Kołowrocki Krzysztof

Soszyńska-Budny Joanna
Maritime University, Gdynia, Poland

Identification of port oil piping transportation system operation process including operating environment threats

Keywords

port oil piping transport, critical infrastructure, operation process, operating environment threats

Abstract

In the paper, the traditional semi-Markov approach to a complex technical system operation process modeling is proposed to model and to identify the port oil piping transportation system operation process including operating environment threats.

1. Introduction

The operation process of a critical infrastructure is very complex and often it is difficult to analyze these critical infrastructure safety with respect to changing in time its operation process states and operating environment conditions that are essential in this analysis. The complexity of the critical infrastructure operation process and its influence on changing in time the critical infrastructure structure and its components' safety parameters are essential in critical infrastructure safety analysis and protection. Usually, the critical infrastructure environment have either an explicit or an implicit strong influence on the critical infrastructure operation process. As a rule, some of the environmental events together with the infrastructure operation conditions define a set of different operation states of the critical infrastructure in which the critical infrastructure change its safety structure and its components safety parameters. In this report, we propose a convenient tool for analyzing this problem applying the semi-Markov model [14]-[16], [18], [23]-[24] of the critical infrastructure operation process, both without including critical infrastructure environment threats and with including them into this model.

2. Identification of critical infrastructure operation process

2.1. Estimating parameters of critical infrastructure operation process including operating environment threats identified by expert opinion – expert data only

In the case of lack of statistical data collection, together with experienced experts operating the critical infrastructure, it is possible to estimate approximately the unknown parameters of the critical infrastructure operation process including operating environment threats performing the following steps:

i) to determine the vector

$$[p'(0)] = [p'_1(0), p'_2(0), \ldots, p'_{\nu'}(0)],$$

of expert evaluations of the probabilities $p'_b(0)$, $b = 1,2,\ldots,\nu'$, of the critical infrastructure operation process staying at the operation states at the initial moment $t = 0$, after explanation to the expert practical meaning of the formula

$$p'_b(0) = \frac{n'_b(0)}{n'(0)} \text{ for } b = 1,2,\ldots,\nu';$$

ii) to determine the matrix

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

of expert evaluations of the probabilities p'_{bl}, $b,l = 1,2,...,\nu'$, of the critical infrastructure operation process transitions from the operation state z_b to the operation state z_l, after explanation to the expert practical meaning of the formula

$$p'_{bl} = \frac{n'_{bl}}{n'_b} \text{ for } b,l = 1,2,...,\nu', b \neq l, \; p_{bb} = 0$$

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

iii) to determine the matrix

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

of expert evaluations of the mean values M'_{bl}, $b,l = 1,2,...,\nu'$, of the critical infrastructure operation process conditional sojourn times θ'_{bl}, $b, l = 1,2,...,\nu'$, at the operation state z_b when the next operation state is z_l, after explanation to the expert practical meaning of these parameters.

3. Applications in port transport including operating environment threats identified by expert opinion – statistical and expert data

3.1. Identification of port oil piping transportation system operation process including operating environment threats identified by expert opinion – statistical and expert data

On the basis of the expert opinions concerning the operation process of the considered port oil pipeline transportation system, in [3] the number of the pipeline system operation process states $\nu' = 28$ is fixed and the operation states z'_b, $b = 1,2,...,28$, are defined as follows:

- the operation states z_i, $i = 1,2,...,7$, without including operating environment threats ut_1, ut_2, ut_3, marked by

$z_i' = z_i$, $i = 1,2,...,7$;

- the operation states z_i, $i = 1,2,...,7$, including the threat ut_1, respectively marked by

z_i', $i = 8,9,...,14$;

- the operation states z_i, $i = 1,2,...,7$, including the threat ut_2, respectively marked by

z_i', $i = 15,16,...,21$;

- the operation states z_i, $i = 1,2,...,7$, including the threat ut_3, respectively marked by

z_i', $i = 22,23,...,28$.

The influence of the above system operation states changing on the changes of the pipeline system safety structure is similar to that described in Section 2.2 [3].
At the system operation states z_1', z_8', z_{15}', z_{22}' and z_7', z_{14}', z_{21}', z_{28}', the system is composed of the subsystem S_3, that is a series-”2 out of 3” system containing three series subsystems with the scheme showed in *Figure 10* [3].
At the system operation state z_2', z_9', z_{16}', z_{23}', the system is composed of a series-parallel subsystem S_3, which contains three pipelines with the scheme showed in *Figure 11* [3].
At the system operation states z_3', z_{10}', z_{17}', z_{24}' and z_5', z_{12}', z_{19}', z_{26}', the system is series and composed of two series-parallel subsystems S_1, S_2 each containing two pipelines with the scheme showed in *Figure 12* [3].
At the operation states z_4', z_{11}', z_{18}', z_{25}' and z_6', z_{13}', z_{20}', z_{27}', the system is series and composed of two series-parallel subsystems S_1, S_2 each containing two pipelines and one series-“2 out of 3” subsystem S_3, with the scheme showed in *Figure 13* [3].

3.2. Defining parameters and data collection of port oil piping transportation system operation process including operating environment threats identified by expert opinion – statistical and expert data

The unknown parameters of the critical infrastructure operation process semi-Markov model are:

- the initial probabilities $p'_b(0)$, $b = 1,2,...,28,$ of the pipeline system operation process staying at the particular states z'_b at the moment $t = 0$,
- the probabilities p'_{bl}, $b,l = 1,2,...,28, b \neq l,$ of the pipeline system operation process transitions from the operation state z'_b into the operation state z'_l,
- the distributions of the pipeline system conditional sojourn times θ'_{bl}, $b,l = 1,2,...,28, b \neq l,$ at the particular operation states and their mean values $M'_{bl} = E[\theta'_{bl}]$, $b,l = 1,2,...,28, b \neq l$.

To identify all these parameters of the pipeline system operation process the statistical data about this process is needed.

