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General model of critical infrastructure accident consequences application to chemical spill consequences generated by dynamic ship critical infrastructure network operating at the Baltic Sea waters. Part 3. Process of environment degradation

Keywords

Baltic Sea region, critical infrastructure, sea accident, accident consequences, environment degradation

Abstract

In the paper, the process of environment degradation at the Baltic Sea area identification is performed. Next, the main characteristics of this process are predicted.

1. Introduction

The probabilistic General Model of Critical Infrastructure Accident Consequences (GMCIAC) [4], [7] includes the process of initiating events [1]-[2], the process of environment threats and the process of environment degradation [3] models.

The modelling critical infrastructure accident consequences was done in [9] through designing the GMCIAC and the identification of its unknown parameters was performed in [10]. Further, the GMCIAC adaptation to the prediction of critical infrastructure accident consequences was done in [11].

2. Application of the model of the process of environment degradation to the Baltic Sea waters

We assume, as in [9], that the process of environment degradation of the sub-region D_k, $k = 1,2,\ldots,n_3$, is taking ℓ_k, $\ell_k \in N$, different environment degradation states $r^1_{(k)}, r^2_{(k)}, \ldots, r^{\ell_k}_{(k)}$. Next, we mark by $R_{(k/\upsilon)}(t)$, $t \in \langle 0,+\infty)$, $k = 1,2,\ldots,n_3$, $\upsilon = 1,2,\ldots,\upsilon_k$, the conditional sub-process of the environment degradation of the sub-region D_k, $k = 1,2,\ldots,n_3$, while the process of environment threats $S_{(k)}(t)$ of the sub-region D_k is at the state $s^{\upsilon}_{(k)}$ $\upsilon = 1,2,\ldots,\upsilon_k$.

The conditional sub-process $R_{(k/\upsilon)}(t)$, is a function defined on the time interval $t \in \langle 0,+\infty)$, depending on the states of the process of environment threats $S_{(k)}(t)$ and taking discrete values in the set $\{r^1_{(k/\upsilon)}, r^2_{(k/\upsilon)}, \ldots, r^{\ell_k}_{(k/\upsilon)}\}$ of the environment degradation states. We assume a semi-Markov model [12]-[19] of the sub-process of environment degradation $R_{(k/\upsilon)}(t)$, and we mark by $\zeta^{ij}_{(k/\upsilon)}$ its random conditional sojourn times at the states $r^i_{(k/\upsilon)}$, when its next state is $r^j_{(k/\upsilon)}$, $i, j = 1,2,\ldots,\ell_k$, $i \neq j$, $k = 1,2,\ldots,n_3$, $\upsilon = 1,2,\ldots,\upsilon_k$.

Under these assumption, the sub-process of environment degradation $R_{(k/\upsilon)}(t)$, for each sub-region D_k, $k = 1,2,\ldots,n_3$, may be described by the vector $[q_{(k/\upsilon)}(0)]_{1x\ell_k}$ of initial probabilities of the sub-process of environment degradation staying at particular environment degradation states at the initial moment $t = 0$, the matrix $[q^{ij}_{(k/\upsilon)}]_{\ell_k x \ell_k}$ of probabilities of transitions between the environment degradation states $r^i_{(k/\upsilon)}$, and $r^j_{(k/\upsilon)}$, and the matrix $[G^{ij}_{(k/\upsilon)}(t)]_{\ell_k x \ell_k}$, of the distribution functions of the conditional sojourn times $\zeta^{ij}_{(k/\upsilon)}$, of the process $R_{(k/\upsilon)}(t)$, at the environment degradation states or equivalently by the matrix $[g^{ij}_{(k/\upsilon)}(t)]_{\ell_k x \ell_k}$, of the density functions of the conditional sojourn times $\zeta^{ij}_{(k/\upsilon)}$, $i, j = 1,2,..., \ell_k$, $i \neq j$, $k = 1,2,\ldots,n_3$, $\upsilon = 1,2,\ldots,\upsilon_k$, of the sub-process of environment degradation at the environment degradation states.

