyard rope transportation systems in Naval Shipyard in Gdynia. A general semi-markov model of a system operation process is proposed and the methods of its parameters statistical identification are presented. Further, the shipyard rope transportation system and the ship rope elevator operation processes are analyzed and their operation states are defined. A preliminary collection of statistical data necessary to the ship transportation systems' operation processes identification is included.

1 SHIPYARD ROPE TRANSPORTATION SYSTEMS - DESCRIPTION

The ship-rope elevator is used to dock and undock ships coming to the Naval Shipyard in Gdynia for repairs. The elevator is composed of a steel platform-carriage and 10 rope-hosting winches fed by separate electric motors. Motors are equipped in ropes "Bridon" with the diameter 47 mm each rope having a maximum load of 300 tones (Kołowrocki 2002, Kołowrocki et al. 2002). The rope transportation system in the Naval Shipyard in Gdynia is composed of three broaching machines working independently equipped in the steel ropes "Drumet" with the diameter 30 mm. This system is used to transfer ships coming to the shipyard for repairs from platform to the repair post and back from repair post to the platform. The load of steel ropes in the broaching machines is measured as a power consumption of amperage. The maximum of power consumption of broaching machines is 100 Ampere.

Generally all actions taken to the ships coming to the shipyard for repairs can be divided into 5 tasks:

- task 1 – ship docking (rope elevator is working),
- task 2 – ship's transportation to the repair post (rope transportation system is working),
- task 3 – the repair measures (both systems are not working),
- task 4 – ship's transportation to the platform (rope transportation system is working),
- task 5 – ship undocking (rope elevator is working).

Figure 1. The ship at the repair post R1/B1.

First during ship docking the ship settled in special supporting carriages on the platform is raised to the wharf level and then the ship is transferred from the platform with the rope broaching machine on a traverser. Next the ship with the traverser, on which the ship is settled, is shifted in the repair post direction. Then after stretching the ropes from the ship to the broaching machine through some blocs, the ship is transferred from the traverser to the repair post. After some repair measures, the ship is transferred back to the traverser and then on the platform. Finally, during undocking the ship on the platform is moved down to the water. There are nine repair posts, denoted by symbols R1-R9. The first repair post R1 can be lengthening to the post R1/B1 for long ships. There are also available two repair depots denoted by symbols B and D. Generally all kind of repairs can be carried out in any repair post. The repair posts R1 and R2 are equipped in crane. The submarines are repaired in the depot. Additionally large vessels are transferred to the repair post R1/B1. The scheme of the plan of repair post placing is given in Figure 2.

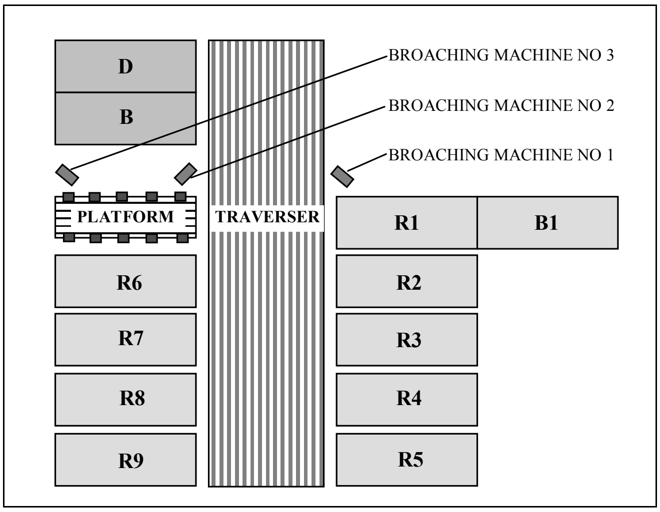

Figure 2. The scheme of the plan of repair post placing.

2 SEMI-MARKOV MODEL OF SYSTEM OPERATION PROCESS

Usually the system environment and infrastructure have either an explicit or implicit strong influence on the system operation process. As a rule some of the initiating environment events and infrastructure conditions define a set of different operation states of the industrial system. Thus, we assume that the system during its operation is operating in $v, v \in N$, different operation states. After this assumptions, we can define the system operation process $Z(t)$, $t \in <0,+\infty>$, with discrete states from the set of states $Z = \{z_1, z_2, \ldots, z_v\}$. If the system operation process $Z(t)$ is semi-markov (Grabski, 2002) with the conditional sojourn times θ_{bl} at the operation states z_b when its next operation state is z_l, $b, l = 1,2,...,v$, $b \neq l$, then it may be described by (Kołowrocki & Soszyńska, 2006):

