Journal of Polish Safety and Reliability Association
Summer Safety and Reliability Seminars, Volume 9, Number 2, 2018

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Safety and resilience of Baltic Port and Shipping Critical Infrastructure Network related to cascading effects and climate-weather change

Keywords

Safety, critical infrastructure, network, cascading effects, climate-weather change process, coefficient of impact

Abstract

The paper is devoted to presentation the safety model for Baltic Port and Shipping Critical Infrastructure Network (*BPSCIN*) taking into account interactions between Baltic Port Critical Infrastructure Network, Baltic Shipping Critical Infrastructure Network and Baltic Ship Traffic and Port Operation Information Critical Infrastructure Network. First of all, the *BPSCIN* and its safety parameters are introduced. Next, the basic information and necessary data to describe the interactions in considered critical infrastructure network are given. Finally, the safety, resilience and risk indicators of the *BPSCIN* are presented.

1. Introduction

Seaports are an important trade hub. Their role for national economies increases year by year. At the same time, the share of the Baltic Sea in European trade is growing. In the period from 2002 to 2015, turnover increased by 56%. Thus, the Baltic ports are an important element for securing the continuity of the society in Baltic Sea Region. Together with ships operating in the Baltic Sea and networks of ICT systems for managing and monitoring ship traffic and port operations, they form the Baltic Port and Shipping Critical Infrastructure Network (*BPSCIN*) [Guze, Kołowrocki, 2016]. The malfunctions one of the three distinguished critical infrastructure network (*CIN*) can cause significant negative influence on societies and natural environment within the region and ashore around. Therefore, the safety modelling of this network of three networks related to operation process is important part of research [Guze, Kołowrocki, 2017a-b]. These studies are conducted based on the assumption that *BPSCIN* is treated as a multi-state and complex technical system [Guze, Kołowrocki, 2017a-b]. The safety and operation process models have been developed and introduced in reports [EU-CIRCLE Report D3.3, 2016], [Kołowrocki, et al., 2017] and earlier in publications [Kołowrocki, 2014], [Kołowrocki, Soszyńska-Budny, 2011].

An important thing in these studies also is to take into account interconnections and interdependencies in network of networks [Blokus-Roszkowska et. al, 2017 a-b].

The main aim of article is to analyse above mentioned interconnections and interdependencies, by introducing an approach to show how one of networks malfunctions influenced on the other two networks. We assume, that particular *CIN* departure from the safety state subsets, causes decreasing lifetimes of the other critical infrastructure networks. The impact of each of distinguished networks, on the other networks, is illustrated by specifying of respective coefficients.

First of all, under these assumptions and taking into account cascading effect, basic safety indicators of the *BPSCIN*: safety function, risk function, mean values and the standard deviations of the lifetime in the safety state subsets and intensities of departure from the safety state subsets are calculated. Next, the same safety indicators are given in relation to climate-weather change process.

2. Baltic Port and Shipping Critical Infrastructure Network and its safety parameters

The Baltic Port and Shipping Critical Infrastructure Network (*BPSCIN*), is a network composed of the following three ($n = 3$) interconnected and interdependent Critical Infrastructure Networks (*CIN*), distinguished and analysed in [Guze, Kołowrocki, 2017a-b], [EU-CIRCLE Report D1.2, 2016]:

– *BPCIN* – the Baltic Port Critical Infrastructure Network CIN_1;
– *BSCIN* – the Baltic Shipping Critical Infrastructure Network CIN_2;
– *BSTPOICIN* – the Baltic Ship Traffic and Port Operation Information Critical Infrastructure Network CIN_3.