3.3. Evaluating parameters of port oil piping transportation system operation process including operating environment threats identified by expert opinion– statistical and expert data

On the basis of the statistical data from Section 3.1.1 [3], using respectively the formulae (2.1)-(2.3) in [3] and (2.4)-(2.6) given in Section 2.2 [3], it is possible to evaluate the following unknown basic parameters of the port oil piping transportation system operation process including operating environment threats without their separation:
- the vector

$$[p(0)]_{1x7} = [0.34, 0.05, 0, 0, 0.23, 0.19, 0.19] \quad (1)$$

of the initial probabilities $p_b(0)$, $b = 1,2,...7,$ of the pipeline system operation process staying at the particular states z_b at the $t = 0$,
- the matrix

$$[p_{bl}]_{7x7} = \begin{bmatrix} 0 & 0.022 & 0.022 & 0 & 0.534 & 0.111 & 0.311 \\ 0.2 & 0 & 0 & 0 & 0 & 0 & 0.8 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0.488 & 0.023 & 0 & 0.023 & 0 & 0.233 & 0.233 \\ 0.095 & 0 & 0 & 0 & 0.667 & 0 & 0238 \\ 0.531 & 0.062 & 0 & 0 & 0.219 & 0.188 & 0 \end{bmatrix} \quad (2)$$

of the probabilities p_{bl}, $b,l = 1,2,...,7,$ of transitions of the pipeline system operation process from the operation state z_b into the operation state z_l;
- the matrix

$$[M_{bl}]_{7x7} = \begin{bmatrix} 0 & 1920 & 480 & 0 & 1999.4 & 1250 & 1129.6 \\ 9960 & 0 & 0 & 0 & 0 & 0 & 810 \\ 575 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 380 \\ 874.7 & 480 & 0 & 300 & 0 & 436.3 & 1042.5 \\ 325 & 0 & 0 & 0 & 510.7 & 0 & 438 \\ 874.1 & 510 & 0 & 0 & 2585.7 & 2380 & 0 \end{bmatrix} \quad (3)$$

of the mean values M_{bl}, $b,l = 1,2,...,7,$ of the conditional sojourn times θ_{bl}, $b,l = 1,2,...,7,$ the pipeline system operation process at the the operation state z_b when the next operation state is z_l.

Some of the values of the probabilities existing in the vector $[p(0)]_{1x7}$ and in the matrix $[p_{bl}]_{7x7}$, besides of that standing on the main diagonal, and equal to zero does not mean that the events they are concerned with, can not appear. They are evaluated on the basis of real statistical data and their values may change and become more precise if the time of the experiment is longer.

Considering expert opinion from BOTD that in all operations states of the port oil piping system, at each of the operation states if $z_b(0) \neq 0$, $b = 1,2,…,7$, the probability of a human error can be approximately evaluated as

$$P_b(ut_1) = P(ut_1) = 1/1158\text{h} = 0.00086,$$

the probability of a terrorist attack can be approximately evaluated as

$$P_b(ut_2) = P(ut_2) = 0,$$

and the probability of an act of vandalism and/or theft can be approximately evaluated as

$$P_b(ut_3) = P(ut_3) = 1/7896\text{h} = 0.000076,$$

We distribute the initial probabilities (1) accordind to the variant 1 procedure defined by (5.1)-(5.4) [3], as follows:

- if $p_b(0) \neq 0$, $b = 1,2, …, 7$,

we replace it by

$$p'_{4(b-1)+1}(0) = p_b(0) - [P(ut_1) + P(ut_2) + P(ut_3)]$$
$$= p_b(0) - [0.00086 + 0.0 + 0.000076]$$
$$= p_b(0) - [0.000936],$$
$$p'_{4(b-1)+1+i}(0) = P(ut_i),\ i = 1,2,3,$$

for $b = 1,2, …, 7$;

- if $p_b(0) = 0$, $b = 1,2, \ldots, 7$,

we replace it by

$p'_{4(b-1)+1}(0) = 0$,
$p'_{4(b-1)+1+i}(0) = 0$, $i = 1,2,3$

for $b = 1,2, \ldots, 7$.

Thus, in particular, we distribute

- $p_1(0) = 0.34$

into the initial probabilities

$p'_1(0) = 0.339064$, $p'_2(0) = 0.00086$,
$p'_3(0) = 0.0$, $p'_4(0) = 0.000076$;

- $p_2(0) = 0.05$

into the initial probabilities

$p'_5(0) = 0.0499064$, $p'_6(0) = 0.00086$,
$p'_7(0) = 0$, $p'_8(0) = 0.000076$;

- $p_3(0) = 0$

into the initial probabilities

$p'_9(0) = 0$, $p'_{10}(0) = 0$, $p'_{11}(0) = 0$, $p'_{12}(0) = 0$;

- $p_4(0) = 0$

into the initial probabilities

$p'_{13}(0) = 0$, $p'_{14}(0) = 0$, $p'_{15}(0) = 0$, $p'_{16}(0) = 0$;

- $p_5(0) = 0.23$

into the initial probabilities

$p'_{17}(0) = 0.229064$, $p'_{18}(0) = 0.00086$,
$p'_{19}(0) = 0.0$, $p'_{20}(0) = 0.000076$;

- $p_6(0) = 0.19$

into the initial probabilities

$p'_{21}(0) = 0.189064$, $p'_{22}(0) = 0.00086$,
$p'_{23}(0) = 0$, $p'_{24}(0) = 0.000076$;

- $p_7(0) = 0.19$

into the initial probabilities

$p'_{25}(0) = 0.189064$, $p'_{26}(0) = 0.00086$,
$p'_{27}(0) = 0$, $p'_{28}(0) = 0.000076$.

After that, we get new vector of initial probabilities of the port oil piping transportation system operation process including operating environment threats with their separation:

$[p'(0)]_{1x28}$
= [0.339064, 0.00086, 0, 0.000076;
0.049604, 0.00086, 0, 0.000076; 0, 0, 0, 0;
0, 0, 0, 0; 0.229064, 0.00086, 0, 0.000076;
0.189064, 0.00086, 0, 0.000076; 0.189064,
0.00086, 0, 0.000076]

Similarly, considering expert opinions from BOTD, we distribute the probabilities of transitions between the operation states (2) accordind to the variant 1 procedure defined by (5.9)-(5.14) [3] as follows:

- if $p_{bl} \neq 0$, $b, l = 1,2, \ldots, 7$,

we replace it by

$p'_{4(b-1)+1\ 4(l-1)+1} = p_{bl} - [P(ut_1) + P(ut_2) + P(ut_3)]$
$= p_{bl} - [\ 0.00086 + 0 + 0.000076]$
$= p_{bl} - [0.000936]$,

$p'_{4(b-1)+1\ 4(l-1)+1+i} = P(ut_i)$, $i = 1,2,3$,

for $b, l = 1,2, \ldots, 7$,

and we additionally assume that

$p'_{4(b-1)+1+i\ 4(b-1)+1} = 1$, $i = 1,2,3$,
$p'_{4(b-1)+1+i\ j} = 0$, $i = 1,2,3$, $j = 1,2,\ldots,28$,

$j \neq 4(b-1)+1$

- if $p_{bl} = 0$, $b, l = 1,2, \ldots, 7$,

we replace it by

$p'_{4(b-1)+1\ 4(l-1)+1} = 0$,
$p'_{4(b-1)+1\ 4(l-1)+1+i}(0) = 0$, , $i = 1,2,3$,

for $b, l = 1,2, \ldots, 7$.