2.1. Parameters evaluation of the process of environment degradation at the Baltic Sea waters

To identify the unknown parameters of the process of environment degradation the suitable statistical data coming from realization should be collected. The statistical identification of the environment degradation was performed on the base on the ship accidents around the Baltic Sea in a period of 11 years (2004-2014). The initial moment $t = 0$ of the process of environment degradation was fixed at the moment when the threat caused by ship accident generated one of the distinguished degradation effects states.

Unfortunately, the less accurate identification of the process of environment degradation is performed for the Baltic Sea waters because of the less sufficiently numerous set of statistical data.

2.1.1. States of the process of environment degradation

Taking into account the expert opinion on varying in time the process of environment degradation, we distinguished its states for particular sub-regions. There are $\ell_1 = 30$ states of the process of environment degradation in the air (D_1 sub-region):

state $r^1_{(1)}$ – accident has happened but it does not caused environment degradations,

state $r^2_{(1)}$ – the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(0, LC_{50}/2>$,

state $r^3_{(1)}$ – the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(LC_{50}/2, LC_{50}>$,

state $r^4_{(1)}$ – the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval (LC_{50},∞),

state $r^5_{(1)}$ – the realised substance caused the aesthetic nuisance of air of the accident area but the closure of area is not required,

state $r^6_{(1)}$ – the realised substance caused the aesthetic nuisance of air of the accident area but the closure of area is not required, and simultaneously the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(0, LC_{50}/2>$,

state $r^7_{(1)}$ – the realised substance caused the aesthetic nuisance of air of the accident area but the closure of area is not required and simultaneously the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(LC_{50}/2, LC_{50}>$,,

state $r^8_{(1)}$ – the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for not more than 2 days, and simultaneously the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(LC_{50}/2, LC_{50}>$,

state $r^9_{(1)}$ – the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for not more than 2 days and simultaneously the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval (LC_{50},∞),

state $r^{10}_{(1)}$ – the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for 2 days or more, and simultaneously the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval (LC_{50},∞),

state $r^{11}_{(1)}$ – the realised substance changed pH regime in the accident area not more than ±1 unit,

state $r^{12}_{(1)}$ – the realised substance changed pH regime in the accident area not more than ±1 unit, and simultaneously the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(LC_{50}/2, LC_{50}>$,

state $r^{13}_{(1)}$ – the realised substance changed pH regime in the accident area not more than ±1 unit, and simultaneously the realised substance caused the aesthetic nuisance of air of the accident area but the closure of area is not required, and additionally the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(0, LC_{50}/2>$,

state $r^{14}_{(1)}$ – the realised substance changed pH regime in the accident area ±1-2 units, and simultaneously the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for not more than 2 days, and additionally the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(LC_{50}/2, LC_{50}>$,

state $r_{(1)}^{15}$ – the realised substance changed pH regime in the accident area ±1-2 units, and simultaneously the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for not more than 2 days, and additionally the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval (LC_{50},∞),

state $r_{(1)}^{16}$ – the realised substance changed pH regime in the accident area ±1-2 units, and simultaneously the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for 2 days or more, and additionally the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval (LC_{50},∞),

state $r_{(1)}^{17}$ – the realised substance decreased oxygen concentration in the air of the accident area of the value up to 2%,

state $r_{(1)}^{18}$ – the realised substance decreased oxygen concentration in the air of the accident area of the value from the interval 2-5%,

state $r_{(1)}^{19}$ – the realised substance decreased oxygen concentration in the air of the accident area of the value more than 5%,

state $r_{(1)}^{20}$ – the realised substance increased the air temperature in the accident area of the value from the interval (10°C,20°C>,

state $r_{(1)}^{21}$ – the realised substance increased the air temperature in the accident area of the value from the interval (10°C,20°C>, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value up to 2%, and additionally the realised substance caused the aesthetic nuisance of air of the accident area but the closure of area is not required,

state $r_{(1)}^{22}$ – the realised substance increased the air temperature in the accident area of the value from the interval (10°C,20°C>, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value up to 2%, and additionally the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for not more than 2 days, and moreover the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval $(LC_{50}/2, LC_{50}>$,