– the vector of probabilities of the system operation process initial states

$$[p_b(0)]_{1\times v} = [p_1(0), p_2(0),..., p_v(0)],$$

where

$$p_b(0) = P(Z(0) = z_b) \text{ for } b = 1,2,...,v,$$

– the matrix of probabilities of the system operation process transitions between the operation states

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

where $p_{bb} = 0$ for $b = 1,2,...,v$,

– the matrix of the system operation process conditional sojourn times θ_{bl} distribution functions

$$[H_{bl}(t)]_{v\times v} = \begin{bmatrix} H_{11}(t) \; H_{12}(t) \ldots H_{1v}(t) \\ H_{21}(t) \; H_{22}(t) \ldots H_{2v}(t) \\ \cdots \\ H_{v1}(t) \; H_{v2}(t) \ldots H_{vv}(t) \end{bmatrix},$$

where

$$H_{bl}(t) = P(\theta_{bl} < t) \text{ for } b, l = 1,2,...,v, \; b \neq l,$$

and

$$H_{bb}(t) = 0 \text{ for } b = 1,2,...,v.$$

Under these assumptions, the mean values of the system operation process conditional sojourn times θ_{bl} are given by

$$M_{bl} = E[\theta_{bl}] = \int_0^\infty t dH_{bl}(t), \; b, l = 1,2,...,v, \; b \neq l. \tag{1}$$

By the formula for total probability the unconditional distribution functions of the sojourn times θ_b of the system operation process $Z(t)$ at the operation states z_b, $b = 1,2,...,v$, are given by

$$H_b(t) = \sum_{l=1}^{v} p_{bl} H_{bl}(t), \; b = 1,2,...,v. \tag{2}$$

Hence, the mean values $E[\theta_b]$ of the system operation process unconditional sojourn times θ_b in the particular operation states are given by

$$M_b = E[\theta_b] = \sum_{l=1}^{v} p_{bl} M_{bl}, \; b = 1,2,...,v, \tag{3}$$

where M_{bl} are defined by Equation 1.

Moreover, it is well known (Grabski, 2002) that the limit values of the system operation process transient probabilities at the particular operation states

$$p_b(t) = P(Z(t) = z_b),\ \ t \in <0,+\infty),\ \ b = 1,2,...,v,$$

are given by

$$p_b = \lim_{t \to \infty} p_b(t) = \frac{\pi_b M_b}{\sum_{l=1}^{v} \pi_l M_l},\ \ b = 1,2,...,v, \tag{4}$$

where M_b, $b = 1,2,...,v,$ are defined by Equation 3, whereas the probabilities π_b of the vector $[\pi_b]_{1xv}$ satisfy the system of equations

$$\begin{cases} [\pi_b] = [\pi_b][p_{bl}] \\ \sum_{l=1}^{v} \pi_l = 1. \end{cases} \tag{5}$$

Other interesting characteristics of the operation process $Z(t)$ possible to obtain are its total sojourn times $\hat{\theta}_b$ in the particular operation states z_b, $b = 1,2,...,v.$ It is well known (Grabski, 2002) that the system operation process total sojourn times $\hat{\theta}_b$ in the particular operation states z_b, for sufficiently large operation time θ, have approximately normal distribution with the expected value given by

$$E[\hat{\theta}_b] = p_b \theta,\ b = 1,2,...,v, \tag{6}$$

where p_b are given by Equation 4.

3 STATISTICAL IDENTIFICATION OF SYSTEM OPERATION PROCESS

In order to estimate parameters of the operation process model the following step should be done (Soszyńska, 2006):

– to fix the number of states v of the system operation process $Z(t)$ and to define the operation states $z_1, z_2, \ldots, z_v$ of the set Z,

– to fix the vector of realizations

$$[n_b(0)] = [n_1(0), n_2(0),..., n_v(0)],$$

of the numbers $n_b(0)$, $b = 1,2,...,v,$ of the system operation process $Z(t)$ transients in the particular states z_b at the initial moment $t = 0$

– to fix the matrix of realizations

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

of the numbers n_{bl}, $b,l = 1,2,...,v,$ of the system operation process $Z(t)$ transitions from the state z_b into the state z_l during the experiment time Θ,