The assessment of the safety and resilience of *BPSCIN* is possible to done under following assumptions:

– CIN_i, i = 1,2,3, are Critical Infrastructure Networks,
– all considered CINs have the safety state set $\{0,1,...,z\}$, $z \ge 1$,
– the safety states are ordered, the safety state 0 is the worst and the safety state z is the best,
– $T_i(u)$, $i = 1,2,...,n$, are independent random variables representing the lifetimes of CIN_i in the safety state subset $\{u,u+1,...,z\}$, while they were in the safety state z at the moment $t = 0$,
– $T(u)$ is a random variable representing the lifetime of a *BPSCIN* in the safety state subset $\{u,u+1,...,z\}$ while it was in the safety state z at the moment t = 0,
– the *BPSCIN* states degrades with time t,
– $s_i(t)$, $i = 1,2,3$, is the CIN_i safety state at the moment t, $t \in <0,\infty)$, given that it was in the safety state z at the moment $t = 0$,
– $s(t)$ is the *BPSCIN* safety state S at the moment t, $t \in <0,\infty)$, given that it was in the safety state z at the moment $t = 0$.

The above assumptions mean that the safety states of the *BPSCIN* with degrading *CI* networks may be changed in time only from better to worse [Kołowrocki, 2014], [Kołowrocki, Soszyńska-Budny, 2011, 2012], [Xue, 1985], [Xue, Yang, 1995].

Further, following five safety states $(z = 4)$, of the *BPSCIN* and each *CI* network, are defined:

– a safety state 4 –*BPSCIN* operations are fully safe - z_4,
– a safety state 3 – *BPSCIN* operations are less safe - z_3,
– a safety state 2 – *BPSCIN* operations are less safe and more dangerous - z_2,
– a safety state 1 – *BPSCIN* operations are less safe and very dangerous - z_1,
– a safety state 0 – *BPSCIN* is destroyed and dangerous for society and environment - z_0.

We assume, that the critical safety state of the *BPSCIN* and the *CINs* are $r = 2$.

The probability that the CIN_i is in the safety state subset $\{u, u+1,..., z\}$, at the moment t, $t \in <0,\infty)$, while it was in the safety state $z = 4$ at the moment $t = 0$, determined as the safety function of a CIN_i, is a vector

$$S_i(t,\cdot) = [S_i(t,0), S_i(t,1), S_i(t,2), S_i(t,3), S_i(t,4)],$$
$$t \in <0,\infty), \quad i = 1,2,3, \tag{1}$$

where

$$S_i(t,u) = P(s_i(t) \ge u | s_i(0) = 4) = P(T_i(u) > t),$$
$$u = 0,1,2,3,4. \tag{2}$$

Under this definition $S_i(t,0) = 1$, $i = 1,2,3$.

Moreover we assume that the *CINs* have identical exponential safety functions

$$S_i(t,\cdot) = [1, S_i(t,1), S_i(t,2), S_i(t,3), S_i(t,4)],$$
$$t \in <0,\infty), \quad i = 1,2,3. \tag{3}$$

with the coordinates

$$S_i(t,u) = \exp[-\lambda_i(u)t], \quad u = 1,2,3,4. \tag{4}$$

The BPSCIN is analysed under the assumption it is a multistate series network. This means that the BPSCIN is in the safety state subset $\{u, u+1,..., z\}$, if and only if all its *BPSCIN* networks are in this subset of safety states. As it has been previously highlighted, there are four safety states and the best state $z = 4$.

The *CINs'* lifetimes in the safety states are expressed in years and they have the exponential safety functions (3)-(4) with the intensities of departure from the safety subsets, by the assumption, given by

$$\lambda_i(1) = 0.02, \quad \lambda_i(2) = 0.05, \quad \lambda_i(3) = 0.08,$$
$$\lambda_i(3) = 0{,}1, \quad i = 1,2,3. \tag{5}$$