state $r_{(1)}^{23}$ – the realised substance increased the air temperature in the accident area of the value from the interval (20°C,30°C>, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value up to 2%,

state $r_{(1)}^{24}$ – the realised substance increased the air temperature in the accident area of the value from the interval (20°C,30°C>, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value from the interval 2-5% and additionally the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for not more than 2 days,

state $r_{(1)}^{25}$ – the realised substance increased the air temperature in the accident area of the value from the interval (20°C,30°C>, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value from the interval 2-5%, and additionally the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for 2 days or more, and moreover the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval (LC_{50},∞),

state $r_{(1)}^{26}$ – the realised substance increased the air temperature in the accident area of the value more than 30°C, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value from the interval 2-5%,

state $r_{(1)}^{27}$ – the realised substance increased the air temperature in the accident area of the value more than 30°C, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value more than 5%, and additionally the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for 2 days or more,

state $r_{(1)}^{28}$ – the realised substance increased the air temperature in the accident area of the value more than 30°C, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value more than 5%, and additionally the realised substance caused the aesthetic nuisance of air of the accident area and the closure of area is required for 2 days or more, and moreover the realised substance caused the pollution and its concentration in the air in the accident area belongs to the interval (LC_{50},∞),

state $r_{(1)}^{29}$ – the realised substance increased the air temperature in the accident area of the value from the interval (20°C,30°C>, state $r_{(1)}^{30}$ – the realised substance increased the air temperature in the accident area of the value more than 30°C, and simultaneously the realised substance decreased oxygen concentration in the air of the accident area of the value up to 2%.

Moreover, there are $\ell_2 = 28$ states for the water surface (D_2 sub-region), $\ell_3 = 28$ states for the water column (D_3 sub-region), $\ell_4 = 31$ states for the sea floor (D_4 sub-region), and $\ell_5 = 23$ states for the coast (D_5 sub-region) that are given in [9].

2.1.2. Probabilities of transitions between states of the process of environment degradation

On the basis of the statistical data, it is possible to evaluate the following unknown basic parameters of the process of environment degradation at the Baltic Sea waters:

- the vectors of the initial probabilities $q_{(k/\upsilon)}^{i}(0)$ of the environment degradation sub-process at the particular states at the moment $t = 0$ as follows:

$$[q_{(1/\upsilon)}(0)]_{1x30} = [1, 0,\ldots, 0]$$

for $\upsilon = 1, 6, 27, 30$,

$$[q_{(2/\upsilon)}(0)]_{1x28} = [1, 0,\ldots, 0]$$

for $\upsilon = 1, 17, 33$,

$$[q_{(3/\upsilon)}(0)]_{1x28} = [1, 0,\ldots, 0]$$

for $\upsilon = 1, 14, 24$,

$$[q_{(4/\upsilon)}(0)]_{1x31} = [1, 0,\ldots, 0]$$

for $\upsilon = 1, 14$,

$$[q_{(5/\upsilon)}(0)]_{1x23} = [1, 0,\ldots, 0]$$

for $\upsilon = 1$,

and

$$[q_{(1/\upsilon)}(0)]_{1x30} = [0, 0,\ldots, 0]$$

for $\upsilon = 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 29, 31, 32, 33, 34, 35$,

$$[q_{(2/\upsilon)}(0)]_{1x28} = [0, 0,\ldots, 0]$$

for $\upsilon = 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32$,

$$[q_{(3/\upsilon)}(0)]_{1x28} = [0, 0,\ldots, 0]$$

for $\upsilon = 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 29$,

$$[q_{(4/\upsilon)}(0)]_{1x31} = [0, 0, \ldots, 0],$$

for $\upsilon = 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29$,

$$[q_{(5/\upsilon)}(0)]_{1x23} = [0, 0, \ldots, 0],$$

for $\upsilon = 2, 3,\ldots, 29$; (1)