Thus, in particular, we distribute:
- $p_{1\ 1} = 0$

into the probabilities of transitions

$p'_{1\,1} = 0$, $p'_{1\,2} = 0$, $p'_{1\,3} = 0$, $p'_{1\,4} = 0$,

- $p_{1\,2} = 0.022$

into the probabilities of transitions

$p'_{1\,5} = 0.021064$, $p'_{1\,6} = 0.00086$,
$p'_{1\,7} = 0$, $p'_{1\,8} = 0.000076$;

- $p_{1\,3} = 0.022$

into the probabilities of transitions

$p'_{1\,9} = 0.021064$, $p'_{1\,10} = 0.00086$,
$p'_{1\,1} = 0$, $p'_{1\,2} = 0.000076$;

- $p_{1\,4} = 0$

into the probabilities of transitions

$p'_{1\,13} = 0$, $p'_{1\,14} = 0$, $p'_{1\,15} = 0$, $p'_{1\,16} = 0$;

- $p_{1\,5} = 0.534$

into the probabilities of transitions

$p'_{1\,17} = 0.533064$, $p'_{1\,18} = 0.00086$,
$p'_{1\,19} = 0$, $p'_{1\,20} = 0.000076$;

- $p_{1\,6} = 0.111$

into the probabilities of transitions

$p'_{1\,21} = 0.110064$, $p'_{1\,22} = 0.00086$,
$p'_{1\,23} = 0$, $p'_{1\,24} = 0.000076$;

- $p_{1\,7} = 0.311$

into the probabilities of transitions

$p'_{1\,25} = 0.310064$, $p'_{1\,26} = 0.00086$,
$p'_{1\,27} = 0$, $p'_{1\,8} = 0.000076$;

and additionally, we assume

$p'_{2\,1} = 1$, $p'_{2\,j} = 0$, $j = 2,3, \ldots, 28$,
$p'_{3\,1} = 1$, $p'_{3\,j} = 0$, $j = 2,3, \ldots, 28$,
$p'_{4\,1} = 1$, $p'_{4\,j} = 0$, $j = 2,3, \ldots, 28$;

to replce the 1st row of the matrix $[p_{bl}]_{7x7}$ given by (2) by the following 4 rows of the matrix $[p'_{bl}]_{28x28}$

[0 0 0 0; 0.021064 0.00086 0 0.000076; 0.021064 0.00086 0 0.000076; 0 0 0 0; 0.533064 0.00086 0.0 0.000076; 0.110064 0.00086 0 0.000076; 0.310064 0.00086 0 0.000076]
[1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0].

We distribute:

- $p_{2\,1} = 0.2$

into the probabilities of transitions

$p'_{5\,1} = 0.199064$, $p'_{5\,2} = 0.00086$,
$p'_{5\,3} = 0$, $p'_{5\,4} = 0.000076$;

- $p_{2\,2} = 0$

into the probabilities of transitions

$p'_{5\,5} = 0$, $p'_{5\,6} = 0$, $p'_{5\,7} = 0$, $p'_{5\,8} = 0$,

- $p_{2\,3} = 0$

into the probabilities of transitions

$p'_{5\,9} = 0$, $p'_{5\,10} = 0$, $p'_{5\,11} = 0$, $p'_{5\,12} = 0$;

- $p_{2\,4} = 0$

into the probabilities of transitions

$p'_{5\,13} = 0$, $p'_{5\,14} = 0$, $p'_{5\,15} = 0$, $p'_{5\,16} = 0$;

- $p_{2\,5} = 0$

into the probabilities of transitions

$p'_{5\,17} = 0$, $p'_{5\,18} = 0$, $p'_{5\,19} = 0$, $p'_{5\,20} = 0$;

- $p_{2\,6} = 0$

into the probabilities of transitions

$p'_{5\,21} = 0$, $p'_{5\,22} = 0$, $p'_{5\,23} = 0$, $p'_{5\,24} = 0$;

- $p_{2\,7} = 0.8$

into the probabilities of transitions

$p'_{5\,25} = 0.799064$, $p'_{1\,26} = 0.00086$,
$p'_{1\,27} = 0$, $p'_{1\,28} = 0.000076$;

and additionally, we assume

$p'_{6\,5} = 1$, $p'_{6\,j} = 0$, $j = 1,2, \ldots 4,6, \ldots, 28$,

$p'_{7\,5} = 1$, $p'_{7\,j} = 0$, $j = 1,2, \ldots 4,6, \ldots, 28$,
$p'_{8\,5} = 1$, $p'_{8\,j} = 0$, $j = 1,2, \ldots 4,6, \ldots, 28$;

to replce the 2nd row of the matrix $[p_{bl}]_{7x7}$ given by (2) by the following 4 rows of the matrix $[p'_{bl}]_{28x28}$

[0.199064 0.00086 0 0.000076; 0 0 0 0; 0 0 0 0;
0 0 0 0; 0 0 0 0; 0 0 0 0; 0.799064 0.00086 0 0.000076]
[0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0].

We distribute:

- $p_{3\,1} = 1$

into the probabilities of transitions

$p'_{9\,1} = 0.999064$, $p'_{9\,2} = 0.00086$,
$p'_{9\,3} = 0$, $p'_{9\,4} = 0.000076$;

- $p_{3\,2} = 0$

into the probabilities of transitions

$p'_{9\,5} = 0$, $p'_{5\,6} = 0$, $p'_{5\,7} = 0$, $p'_{5\,8} = 0$;

- $p_{3\,3} = 0$

into the probabilities of transitions

$p'_{9\,9} = 0$, $p'_{9\,10} = 0$, $p'_{9\,11} = 0$, $p'_{9\,12} = 0$;

- $p_{3\,4} = 0$

into the probabilities of transitions

$p'_{9\,13} = 0$, $p'_{9\,14} = 0$, $p'_{9\,15} = 0$, $p'_{9\,16} = 0$;

- $p_{3\,5} = 0$

into the probabilities of transitions

$p'_{9\,17} = 0$, $p'_{9\,18} = 0$, $p'_{9\,19} = 0$, $p'_{9\,20} = 0$;

- $p_{3\,6} = 0$

into the probabilities of transitions

$p'_{9\,21} = 0$, $p'_{9\,22} = 0$, $p'_{9\,23} = 0$, $p'_{9\,24} = 0$;

- $p_{3\,7} = 0$

into the probabilities of transitions

$p'_{9\,25} = 0$, $p'_{9\,26} = 0$, $p'_{9\,27} = 0$, $p'_{9\,28} = 0$;

and additionally, we assume

$p'_{10\,9} = 1$, $p'_{10\,j} = 0$, $j = 1,2, \ldots 8,10, \ldots, 28$,
$p'_{11\,9} = 1$, $p'_{11\,j} = 0$, $j = 1,2, \ldots 8,10, \ldots, 28$,
$p'_{12\,9} = 1$, $p'_{12\,j} = 0$, $j = 1,2, \ldots 8,10, \ldots, 28$;

to replce the 3rd row of the matrix $[p_{bl}]_{7x7}$ given by (2) by the following 4 rows of the matrix $[p'_{bl}]_{28x28}$

[0.999064 0.00086 0 0.000076; 0 0 0 0; 0 0 0 0;
0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0].