– to fix the vector of realizations

$$[p(0)] = [p_1(0), p_2(0), \ldots, p_v(0)],$$

of the initial probabilities $p_b(0)$, $b = 1,2,...,v,$ of the system operation process $Z(t)$ transients in the particular states z_b at the moment $t = 0$, according to the formula

$$p_b(0) = \frac{n_b(0)}{n(0)}\ \text{ for } b = 1,2,...,v,$$

where

$$n(0) = \sum_{b=1}^{\nu} n_b(0),$$

is the total number of the system operation process $Z(t)$ realisations at $t = 0$,

– to fix the matrix of realisations

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

of the transition probabilities p_{bl}, $b,l = 1,2,...,\nu$, of the system operation process $Z(t)$ from the operation state z_b into the operation state z_l during the experiment time Θ, according to the formula

$$p_{bl} = \frac{n_{bl}}{n_b} \text{ for } b,l = 1,2,...,\nu,\; b \neq l,$$

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

where

$$n_b = \sum_{b \neq l}^{\nu} n_{bl}\,,\; b = 1,2,...,\nu,$$

is the realization of the total number of the system operation process $Z(t)$ transitions from the operation state z_b during the experiment time Θ,

– to formulate and to verify the hypotheses about the conditional distribution functions $H_{bl}(t)$ of the system operation process $Z(t)$ sojourn times θ_{bl}, $b,l = 1,2,...,\nu$, $b \neq l$, in the state z_b while the next transition is the state z_l on the base of their realizations θ_{bl}^k, $k = 1,2,...,n_{bl}$ during the experiment time Θ.

4 SHIPYARD ROPE TRANSPORTATION SYSTEMS PRELIMINARY DATA COLLECTION PRESENTING

The rope transportation system reliability depends strongly on the tonnage of transferred ships and therefore we can divide system's load into six groups:

– without loading,
– loading over 0 up to 500 tonnes,
– loading over 500 up to 1000 tonnes,
– loading over 1000 up to 1500 tonnes,
– loading over 1500 up to 2000 tonnes,
– loading over 2000 up to 2500 tonnes.

The broaching machines in the transportation system are numbered 1, 2, 3. There is used one or there are used two broaching machines depending on weight and length of the ship and on which repair post the ship should be transferred. There are never used all three broaching machines simultaneously. So, the system under consideration is in order if one or two of the broaching machines are not failed. Due to this fact we can conclude that it a “1 out of 3” or “2 out of 3” system. The scheme of the transportation system is given in Figure 3.

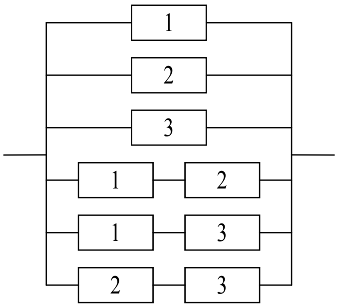

Figure 3. The scheme of the transportation system.

With this knowledge during ships' transportation we can distinguish the following situations:

- the ship is transferred using only the broaching machine number 1,
- the ship is transferred using only the broaching machine number 2,
- the ship is transferred using only the broaching machine number 3,
- the ship is transferred using two broaching machines number 1 and 2,
- the ship is transferred using two broaching machines number 1 and 3,
- the ship is transferred using two broaching machines number 2 and 3.

Figure 4. The ship during transportation from the traverser to the repair post R7.

Now we can analyze the ship transportation system in Naval Shipyard in Gdynia taking into account the system operation process and its varying in time reliability structures. Considering the weight and size of the vessel, i.e. the system's loading and the place where the ship is transferred, that has influence on the decision which broaching machines are used, we can distinguish following ($v = 25$) operation states of the system operation process $Z(t)$:

an operation state z_1 – the system is without loading,
an operation state z_2 – loading over 0 up to 500 tonnes and the broaching machine no. 1 is used,
an operation state z_3 – loading over 0 up to 500 tonnes and the broaching machine 2 is used,
an operation state z_4 – loading over 0 up to 500 tonnes and the broaching machine 3 is used,
an operation state z_5 – loading over 500 up to 1000 tonnes and the broaching machine 1 is used,
an operation state z_6 – loading over 500 up to 1000 tonnes and the broaching machine 2 is used,
an operation state z_7 – loading over 500 up to 1000 tonnes and the broaching machine 3 is used,
an operation state z_8 – loading over 1000 up to 1500 tonnes and the broaching machine 1 is used,
an operation state z_9 – loading over 1000 up to 1500 tonnes and the broaching machine 2 is used,
an operation state z_{10} – loading over 1000 up to 1500 tonnes and the broaching machine 3 is used,
an operation state z_{11} – loading over 1000 up to 1500 tonnes and the broaching machines 1 and 2 are used,
an operation state z_{12} – loading over 1000 up to 1500 tonnes and the broaching machines 1 and 3 are used,
an operation state z_{13} – loading over 1000 up to 1500 tonnes and the broaching machines 2 and 3 are used,
an operation state z_{14} – loading over 1500 up to 2000 tonnes and the broaching machine 1 is used,
an operation state z_{15} – loading over 1500 up to 2000 tonnes and the broaching machine 2 is used,
an operation state z_{16} – loading over 1500 up to 2000 tonnes and the broaching machine 3 is used,
an operation state z_{17} – loading over 1500 up to 2000 tonnes and the broaching machines 1 and 2 are used,
an operation state z_{18} – loading over 1500 up to 2000 tonnes and the broaching machines 1 and 3 are used,
an operation state z_{19} – loading over 1500 up to 2000 tonnes and the broaching machines 2 and 3 are used,
an operation state z_{20} – loading over 2000 up to 2500 tonnes and the broaching machine 1 is used,
an operation state z_{21} – loading over 2000 up to 2500 tonnes and the broaching machine 2 is used,
an operation state z_{22} – loading over 2000 up to 2500 tonnes and the broaching machine 3 is used,
an operation state z_{23} – loading over 2000 up to 2500 tonnes and the broaching machines 1 and 2 are used,
an operation state z_{24} – loading over 2000 up to 2500 tonnes and the broaching machines 1 and 3 are used,
an operation state z_{25} – loading over 2000 up to 2500 tonnes and the broaching machines 2 and 3 are used.

All preliminary defined operation states of the ships' transportation system operation process will be verified in they are necessary in practice after the experiment time i.e. after full identification of ships' transportation system operation process.

For example a vessel with tonnage 1500 tones is dragged first from the platform to the traverser during 3 hours and 15 minutes using broaching machine number 3 and next with the same broaching machine from the traverser to the repair post R4 during 45 minutes, so the system operation process $Z(t)$ is in operation state z_{10}. A vessel with a tonnage 1700 t is transferred using two broaching machines number 1 and 2 from the repair post R1 to the traverser during 1 hour 30 minutes (an operation state z_{17}) and then for about 1 hour from the traverser to the platform using one broaching machine number 1 (an operation state z_{14}).

To identify all parameters of this system operation process the statistical data are still collected as a part of the Poland Singapore Joint Research Project "Safety and Reliability of Complex Industrial Systems and Processes". Preliminary statistical data are given in Tables 1 and 2.

Table 1. Preliminary set of realizations of rope transportation system in Naval Shipyard in Gdynia operation process conditional sojourn times in particular states

Number of realization	Ship's tonnage	Broaching machine 1	2	3	Operation state	Date	Start time	Time of state duration	Start post	End post
1	1700 t	X	X		z_{17}	24.02.08	20:00	1h 30m	R1/B1	T
2	1700 t	X			z_{14}	24.02.08	22:10	1h	T	P
3	1200 t			X	z_{10}	25.02.08	21:30	2h 30m	P	R1
4	1500 t			X	z_{10}	13.03.08	19:25	3h 15m	P	T
5	1500 t			X	z_{10}	13.03.08	23:20	45m	T	R4
6	600 t			X	z_7	20.03.08	09:15	25m	R7	T
7	600 t			X	z_7	20.03.08	10:35	30m	T	B

P – platform, T – traverser, B – depot, R1, R4, R7, R1/B1 – repair posts,

Having given the preliminary statistical data in Table 1 we can begin the statistical identification of the system operation process. We assume that the numbers n_{bl}, $b,l = 1,2,\ldots,v, b \neq l,$ of realizations of the system operation process $Z(t)$ transitions from the state z_b into the state z_l during the experiment time Θ should be equal at least 40. We expect the experiment time to be about 1 year to have fulfilled the above condition. After this period of time the full identification of ships' transportation system operation process will be performed.

At the initial moment $t = 0$ the system operation process is in the operation state z_1 (without loading) and the initial probabilities of the system operation process transients in the particular state at the moment $t = 0$ are equal

$$p_1(0) = 1, \quad p_b(0) = 0 \text{ for } b = 2,3,\ldots,25.$$

After collecting all necessary data during the experiment time we can determine sojourn times θ_{bl}, $b,l = 1,2,\ldots,v, b \neq l,$ of the system operation process $Z(t)$ in the state z_b, while the next transition is to the state z_l on the base of their realizations θ_{bl}^k, $k = 1,2,\ldots,n_{bl}$, during the experiment time Θ.