- the matrix $[q_{(k/\upsilon)}^{ij}]$ $i, j = 1,2,\ldots,\ell_k$, $k = 1,2,\ldots,5$, $\upsilon = 1,2,\ldots,\upsilon_k$, of the probabilities of transitions of the of the sub-process $R_{(k/\upsilon)}(t)$ transitions from the state $r_{(k/\upsilon)}^{i}$, into the state $r_{(k/\upsilon)}^{j}$, during the experimental time. The probabilities of transitions that are not equal to 0 are as follows:

$$q_{(1/6)}^{1\,2} = 1,\ q_{(1/6)}^{2\,1} = 1; \tag{2}$$

$$q_{(1/27)}^{1\,6} = 1,\ q_{(1/27)}^{6\,1} = 1; \tag{3}$$

$$q_{(1/30)}^{1\,11} = 1,\ q_{(1/30)}^{11\,1} = 1; \tag{4}$$

$$q_{(2/17)}^{1\,27} = 1,\ q_{(2/17)}^{12\,1} = 1,\ q_{(2/17)}^{16\,12} = 1,\ q_{(2/17)}^{21\,16} = 1,$$
$$q_{(2/17)}^{25\,21} = 1,\ q_{(2/17)}^{27\,25} = 1; \tag{5}$$

$$q_{(2/33)}^{1\,6} = 1,\ q_{(2/33)}^{6\,1} = 1; \tag{6}$$

$$q_{(3/14)}^{1\,27} = 1,\ q_{(3/14)}^{12\,1} = 1,\ q_{(3/14)}^{16\,12} = 1,\ q_{(3/14)}^{21\,16} = 1,$$
$$q_{(3/14)}^{25\,21} = 1,\ q_{(3/14)}^{27\,25} = 1; \tag{7}$$

$$q_{(3/24)}^{1\,6} = 1,\ q_{(3/24)}^{6\,1} = 1; \tag{8}$$

$$q_{(4/14)}^{1\,30} = 1,\ q_{(4/14)}^{12\,1} = 1,\ q_{(4/14)}^{16\,12} = 1,\ q_{(4/14)}^{21\,16} = 1,$$
$$q_{(4/14)}^{28\,21} = 1,\ q_{(4/14)}^{30\,28} = 1. \tag{9}$$

The values of some probabilities existing in the vectors $[q_{(k/\upsilon)}(0)]$ and in the matrix $[q^{ij}_{(k/\upsilon)}]$, besides of those standing on the main diagonal, equal to zero do not mean that the events they are concerned with, cannot appear. They evaluated on the basis of real statistical data and their values may change and become more precise if the duration of the experiment is longer.

2.1.3. Evaluation of distributions and mean values of the process of environment degradation conditional sojourn times

Because we only have the number of realizations of the sub-process of environment degradation and its all realizations are equal to an approximate value, we assume that this time has the uniform distribution in the interval from this value minus its half to this value plus its half.
The uniform distribution functions of the sub-process of environment degradation for particular conditional sojourn times $\zeta^{ij}_{(k/\upsilon)}$ are identified on the basis of statistical data coming from its process realizations at the Baltic Sea waters given in Appendix 6 in [10]. For instance, the sub-process of environment degradation the conditional sojourn time $\zeta^{12}_{(1/6)}$ assumed $n^{12}_{(1/6)} = 1$ value equals to 1, we assume that it has the uniform distribution function given by

$$G^{12}_{(1/6)}(t) = \begin{cases} 0, & t < 0.5 \\ t, & 0.5 \le t < 1.5 \\ 1, & t \ge 1.5. \end{cases} \quad (10)$$

In the case when as a result of the experiment, coming from experts, we have less than 28 realizations of the process of environment degradation, we determined this conditional sojourn times have the empirical distributions. The empirical distribution functions of the process of environment degradation for particular conditional sojourn times $\zeta^{ij}_{(k/\upsilon)}$ are identified on the basis of statistical data coming from its process realizations at the Baltic Sea waters given in Appendix 6 in [10]. For instance, the process initiating events conditional time $\zeta^{61}_{(1/27)}$ assumed $n^{61}_{(1/27)} = 2$ values. The order sample realizations $\zeta^{61}_{(1/27)}$ is: 180, 300. Thus, we assume that conditional sojourn time $\zeta^{61}_{(1/27)}$ has the empirical distribution function given by

$$G^{61}_{(1/27)}(t) = \begin{cases} 0, & t < 180 \\ 1/2, & 180 \le t < 300 \\ 1, & t \ge 300. \end{cases} \quad (11)$$