We distribute:

- $p_{4\,1} = 0$

into the probabilities of transitions

$p'_{13\,1} = 0$, $p'_{13\,2} = 0$, $p'_{13\,3} = 0$, $p'_{13\,4} = 0$;

- $p_{4\,2} = 0$

into the probabilities of transitions

$p'_{13\,5} = 0$, $p'_{13\,6} = 0$, $p'_{13\,7} = 0$, $p'_{13\,8} = 0$;

- $p_{4\,3} = 0$

into the probabilities of transitions

$p'_{13\,9} = 0$, $p'_{13\,10} = 0$, $p'_{13\,11} = 0$, $p'_{13\,12} = 0$;

- $p_{4\,4} = 0$

into the probabilities of transitions

$p'_{13\,13} = 0$, $p'_{13\,14} = 0$, $p'_{13\,15} = 0$, $p'_{13\,16} = 0$;

- $p_{4\,5} = 0$

into the probabilities of transitions

$p'_{13\,17} = 0$, $p'_{13\,18} = 0$, $p'_{13\,19} = 0$, $p'_{13\,20} = 0$;

- $p_{4\,6} = 0$

into the probabilities of transitions

$p'_{13\,21} = 0$, $p'_{13\,22} = 0$, $p'_{13\,23} = 0$, $p'_{13\,24} = 0$;

- $p_{4\,7} = 1$

into the probabilities of transitions

$p'_{13\,25} = 0.999064$, $p'_{13\,26} = 0.00086$,
$p'_{13\,27} = 0.0$, $p'_{13\,28} = 0.000076$;

and additionally, we assume

$p'_{14\,13} = 1$, $p'_{14\,j} = 0$, $j = 1,2, \ldots 12,14, \ldots, 28$,
$p'_{15\,13} = 1$, $p'_{15\,j} = 0$, $j = 1,2, \ldots 12,14, \ldots, 28$,
$p'_{16\,13} = 1$, $p'_{16\,j} = 0$, $j = 1,2, \ldots 12,14, \ldots, 28$;

to replce the 4th row of the matrix $[p_{bl}]_{7x7}$ given by (2) by the following 4 rows of the matrix $[p'_{bl}]_{28x28}$

[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0.999064 0.00086 0.0 0.000076]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0].

We distribute:

- $p_{5\,1} = 0.488$

into the probabilities of transitions

$p'_{17\,1} = 0.487064$, $p'_{17\,2} = 0.00086$,
$p'_{13\,3} = 0$, $p'_{13\,4} = 0.000076$;

- $p_{5\,2} = 0.023$

into the probabilities of transitions

$p'_{17\,5} = 0.022064$, $p'_{17\,6} = 0.00086$,
$p'_{17\,7} = 0$, $p'_{17\,8} = 0.000076$;

- $p_{5\,3} = 0$

into the probabilities of transitions

$p'_{17\,9} = 0$, $p'_{17\,10} = 0$, $p'_{17\,11} = 0$, $p'_{17\,12} = 0$;

- $p_{5\,4} = 0.023$

into the probabilities of transitions

$p'_{17\,13} = 0.022064$, $p'_{17\,14} = 0.00086$,
$p'_{17\,15} = 0$, $p'_{17\,16} = 0.000076$;

- $p_{5\,5} = 0$

into the probabilities of transitions

$p'_{17\,17} = 0$, $p'_{17\,18} = 0$, $p'_{17\,19} = 0$, $p'_{17\,20} = 0$;

- $p_{5\,6} = 0.233$

into the probabilities of transitions

$p'_{17\,21} = 0.232064$, $p'_{17\,22} = 0.00086$,
$p'_{17\,23} = 0$, $p'_{17\,24} = 0.000076$;

- $p_{5\,7} = 0.233$

into the probabilities of transitions

$p'_{17\,25} = 0.232064$, $p'_{17\,26} = 0.00086$,
$p'_{17\,27} = 0$, $p'_{17\,28} = 0.000076$;

and additionally, we assume

$p'_{18\,17} = 1$, $p'_{18\,j} = 0$, $j = 1,2, \ldots 16,18, \ldots, 28$,
$p'_{19\,17} = 1$, $p'_{19\,j} = 0$, $j = 1,2, \ldots 16,18, \ldots, 28$,
$p'_{20\,17} = 1$, $p'_{20\,j} = 0$, $j = 1,2, \ldots 16,18, \ldots, 28$;

to replce the 5th row of the matrix $[p_{bl}]_{7x7}$ given by (2) by the following 4 rows of the matrix $[p'_{bl}]_{28x28}$

[0.487064 0.00086 0 0.000076; 0.022064 0.00086 0 0.000076; 0 0 0 0; 0.022064 0.00086 0 0.000076; 0 0 0 0; 0.232064 0.00086 0 0.000076; 0.232064 0.00086 0 0.000076]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0; 0 0 0 0].

We distribute:

- $p_{6\,1} = 0.095$

into the probabilities of transitions

$p'_{21\,1} = 0.094064$, $p'_{17\,2} = 0.00086$,
$p'_{13\,3} = 0$, $p'_{13\,4} = 0.000076$;

- $p_{6\,2} = 0$

into the probabilities of transitions

$p'_{21\,5} = 0$, $p'_{21\,6} = 0$, $p'_{21\,7} = 0$, $p'_{21\,8} = 0$;

- $p_{6\,3} = 0$

into the probabilities of transitions

$p'_{21\,9} = 0$, $p'_{21\,10} = 0$, $p'_{21\,11} = 0$, $p'_{21\,12} = 0$;

- $p_{6\,4} = 0$

into the probabilities of transitions

$p'_{21\,13} = 0$, $p'_{21\,14} = 0$, $p'_{21\,15} = 0$, $p'_{21\,16} = 0$;

- $p_{6\,5} = 0.667$

into the probabilities of transitions

$p'_{21\,17} = 0.666064$, $p'_{21\,18} = 0.00086$,
$p'_{21\,19} = 0$, $p'_{21\,20} = 0.000076$;

- $p_{6\,6} = 0$

into the probabilities of transitions

$p'_{21\,21} = 0$, $p'_{21\,22} = 0$, $p'_{21\,23} = 0$, $p'_{21\,24} = 0$;

- $p_{6\,7} = 0.238$

into the probabilities of transitions

$p'_{21\,25} = 0.237064$, $p'_{17\,26} = 0.00086$,
$p'_{17\,27} = 0$, $p'_{17\,28} = 0.000076$;

and additionally, we assume

$p'_{22\,21} = 1$, $p'_{22\,j} = 0$, $j = 1,2, \ldots 20,22, \ldots, 28$,
$p'_{23\,21} = 1$, $p'_{23\,j} = 0$, $j = 1,2, \ldots 20,22, \ldots, 28$,
$p'_{23\,21} = 1$, $p'_{24\,j} = 0$, $j = 1,2, \ldots 20,22, \ldots, 28$;

to replce the 6th row of the matrix $[p_{bl}]_{7x7}$ given by (2) by the following 4 rows of the matrix $[p'_{bl}]_{28x28}$

[0.094064 0.00086 0 0.000076; 0 0 0 0; 0 0 0 0;
0 0 0 0; 0.666064 0.00086 0.0 0.000076; 0 0 0 0;
0.237064 0.00086 0 0.000076]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0; 0 0 0 0].