Considering data given in Table 1 we get the preliminary set of realizations of analyzed transportation system's operation process conditional sojourn times θ_{bl} in the state z_b, while the next transition is to the state z_l:

$$\theta_{1,17}^1 = \text{4 days 20 hours}, \ \theta_{17,1}^1 = \text{1 hour 30 min.},$$

$$\theta_{1,14}^2 = \text{40 minutes}, \ \theta_{14,1}^2 = \text{1 hour},$$

$$\theta_{1,10}^3 = \text{22 hours 20 minutes}, \ \theta_{10,1}^3 = \text{2 hours 30 min.},$$

$$\theta_{1,10}^4 = \text{16 days 19 hours 25 min.}, \ \theta_{10,1}^4 = \text{3 hours 15 minutes},$$

$$\theta_{1,10}^5 = \text{40 minutes}, \ \theta_{10,1}^5 = \text{45 minutes},$$

$$\theta_{1,7}^6 = \text{6 days 9 hours 10 minutes}, \theta_{7,1}^6 = \text{25 minutes},$$

$$\theta_{1,7}^7 = \text{55 minutes}, \ \theta_{7,1}^7 = \text{30 minutes}.$$

From the specification of the system we can notice that after transferring the ship the system operation process always has to transit to the operation state z_1 in which the system is without loading. So the system operation process $Z(t)$ from the operation state z_1 can be changed into any state from z_2 to z_{25}, and then the system operation process always came back to the operation state z_1. Even if after one ship transportation the second ship should be transferred there is needed some time to draw the ropes from the broaching machines to the transferred ship and during this time the analyzed system is without loading. Due to above remarks we conclude that:

$$\theta_{bl}^{k} = 0 \text{ for } b,l = 2,\ldots,v, \; k = 1,2,\ldots,n_{bl}.$$

5 SHIP-ROPE ELEVATOR PRELIMINARY DATA COLLECTION PRESENTING

The ship-rope elevator in Naval Shipyard in Gdynia is widely described and analyzed under the assumption that its components are independent in (Kołowrocki, 2002, 2004) and as a system with dependent components in (Blokus-Roszkowska, 2006).

Figure 5. The ship while docking.

Considering the tonnage of the docked and undocked ships by the rope elevator in Naval Shipyard in Gdynia we can divide the system's load, similarly as in the previous ships' transportation system, into six groups and due to fact that the rope elevator system depends mainly on the tonnage of docking ships we can distinguish the following (v = 6) operation states of the rope elevator system operation process:

an operation state z_1 – without loading,
an operation state z_2 – loading over 0 up to 500 tonnes,
an operation state z_3 – loading over 500 up to 1000 tonnes,
an operation state z_4 – loading over 1000 up to 1500 tonnes,
an operation state z_5 – loading over 1500 up to 2000 tonnes,
an operation state z_6 – loading over 2000 up to 2500 tonnes.

Table 2. Preliminary set of realizations of rope elevator in Naval Shipyard in Gdynia operation process conditional sojourn times in particular states

Lp.	Operation state	Rope-hosting winches										Date	Start time	Time of state duration	Rising	Moving down
		1	2	3	4	5	6	7	8	9	10					
1	z_2	X	X	X	X	X	X	X	X	X	X	21.02.08	15:40	25 m		X
2	z_2	X	X	X	-	-	X	X	X	X	X	21.02.08	16:45	30 m	X	
3	z_5	X	X	X	X	X	X	X	X	X	X	24.02.08	23:50	40 m		X
4	z_4	X	X	X	X	X	X	X	X	X	X	25.02.08	19:15	40 m	X	
5	z_4	X	X	X	X	X	X	X	X	X	X	25.02.08	20:40	10 m		X
6	z_2	X	X	X	X	X	X	X	X	X	X	07.03.08	13:55	50 m	X	
7	z_4	X	X	X	X	X	X	X	X	X	X	13.03.08	15:30	1 h 30 m	X	
8	z_4	X	X	X	X	X	X	X	X	X	X	17.03.08	14:00	4 h 15 m	X	
9	z_4	X	X	X	X	X	X	X	X	X	X	19.03.08	02:00	3 h		X

Analyzing the data collected in Table 2 we can notice that not always all 10 rope-hosting winches are loaded. This notice will have influence in the further system's reliability analysis on the reliability functions of the ropes in the winches. More precisely, if some winches (i.e. ropes in the winches) are used more often or are more loaded during ships' docking and undocking then these ropes' reliability functions will be worse than reliability functions of the ropes in the winches used less. With this knowledge the rope elevator in the further reliability analysis will be described as a non-homogeneous system.