We have proceeded with the remaining conditional times at the states of the sub-process of environment degradation in the same way and approximately fix they distribution.
Further, for distributions identified in this section the approximate empirical values of the mean values $M^{ij}_{(k/\upsilon)} = E[\zeta^{ij}_{(k/\upsilon)}]$, $i, j = 1,2,\dots,\ell_k$, $i \neq j$, $k = 1,2,\dots,5$, $\ell_1 = 30$, $\ell_2 = 28$, $\ell_3 = 28$, $\ell_4 = 31$, $\ell_5 = 23$, $\upsilon_1 = 35$, $\upsilon_2 = 33$, $\upsilon_3 = 29$, $\upsilon_4 = 29$, $\upsilon_5 = 29$, of the process of environment degradation conditional sojourn times at particular states at the Baltic Sea waters can be determined and they are as follows:

$$M^{1\,2}_{(1/6)} = 1,\ M^{2\,1}_{(1/6)} = 240,\ M^{1\,6}_{(1/27)} = 1,\ M^{6\,1}_{(1/27)} = 240,$$

$$M^{1\,11}_{(1/30)} = 1,\ M^{11\,1}_{(1/30)} = 240,\ M^{1\,27}_{(2/17)} = 1,$$

$$M^{12\,1}_{(2/17)} = 2880,\ M^{16\,12}_{(2/17)} = 3780,\ M^{21\,16}_{(2/17)} = 2880,$$

$$M^{25\,21}_{(2/17)} = 300,\ M^{27\,25}_{(2/17)} = 240,\ M^{1\,6}_{(2/33)} = 1,$$

$$M^{6\,1}_{(2/33)} = 1440,\ M^{1\,27}_{(3/14)} = 1,\ M^{12\,1}_{(3/14)} = 2880,$$

$$M^{16\,12}_{(3/14)} = 3780,\ M^{21\,16}_{(3/14)} = 2880,\ M^{25\,21}_{(3/14)} = 300,$$

$$M^{27\,25}_{(3/14)} = 240,\ M^{1\,6}_{(3/24)} = 1,\ M^{6\,1}_{(3/24)} = 1440,$$

$$M^{1\,30}_{(4/14)} = 1,\ M^{12\,1}_{(4/14)} = 2880,\ M^{16\,12}_{(4/14)} = 3780,$$

$$M^{21\,16}_{(4/14)} = 2880,\ M^{28\,21}_{(4/14)} = 300,\ M^{30\,28}_{(4/14)} = 240. \quad (12)$$

2.1.4. Prediction of the process of environment degradation

Using the identified parameters of the process of environment degradation in Section 2.1.2 and 2.1.3, it is possible to predict its characteristics [11]. Namely, considering (2)-(9) and (12), the mean values of the process of environment degradation at the Baltic Sea waters unconditional sojourn times at the particular states are:

$$M^{1}_{(1/6)} = 1,\ M^{2}_{(1/6)} = 240; \quad (13)$$

$$M^{1}_{(1/27)} = 1,\ M^{6}_{(1/27)} = 240; \quad (14)$$

$$M^{1}_{(1/30)} = 1,\ M^{11}_{(1/30)} = 240; \quad (15)$$

$$M^{1}_{(2/17)} = 1,\ M^{12}_{(2/17)} = 2880,\ M^{16}_{(2/17)} = 3780,$$
$$M^{21}_{(2/17)} = 2880,\ M^{25}_{(2/17)} = 300,\ M^{27}_{(2/17)} = 240; \quad (16)$$

$$M^{1}_{(2/33)} = 1,\ M^{6}_{(2/33)} = 1440; \quad (17)$$

$$M^{1}_{(3/14)} = 1,\ M^{12}_{(3/14)} = 2880,\ M^{16}_{(3/14)} = 3780,$$
$$M^{21}_{(3/14)} = 2880,\ M^{25}_{(3/14)} = 300,\ M^{27}_{(3/14)} = 240; \quad (18)$$

$$M^{1}_{(3/24)} = 1,\ M^{6}_{(3/24)} = 1440; \quad (19)$$

$$M^{1}_{(4/14)} = 1,\ M^{12}_{(4/14)} = 2880,\ M^{16}_{(4/14)} = 3780,$$
$$M^{21}_{(4/14)} = 2880,\ M^{28}_{(4/14)} = 300,\ M^{30}_{(4/14)} = 240. \quad (20)$$