We distribute:

- $p_{7\,1} = 0.531$

into the probabilities of transitions

$p'_{25\,1} = 0.530064$, $p'_{17\,2} = 0.00086$,
$p'_{13\,3} = 0$, $p'_{13\,4} = 0.000076$;

- $p_{72} = 0.062$

into the probabilities of transitions

$p'_{25\,5} = 0.0610064$, $p'_{21\,6} = 0.00086$,
$p'_{21\,7} = 0$, $p'_{21\,8} = 0.000076$;

- $p_{7\,3} = 0$

into the probabilities of transitions

$p'_{25\,9} = 0$, $p'_{25\,10} = 0$, $p'_{25\,11} = 0$, $p'_{25\,12} = 0$;

- $p_{7\,4} = 0$

into the probabilities of transitions

$p'_{25\,13} = 0$, $p'_{25\,14} = 0$, $p'_{25\,15} = 0$, $p'_{25\,16} = 0$;

- $p_{7\,5} = 0.219$

into the sum of probabilities of transitions

$p'_{25\,17} = 0.218064$, $p'_{21\,18} = 0.00086$,
$p'_{21\,19} = 0$, $p'_{21\,20} = 0.000076$;

- $p_{7\,6} = 0.188$

into the probabilities of transitions

$p'_{21\,21} = 0.187064$, $p'_{21\,22} = 0.00086$,
$p'_{21\,23} = 0$, $p'_{21\,24} = 0.000076$;

- $p_{7\,7} = 0$

into the probabilities of transitions

$p'_{25\,25} = 0$, $p'_{17\,26} = 0$, $p'_{17\,27} = 0$, $p'_{17\,28} = 0$;

and additionally, we assume

$p'_{26\,25} = 1$, $p'_{26\,j} = 0$, $j = 1,2, \ldots 24,26, \ldots, 28$,
$p'_{27\,25} = 1$, $p'_{27\,j} = 0$, $j = 1,2, \ldots 24,26, \ldots, 28$,
$p'_{28\,25} = 1$, $p'_{28\,j} = 0$, $j = 1,2, \ldots 24,26, \ldots, 28$;

to replce the 7th row of the matrix $[p_{bl}]_{7x7}$ given by (2) by the following 4 rows of the matrix $[p'_{bl}]_{28x28}$

[0.530064 0.00086 0 0.000076; 0.061064 0.00086 0
0.000076; 0 0 0 0; 0 0 0 0; 0.218064 0.00086 0
0.000076; 0.187064 0.00086 0 0.000076; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 1 0 0 0].

Finally, we transform the corresponding matrix $[M_{bl}]_{7x7}$ of the mean values of the conditional sojourn times θ_{bl}, $b, l = 1,2, \ldots, 7$, into the the matrix $[M'_{bl}]_{28x28}$ of the mean values of the conditional sojourn times θ'_{bl}, $b, l = 1,2, \ldots, 28$, according to the procedure (5.21)-(5.24) [3], in the following way:

- if $M_{bl}(0) \neq 0,\ b,l = 1,2,\ldots,7$,

we fix the mean values

$M'_{4(b-1)+1+i\ 4(b-1)+1}\ \ i = 1,2,3,\ b = 1,2,\ldots,7$,

on the basis of expert opinions and assume

$M'_{4(b-1)+1+i\ j} = 0,\ i = 1,2,3,\ j = 1,2,\ldots,28$,

and $j \neq 4(b-1)+1$,

and

$$M'_{4(b-1)+1\;4(l-1)+1} = M_{bl} - \sum_{i=1}^{3} M'_{4(b-1)+1+i\;4(b-1)+1},$$

- if $M_{bl}(0) = 0,\ \ b,l = 1,2,...,7,$

we replace it by

$M'_{4(b-1)+1\;4(l-1)+1} = 0,$
$M'_{4(b-1)+1\;4(l-1)+1+i} = 0,\ \ i = 1,2,3,$

for $b,l = 1,2,...,7.$

Considering expert opinions [BOTD] that in all operations states of the port oil piping system the mean value of the time needed to eliminate a human error is approximately equal to 2h, the mean value of the time needed to eliminate a a terrorist attack is equal to 0h (it is assumed that the system does not work under that threats), the mean value of the time needed to eliminate an act of vandalism and/or theft is approximately equel to 8h, we distribute the mean values of the piping system operation process conditional sojourn times at the operation states (3) in the following way:
We fix the mean values:

$M'_{2\,1} = 2,\ M'_{3\,1} = 0,\ M'_{4\,1} = 8.$

We distribute:

- $M_{1\,1} = 0$

into the mean values

$M'_{1\,1} = 0,\ M'_{1\,2} = 0,\ M'_{1\,3} = 0,\ M'_{1\,4} = 0;$

- $M_{1\,2} = 1920$

into the mean values

$M'_{1\,5} = 1910,\ M'_{1\,6} = 1910,$
$M'_{1\,7} = 1910,\ M'_{1\,8} = 1910;$

- $M_{1\,3} = 480$

into the mean values

$M'_{1\,9} = 470,\ M'_{1\,10} = 470,\ M'_{1\,11} = 470,\ M'_{1\,12} = 470;$

- $M_{1\,4} = 0$

into the mean values

$M'_{1\,13} = 0,\ M'_{1\,14} = 0,\ M'_{1\,15} = 0,\ M'_{1\,16} = 0;$

- $M_{1\,5} = 1999.4$

into the mean values

$M'_{1\,17} = 1989.4,\ M'_{1\,18} = 1989.4,$
$M'_{1\,19} = 1989.4,\ M'_{1\,20} = 1989.4,$

- $M_{1\,6} = 1250$

into the mean values

$M'_{1\,21} = 1240,\ M'_{1\,22} = 1240,$
$M'_{1\,23} = 1240,\ M'_{1\,24} = 1240;$

- $M_{1\,7} = 1129.6$

into the mean values

$M'_{1\,25} = 1119.6,\ M'_{1\,26} = 1119.6$
$M'_{1\,27} = 1119.6,\ M'_{1\,28} = 1119.6;$

and additionally we assume

$M'_{2\,l} = 0,\ l = 2,3,\ \ldots,\ 28,$
$M'_{3\,l} = 0,\ l = 2,3,\ \ldots,\ 28,$
$M'_{4\,l} = 0,\ l = 2,3,\ \ldots,\ 28;$

to replce the 1st row of the matrix $[M_{bl}]_{7x7}$ given by (3) by the following 4 rows of the matrix $[M'_{bl}]_{28x28}$

[0 0 0 0; 1910 1910 0.0 1910; 470 470 0 470;
0 0 0 0;1989.4 1998.4 1989.4 1989.4; 1240 1240 1240
1240; 119.6 1119.6 1119.6 1119.66]
[2 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[8 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0].