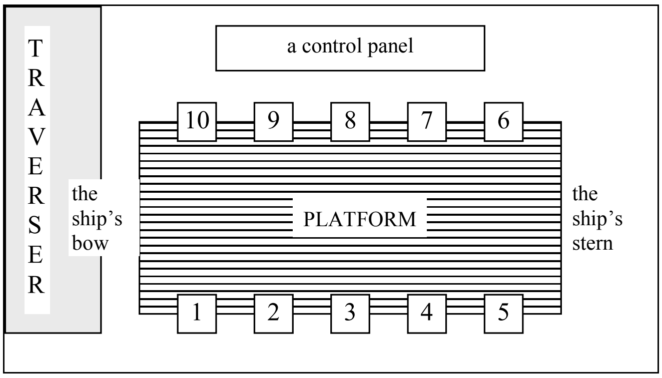

Figure 6. The scheme of the winches arrangement.

On the basis of the statistical identification of system operation process given in Section 3 we obtain the preliminary set of realizations of the elevator operation process conditional sojourn times θ_{bl} in the state z_b, while the next transition is to the state z_l:

$\theta_{12}^1 =$ 1 day 15 hours 40 minutes, $\theta_{21}^1 =$ 25 minutes,

$\theta_{12}^2 =$ 40 minutes, $\theta_{21}^2 =$ 30 minutes,

$\theta_{15}^3 =$ 3 days 6 hours 35 minutes, $\theta_{51}^3 =$ 40 minutes,

$\theta_{14}^4 =$ 18 hours 45 minutes, $\theta_{41}^4 =$ 40 minutes,

$\theta_{14}^5 =$ 45 minutes, $\theta_{41}^5 =$ 10 minutes,

$\theta_{12}^6 =$ 10 days 17 hours 5 minutes, $\theta_{21}^6 =$ 50 minutes,

$\theta_{14}^7 =$ 6 days 45 minutes, $\theta_{41}^7 =$ 1 hour 30 minutes,

$\theta_{14}^{8} =$ 3 days 21 hours, $\theta_{41}^{8} =$ 4 hours 15 minutes,

$\theta_{14}^{9} =$ 1 day 7 hours 45 minutes, $\theta_{41}^{9} =$ 3 hours.

REFERENCES

1. Blokus A., Kołowrocki K., Soszyńska J. 2005. Reliability of port transportation systems related to their operation processes. *Proc. 12-th International Congress of the International Maritime Association of the Mediterranean - IMAM 2005*: 1487-1495.
2. Blokus-Roszkowska A. 2006. Reliability analysis of multi-state rope transportation system with dependent components. *Proc. International Conference ESREL'06, Safety and Reliability for Managing Risk*: 1561-1568.
3. Blokus-Roszkowska A. 2007. On component failures' dependency influence on system's lifetime. *International Journal of Reliability, Quality and Safety Engineering. Special Issue: System Reliability and Safety,* Vol. 14, No. 6: 1-19.
4. Grabski, F. 2002. *Semi-Markov Models of Systems Reliability and Operations*. Warsaw: Systems Research Institute, Polish Academy of Sciences.
5. Kołowrocki K. 2002. Reliability and risk evaluation of large port and shipyard transportation systems. *Proc. 3-rd International Congress on Maritime Technological Innovations and Research*: 581-589.
6. Kołowrocki, K. 2004. *Reliability of Large Systems*. Amsterdam - Boston - Heidelberg - London - New York - Oxford - Paris - San Diego - San Francisco - Singapore - Sydney - Tokyo: Elsevier.
7. Kołowrocki, K. et al. 2002. Asymptotic approach to reliability analysis and optimisation of complex transport systems (*in Polish*). Gdynia: Maritime University. Project founded by the Polish Committee for Scientific Research.
8. Kołowrocki, K. & Soszyńska, J. 2006. Reliability and availability of complex systems. *Quality and Reliability Engineering International*. Vol. 22, Issue 1: 79-99.
9. Soszyńska, J. 2006. Reliability evaluation of a port oil transportation system in variable operation conditions. *International Journal of Pressure Vessels and Piping.* Vol. 83, Issue 4: 304-310.