Since from the system of equations (4.30) in [9] takes the following form

$$\begin{cases} [\pi^{i}_{(k/\upsilon)}]_{1\mathrm{x}\ell_k} = [\pi^{i}_{(k/\upsilon)}]_{1\mathrm{x}\ell_k}[q^{ij}_{(k/\upsilon)}]_{\ell_k\mathrm{x}\ell_k} \\ \sum_{j=1}^{\ell_k} \pi^{j}_{(k/\upsilon)} = 1, \end{cases}$$

where

$i, j = 1,2,..., \ell_k,\ i \neq j, k = 1,2,...,5,\ \ell_1 = 30,\ \ell_2 = 28,\ \ell_3 = 28,\ \ell_4 = 31,\ \ell_5 = 23,\ \upsilon_1 = 35,\ \upsilon_2 = 33,\ \upsilon_3 = 29,\ \upsilon_4 = 29,\ \upsilon_5 = 29,$

we get its following solution:

$$\pi^{1}_{(1/6)} \cong 0.5,\ \pi^{2}_{(1/6)} \cong 0.5; \quad (21)$$

$$\pi^{1}_{(1/27)} = 0.5,\ \pi^{6}_{(1/27)} = 0.5; \quad (22)$$

$$\pi^{1}_{(1/30)} = 0.5,\ \pi^{11}_{(1/30)} = 0.5; \quad (23)$$

$$\pi^{1}_{(2/17)} \cong 0.1667,\ \pi^{12}_{(2/17)} \cong 0.1667,\ \pi^{16}_{(2/17)} \cong 0.1667,$$
$$\pi^{21}_{(2/17)} \cong 0.1667,\ \pi^{25}_{(2/17)} \cong 0.1666,$$
$$\pi^{27}_{(2/17)} \cong 0.1666; \quad (24)$$

$$\pi^{1}_{(2/33)} \cong 0.5,\ \pi^{6}_{(2/33)} \cong 0.5; \quad (25)$$

$$\pi^{1}_{(3/14)} \cong 0.1667,\ \pi^{12}_{(3/14)} \cong 0.1667,\ \pi^{16}_{(3/14)} \cong 0.1667,$$
$$\pi^{21}_{(3/14)} \cong 0.1667,\ \pi^{25}_{(3/14)} \cong 0.1666,$$
$$\pi^{27}_{(3/14)} \cong 0.1666; \quad (26)$$

$$\pi^{1}_{(3/24)} \cong 0.5,\ \pi^{2}_{(3/24)} \cong 0.5; \quad (27)$$

$$\pi^{1}_{(4/14)} \cong 0.1667,\ \pi^{12}_{(4/14)} \cong 0.1667,\ \pi^{16}_{(4/14)} \cong 0.1667,$$
$$\pi^{21}_{(4/14)} \cong 0.1667,\ \pi^{28}_{(4/14)} \cong 0.1666,$$
$$\pi^{30}_{(4/14)} \cong 0.1666. \quad (28)$$