We fix the mean values:

$M'_{6\,5} = 2,\ M'_{7\,5} = 0,\ M'_{8\,5} = 8.$

We distribute:

- $M_{2\,1} = 9960$

into the mean values

$M'_{5\,1} = 9950,\ M'_{5\,2} = 9950,$
$M'_{5\,3} = 9950,\ M'_{5\,4} = 9950;$

- $M_{2\,2} = 0$

into the mean values

$M'_{5\,5} = 0,\ M'_{5\,6} = 0,\ M'_{5\,7} = 0,\ M'_{5\,8} = 0;$

- $M_{2\,3} = 0$

into the mean values

$M'_{5\,9} = 0$, $M'_{5\,10} = 0$, $M'_{5\,11} = 0$, $M'_{5\,12} = 0$;

- $M_{2\,4} = 0$

into the mean values

$M'_{5\,13} = 0$, $M'_{5\,14} = 0$, $M'_{5\,15} = 0$, $M'_{5\,16} = 0$;

- $M_{2\,5} = 0$

into the mean values

$M'_{5\,17} = 0$, $M'_{5\,18} = 0$, $M'_{5\,19} = 0$, $M'_{5\,20} = 0$;

- $M_{2\,6} = 0$

into the mean values

$M'_{5\,21} = 0$, $M'_{5\,22} = 0$, $M'_{5\,23} = 0$, $M'_{5\,24} = 0$;

- $M_{2\,7} = 810$

into the mean values

$M'_{5\,25} = 800$, $M'_{5\,26} = 800$, $M'_{5\,27} = 800$, $M'_{5\,28} = 800$;

and additionally we assume

$M'_{6\,l} = 0$, $l = 1,2, \ldots, 4,6, \ldots, 28$,
$M'_{7\,l} = 0$, $l = 1,2, \ldots, 4,6, \ldots, 28$,
$M'_{8\,l} = 0$, $l = 1,2, \ldots, 4,6, \ldots, 28$;

to replce the 2nd row of the matrix $[M_{bl}]_{7x7}$ given by (3) by the following 4 rows of the matrix $[M'_{bl}]_{28x28}$

[9950 9950 9950 9950; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0; 0 0 0 0; 800 800 800 800]
[0 0 0 0; 2 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 8 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0].

We fix the mean values:

$M'_{10\,9} = 2$, $M'_{11\,9} = 0$, $M'_{12\,9} = 8$;

We distribute:

- $M_{3\,1} = 575$

into the mean values

$M'_{9\,1} = 565$, $M'_{9\,2} = 565$, $M'_{9\,3} = 565$, $M'_{9\,4} = 565$,

- $M_{3\,2} = 0$

into the mean values

$M'_{9\,5} = 0$, $M'_{9\,6} = 0$, $M'_{9\,7} = 0$, $M'_{9\,8} = 0$;

- $M_{3\,3} = 0$

into the mean values

$M'_{9\,9} = 0$, $M'_{9\,10} = 0$, $M'_{9\,11} = 0$, $M'_{9\,12} = 0$,

- $M_{3\,4} = 0$

into the mean values

$M'_{9\,13} = 0$, $M'_{9\,14} = 0$, $M'_{9\,15} = 0$, $M'_{9\,16} = 0$,

- $M_{3\,5} = 0$

into the mean values

$M'_{9\,17} = 0$, $M'_{9\,18} = 0$, $M'_{9\,19} = 0$, $M'_{9\,20} = 0$,

- $M_{3\,6} = 0$

into the mean values

$M'_{9\,21} = 0$, $M'_{9\,22} = 0$, $M'_{9\,23} = 0$, $M'_{9\,24} = 0$,

- $M_{3\,7} = 0$

into the mean values

$M'_{9\,25} = 0$, $M'_{9\,26} = 0$, $M'_{9\,27} = 0$, $M'_{9\,28} = 0$,

and additionally we assume

$M'_{10\,l} = 0$, $l = 1,2, \ldots, 8,10, \ldots, 28$,
$M'_{11\,l} = 0$, $l = 1,2, \ldots, 8,10, \ldots, 28$,
$M'_{12\,l} = 0$, $l = 1,2, \ldots, 8,10, \ldots, 28$;

to replce the 3rd row of the matrix $[M_{bl}]_{7x7}$ given by (3) by the following 4 rows of the matrix $[M'_{bl}]_{28x28}$

[565 565 565 565; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 2 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 8 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0].

We fix the mean values:

$M'_{14\,13} = 2$, $M'_{15\,13} = 0$, $M'_{16\,13} = 8$.

We distribute:

- $M_{4\,1} = 0$

into the mean values

$M'_{13\,1} = 0$, $M'_{13\,2} = 0$, $M'_{13\,3} = 0$, $M'_{13\,4} = 0$;

- $M_{4\,2} = 0$

into the mean values

$M'_{13\,5} = 0$, $M'_{13\,6} = 0$, $M'_{13\,7} = 0$, $M'_{13\,8} = 0$;

- $M_{4\,3} = 0$

into the mean values

$M'_{13\,9} = 0$, $M'_{13\,10} = 0$, $M'_{13\,11} = 0$, $M'_{13\,12} = 0$;

- $M_{4\,4} = 0$

into the mean values

$M'_{13\,13} = 0$, $M'_{13\,14} = 0$, $M'_{13\,15} = 0$, $M'_{13\,16} = 0$;

- $M_{4\,5} = 0$

into the mean values

$M'_{13\,17} = 0$, $M'_{13\,18} = 0$, $M'_{13\,19} = 0$, $M'_{13\,20} = 0$;

- $M_{4\,6} = 0$

into the mean values

$M'_{13\,21} = 0$, $M'_{13\,22} = 0$, $M'_{13\,23} = 0$, $M'_{13\,24} = 0$;

- $M_{4\,7} = 380$

into the mean values

$M'_{13\,25} = 370$, $M'_{13\,26} = 370$, $M'_{13\,27} = 370$, $M'_{13\,28} = 370$;

and additionally we assume

$M'_{14\,l} = 0$, $l = 1,2, \ldots, 12,14, \ldots, 28$,
$M'_{15\,l} = 0$, $l = 1,2, \ldots, 12,14, \ldots, 28$,
$M'_{16\,l} = 0$, $l = 1,2, \ldots, 12,14, \ldots, 28$;

to replce the 4th row of the matrix $[M_{bl}]_{7x7}$ given by (3) by the following 4 rows of the matrix $[M'_{bl}]_{28x28}$

[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 370 370 370 370]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 2 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 8 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0].