Then after considering (13)-(20) respectively and applying (4.29) in [9] we get the approximate limit values of transient probabilities at the particular states of the process of environment degradation:

$$q^{1}_{(1/6)} = 0.00415,\ q^{2}_{(1/6)} = 0.99585; \quad (29)$$

$$q^{1}_{(1/27)} = 0.00415,\ q^{6}_{(1/27)} = 0.99585; \quad (30)$$

$$q^{1}_{(1/30)} = 0.00415,\ q^{11}_{(1/30)} = 0.99585; \quad (31)$$

$$q^{1}_{(2/17)} = 0.00010,\ q^{12}_{(2/17)} = 0.28570,$$
$$q^{16}_{(2/17)} = 0.37497,\ q^{21}_{(2/17)} = 0.28570,$$
$$q^{25}_{(2/17)} = 0.02974,\ q^{27}_{(2/17)} = 0.02379; \quad (32)$$

$$q^{1}_{(2/33)} = 0.00069,\ q^{6}_{(2/33)} = 0.99931; \quad (33)$$

$$q^{1}_{(3/14)} = 0.00010,\ q^{12}_{(3/14)} = 0.28570,$$
$$q^{16}_{(3/14)} = 0.37497,\ q^{21}_{(3/14)} = 0.28570,$$
$$q^{25}_{(3/14)} = 0.02974,\ q^{27}_{(3/14)} = 0.02379; \quad (34)$$

$$q^{1}_{(3/24)} = 0.00069,\ q^{6}_{(3/24)} = 0.99931; \quad (35)$$

$$q^{1}_{(4/14)} = 0.00010,\ q^{12}_{(4/14)} = 0.28570,$$
$$q^{16}_{(4/14)} = 0.37497,\ q^{21}_{(4/14)} = 0.28570,$$
$$q^{28}_{(4/14)} = 0.02974,\ q^{30}_{(4/14)} = 0.02379. \quad (36)$$

Further, by (4.31) in [9] and considering (29)-(36) respectively, the approximate mean values of the sojourn total times $\hat{\zeta}^{i}$ of the sub-processes of environment degradation $R_{(k/\upsilon)}(t)$ in the time interval ζ = 1 month = 43200 minutes at the particular states $r^{i}_{(k/\upsilon)}$, expressed in minutes are:

$$\hat{M}^{1}_{(1/6)} = 179.25,\ \hat{M}^{2}_{(1/6)} = 43020.75; \tag{37}$$

$$\hat{M}^{1}_{(1/27)} = 179.25,\ \hat{M}^{6}_{(1/27)} = 43020.75; \tag{38}$$

$$\hat{M}^{1}_{(1/30)} = 179.25,\ \hat{M}^{11}_{(1/30)} = 43020.75; \tag{39}$$

$$\hat{M}^{1}_{(2/17)} = 4.29,\ \hat{M}^{12}_{(2/17)} = 12342.03,$$
$$\hat{M}^{16}_{(2/17)} = 16198.91,\ \hat{M}^{21}_{(2/17)} = 12342.03,$$
$$\hat{M}^{25}_{(2/17)} = 1284.86,\ \hat{M}^{27}_{(2/17)} = 1027.89; \tag{40}$$

$$\hat{M}^{1}_{(2/33)} = 29.98,\ \hat{M}^{6}_{(2/33)} = 43170.02; \tag{41}$$

$$\hat{M}^{1}_{(3/14)} = 4.29,\ \hat{M}^{12}_{(3/14)} = 12342.03,$$
$$\hat{M}^{16}_{(3/14)} = 16198.91,\ \hat{M}^{21}_{(3/14)} = 12342.03,$$
$$\hat{M}^{25}_{(3/14)} = 1284.86,\ \hat{M}^{27}_{(3/14)} = 1027.89; \tag{42}$$

$$\hat{M}^{1}_{(3/24)} = 29.98,\ \hat{M}^{6}_{(3/24)} = 43170.02; \tag{43}$$

$$\hat{M}^{1}_{(4/14)} = 4.29,\ \hat{M}^{12}_{(4/14)} = 12342.03,$$
$$\hat{M}^{16}_{(4/14)} = 16198.91,\ \hat{M}^{21}_{(4/14)} = 12342.03,$$
$$\hat{M}^{28}_{(4/14)} = 1284.86,\ \hat{M}^{30}_{(4/14)} = 1027.89. \tag{44}$$

3. Conclusion

The results (29)-(36) and (37)-(44) are main characteristics of the considered process of environment degradation that is the third part of the integrated model of critical infrastructure accident consequences [7]. This characteristics together with results obtained in [5]-[6] can be used to the prediction of critical infrastructure accident losses [8].

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