We fix the mean values:

$M'_{18\,17} = 2$, $M'_{19\,17} = 0$, $M'_{20\,17} = 8$.

We distribute:

- $M_{5\,1} = 874.7$

into the mean values

$M'_{17\,1} = 864.7$, $M'_{17\,2} = 864.7$,
$M'_{17\,3} = 864.7$, $M'_{17\,4} = 864.7$;

- $M_{5\,2} = 480$

into the mean values

$M'_{17\,5} = 470$, $M'_{17\,6} = 470$, $M'_{17\,7} = 470$, $M'_{17\,8} = 470$;

- $M_{5\,3} = 0$

into the mean values

$M'_{17\,9} = 0$, $M'_{17\,10} = 0$, $M'_{17\,11} = 0$, $M'_{17\,12} = 0$;

$M_{5\,4} = 300$

into the mean values

$M'_{17\,13} = 290$, $M'_{17\,14} = 290$, $M'_{17\,15} = 290$, $M'_{17\,16} = 290$;

- $M_{5\,5} = 0$

into the mean values

$M'_{17\,17} = 0$, $M'_{13\,18} = 0$, $M'_{13\,19} = 0$, $M'_{13\,20} = 0$;

- $M_{5\,6} = 436.3$

into the mean values

$M'_{17\,21} = 426.3$, $M'_{17\,22} = 426.3$,
$M'_{17\,23} = 426.3$, $M'_{17\,24} = 426.3$;

- $M_{5\,7} = 1042.5$

into the mean values

$M'_{17\,25} = 1032.5$, $M'_{17\,26} = 1032.5$,
$M'_{17\,27} = 1032.5$, $M'_{17\,28} = 1032.5$;

and additionally we assume

$M'_{18\,l} = 0$, $l = 1,2, \ldots, 16,18, \ldots, 28$,
$M'_{19\,l} = 0$, $l = 1,2, \ldots, 16,18, \ldots, 28$,
$M'_{20\,l} = 0$, $l = 1,2, \ldots, 12,14, \ldots, 28$;

to replce the 5th row of the matrix $[M_{bl}]_{7x7}$ given by (3) by the following 4 rows of the matrix $[M'_{bl}]_{28x28}$

[864.7 864.7 864.7 864.7; 470 470 470 470; 0 0 0 0; 290 290 290 290; 0 0 0 0; 426.3 426.3 426.3 426.3; 1032.5 1032.5 1032.5 1032.5]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 2 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 8 0 0 0; 0 0 0 0; 0 0 0 0].

We fix the mean values:

$M'_{22\,21} = 2$, $M'_{23\,21} = 0$, $M'_{24\,21} = 8$.

We distribute:

- $M_{6\,1} = 325$

into the mean values

$M'_{21\,1} = 315$, $M'_{21\,2} = 315$, $M'_{21\,4} = 355$;

- $M_{6\,2} = 0$

into the mean values

$M'_{21\,5} = 0$, $M'_{21\,6} = 0$, $M'_{21\,7} = 0$, $M'_{21\,8} = 0$;

- $M_{6\,3} = 0$

into the mean values

$M'_{21\,9} = 0$, $M'_{21\,10} = 0$, $M'_{21\,11} = 0$, $M'_{21\,12} = 0$;

- $M_{6\,4} = 510.7$

into the mean values

$M'_{21\,13} = 500.7$, $M'_{21\,14} = 500.7$,
$M'_{21\,15} = 500.7$, $M'_{21\,16} = 500.7$;

- $M_{6\,5} = 0$

into the mean values

$M'_{21\,17} = 0$, $M'_{21\,18} = 0$, $M'_{21\,19} = 0$, $M'_{21\,20} = 0$;

- $M_{6\,6} = 0$

into the mean values

$M'_{21\,21} = 0$, $M'_{21\,22} = 0$, $M'_{21\,23} = 0$, $M'_{21\,24} = 0$;

- $M_{6\,7} = 438$

into the mean values

$M'_{21\,25} = 428$, $M'_{21\,26} = 428$,
$M'_{21\,27} = 428$, $M'_{21\,28} = 428$;

and additionally we assume

$M'_{22\,l} = 0$, $l = 1,2, \ldots, 20,22, \ldots, 28$,
$M'_{23\,l} = 0$, $l = 1,2, \ldots, 20,22, \ldots, 28$,
$M'_{24\,l} = 0$, $l = 1,2, \ldots, 20,22, \ldots, 28$;

to replce the 6th row of the matrix $[M_{bl}]_{7x7}$ given by (6.3) by the following 4 rows of the matrix $[M'_{bl}]_{28x28}$

[315 315 315 315; 0 0 0 0; 0 0 0 0; 500.7 500.7500.7 500.7; 0 0 0 0; 0 0 0 0; 428 428 428 428]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 2 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 8 0 0 0; 0 0 0 0].

We fix the mean values:

$M'_{26\,25} = 2$, $M'_{27\,25} = 0$, $M'_{28\,25} = 8$.

We distribute:

- $M_{7\,1} = 874.1$

into the mean values

$M'_{25\,1} = 864.1$, $M'_{25\,2} = 864.1$,
$M'_{25\,3} = 864.1$, $M'_{25\,4} = 864.1$;

- $M_{7\,2} = 510$

into the mean values

$M'_{25\,5} = 500$, $M'_{25\,6} = 500$, $M'_{25\,8} = 500$;

- $M_{7\,3} = 0$

into the mean values

$M'_{25\,9} = 0$, $M'_{25\,10} = 0$, $M'_{25\,11} = 0$, $M'_{25\,12} = 0$;

- $M_{7\,4} = 0$

into the mean values

$M'_{25\,13} = 0$, $M'_{25\,14} = 0$, $M'_{25\,15} = 0$, $M'_{25\,16} = 0$;

- $M_{7\,5} = 2585.7$

into the the mean values

$M'_{25\,17} = 2575.7$, $M'_{25\,18} = 2575.7$,
$M'_{25\,19} = 2575.7$, $M'_{25\,20} = 2575.7$;

- $M_{7\,6} = 2380$

into the mean values

$M'_{25\,21} = 2370$, $M'_{25\,22} = 2370$,
$M'_{25\,23} = 2370$, $M'_{25\,24} = 2370$;

- $M_{7\,7} = 0$

into the mean values

$M'_{25\,25} = 0$, $M'_{25\,26} = 0$, $M'_{25\,26} = 0$, $M'_{25\,26} = 0$;

and additionally we assume

$M'_{26\,l} = 0$, $l = 1,2, \ldots, 24,26, \ldots, 28$,
$M'_{27\,l} = 0$, $l = 1,2, \ldots, 24,26, \ldots, 28$,
$M'_{28\,l} = 0$, $l = 1,2, \ldots, 24,26, \ldots, 28$;

to replce the 7th row of the matrix $[M_{bl}]_{7x7}$ given by (3) by the following 4 rows of the matrix $[M'_{bl}]_{28x28}$

[840.9 840.9 840.9 840.9; 500 500 500 500; 0 0 0 0; 0 0 0 0; 2575.7 2575.7 2575.7 2575.7; 2370 2370 2370 2370; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 2 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0]
[0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 0 0 0 0; 8 0 0 0].

4. Conclusion

In the paper there are presented the port oil piping transportation system operation process including operating environment threats. Next this model will be used to construct the integrated general safety probabilistic model of the critical infrastructure related to its operation process and climate-weather process [3].
The model further development will be done in the following EU-CIRCLE project reports: [4]-[6], [9]-[13].

Acknowledgments

The paper presents the results developed in the scope of the EU-CIRCLE project titled “A pan – European framework for strengthening Critical Infrastructure resilience to climate change” that has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 653824. http://www.eu-circle.eu/.

References

[1] EU-CIRCLE Report D1.1. (2015). *EU-CIRCLE Taxonomy*.
[2] EU-CIRCLE Report D1.4-GMU3. (2016). *Holistic approach to analysis and identification of critical infrastructures within the Baltic Sea area and its surroundings – Formulating the concept of a global network of critical infrastructures in this region (“network of networks” approach).*
[3] EU-CIRCLE Report D2.1-GMU2. (2016). *Modelling outside dependences influence on Critical Infrastructure Safety (CIS) – Modelling Critical Infrastructure Operation Process (CIOP) including Operating Environment Threats (OET).*
[4] EU-CIRCLE Report D2.1-GMU3. (2016). Modelling outside dependences influence on Critical Infrastructure Safety (CIS) – Modelling Climate-Weather Change Process (C-WCP) including Extreme Weather Hazards (EWH).
[5] EU-CIRCLE Report D2.1-GMU4. (2016). *Modelling outside dependences influence on Critical Infrastructure Safety (CIS) - Designing Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH) by linking CIOP and C-WCP models.*
[6] EU-CIRCLE Report D2.2-GMU1. (2016). *Modelling port piping transportation system operation process at the southern Baltic Sea area using the Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH) in this region.*
[7] EU-CIRCLE Report D2.2-GMU2. (2016). *Modelling maritime ferry transportation system operation process at the Baltic Sea area using the Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH) in this region*.
[8] EU-CIRCLE Report D2.2-GMU3. (2016). *Modelling port, shipping and ship traffic and port operation information critical infrastructures network operation process at the Baltic Sea area using the Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH) in this region.*
[9] EU-CIRCLE Report D2.2-GMU4. (2016). *Modelling the operation process of the Baltic Sea critical infrastructures global network of interconnected and interdependent critical infrastructures located within the Baltic Sea and ashore around that function collaboratively using the Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather*

Hazards (EWE) in its operating environment ("network of networks" approach).

[10] EU-CIRCLE Report D2.3-GMU1. (2016). *Identification methods and procedures of Critical Infrastructure Operation Process (CIOP) including Operating Environment Threats (OET).*

[11] EU-CIRCLE Report D2.3-GMU3. (2016). *Identification methods and procedures of unknown parameters of Critical Infrastructure Operation Process General Model (CIOPGM) related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH).*

[12] EU-CIRCLE Report D2.3-GMU4. (2016). *Evaluation of unknown parameters of a port oil piping transportation system operation process related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH) at the southern Baltic Sea area*.

[13] EU-CIRCLE Report D2.3-GMU5. (2016). *Evaluation of unknown parameters of a maritime ferry transportation system operation process related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH) at the Baltic Sea area*.

[14] Ferreira, F. & Pacheco, A. (2007). Comparison of level-crossing times for Markov and semi-Markov processes. *Statistics and Probability Letters* 7, 2, 151-157.

[15] Glynn, P.W. & Haas, P.J. (2006). Laws of large numbers and functional central limit theorems for generalized semi-Markov processes. *Stochastic Models* 22, 2, 201-231.

[16] Grabski, F. (2002). *Semi-Markov Models of Systems Reliability and Operations Analysis*. System Research Institute, Polish Academy of Science (*in Polish*).

[17] Guze, S., Kołowrocki, K. & Soszyńska, J. (2008). Modeling environment and infrastructure influence on reliability and operation processes of port transportation systems. *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 2, 1, 179-188.

[18] Kołowrocki, K. (2014). *Reliability of Large and Complex Systems*. Amsterdam, Boston, Heidelberd, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sidney, Tokyo, Elsevier.

[19] Kolowrocki, K. & Soszynska, J. (2009). Modeling environment and infrastructure influence on reliability and operation process of port oil transportation system. *Electronic Journal Reliability & Risk Analisys: Theory & Applications* 2, 3, 131-142.

[20] Kolowrocki, K. & Soszynska, J. (2009). Safety and risk evaluation of Stena Baltica ferry in variable operation conditions. *Electronic Journal Reliability & Risk Analisys: Theory & Applications* 2, 4, 168-180.

[21] Kolowrocki, K. & Soszynska, J. (2010). Reliability modeling of a port oil transportation system's operation processes. *International Journal of Performance Engineering* 6, 1, 77-87.

[22] Kolowrocki, K. & Soszynska, J. (2010). Reliability, availability and safety of complex technical systems: modelling –identification – prediction – optimization. *Journal of Polish Safety and Reliability Association, Summer Safetyand Reliability Seminars* 4, 1, 133-158.

[23] Kołowrocki, K. & Soszyńska-Budny, J. (2011). *Reliability and Safety of Complex Technical Systems and Processes: Modeling - Identification - Prediction – Optimization*. London, Dordrecht, Heildeberg, New York, Springer.

[24] Kolowrocki, K. & Soszynska, J. (2016). Modelling critical infrastructure operation process including operating environment threats. *Journal of Polish Safety and Reliability Association, Summer Safetyand Reliability Seminars* 7, 3, 81-88.

[25] Limnios, N. & Oprisan, G. (2005). *Semi-Markov Processes and Reliability*. Birkhauser, Boston.

[26] Mercier, S. (2008). Numerical bounds for semi-Markovian quantities and application to reliability. *Methodology and Computing in Applied Probability* 10, 2, 179-198.

[27] Soszyńska, J. (2007). *Systems reliability analysis in variable operation conditions.* PhD Thesis, Gdynia Maritime University-System Research Institute Warsaw (in Polish).

[28] Soszyńska, J., Kołowrocki, K., Blokus-Roszkowska, A. et al. (2010). Prediction of complex technical systems operation processes. *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 4, 2, 379-510.