3. Interactions between Critical Infrastructure Networks

We suppose, that the considered Critical Infrastructure Network is interconnected and interdependent [EU-CIRCLE Report D3.1, 2016]. The CIN forming the *BPSCIN* are interacting each other. Thus, the *CIN* departure from the safety state subsets causes decreasing lifetimes of the remaining *CINs*. Then, if the CIN_j (j = 1,2,3) leaves the safety state subset {u,u+1,…,4} (u = 1,2,3,4), then the safety parameters of the remaining *CIN* worsen depending on the type of the network CIN_j with the coefficients of the *CIN* impact on the other critical infrastructure networks. It means, that the *CINs* lifetimes and their mean values in the subset {υ,υ+1,…,4} ($\upsilon = u, u$-1,…,1 and u = 1,2,3,4) decrease according to the formulas

$$T_{i/j}(\upsilon) = [1 - q(\upsilon, CIN_i, CIN_j)] \cdot T_i(\upsilon), \quad (6)$$

$$E[T_{i/j}(\upsilon)] = [1 - q(\upsilon, CIN_i, CIN_j)] \cdot E[T_i(\upsilon)],$$
$$i = 1,2,3, \ j = 1,2,3, \quad (7)$$

where $q(\upsilon, CIN_i, CIN_j)$ are the coefficients of the network CIN_j impact on the functioning of other networks CIN_i (i = 1,2,3 , $i \neq j$),

$$q(\upsilon, CIN_i, CIN_i) = 0, \ i = 1,2,3, \quad (8)$$

and

$$0 \le q(\upsilon, CIN_i, CIN_j) < 1 \quad (9)$$

for i = 1, 2,3, j = 1,2,3, $\upsilon = u, u-1,\ldots,1$ and u = 1,2,3,4. These coefficients, existing in (6)-(7), take by the assumption following values

$$q(3, CIN_i, CIN_1) = 0.5,$$
$$q(2, CIN_i, CIN_1) = 0.2,$$
$$q(1, CIN_i, CIN_1) = 0.5, \ i = 2,3, \quad (10)$$

$$q(3, CIN_i, CIN_2) = 0.3,$$
$$q(2, CIN_i, CIN_2) = 0.05,$$
$$q(1, CIN_i, CIN_2) = 0.1, \ i = 1,3, \quad (11)$$

$$q(3, CIN_i, CIN_3) = 0.1,$$
$$q(2, CIN_i, CIN_3) = 0.1,$$
$$q(1, CIN_i, CIN_3) = 0.2, \ i = 1,2, \quad (12)$$

and (8) holds.

Consequently, the safety function of CIN_i (i = 1,2,3) after the departure of CIN_j (j = 1,2,3) from the subset {u,u+1,…,4} (u = 1,2,3,4), is defined as a vector

$$S_{i/j}(t,\cdot) = [1, S_{i/j}(t,1), S_{i/j}(t,2), S_{i/j}(t,3), S_{i/j}(t,4)],$$
$$t \ge 0, \ i = 1,2,3, \ j = 1,2,3, \quad (13)$$

with the coordinates given by

$$S_{i/j}(t,\upsilon) = P(T_{i/j}(\upsilon) > t),$$
$$\upsilon = u, u-1,\ldots,1, \ u = 1,2,3,4, \quad (14)$$

$$S_{i/j}(t,\upsilon) = P(T_{i/j}(\upsilon) > t) = P(T_i(\upsilon) > t) = S_i(t,\upsilon),$$
$$\upsilon = u+1,\ldots,3, \ u = 1,2,3,4. \quad (15)$$

Under the assumption about the exponential distribution, the conditional intensities of the CIN_i departure from the subset {υ,υ+1,…,4} after the departure of the CIN_j, by (7), are

$$\lambda_{i/j}(\upsilon) = \frac{\lambda_i(\upsilon)}{1 - q(\upsilon, CIN_i, CIN_j)}, \quad (16)$$

for $i = 1,2,3, \ \ j = 1,2,3, \ \ \upsilon = u, u-1,\ldots,1, \ \ u = 1,2,3.$

Thus, considering (4), (13)-(15) and (16), the CIN_i (i = 1,2,3) after the departure of CIN_j (j = 1,2,3) from the safety subset have the safety functions (13) with the coordinates

$$S_{i/j}(t,\upsilon) = \exp\Big[-\frac{\lambda_i(\upsilon)}{1 - q(\upsilon, CIN_i, CIN_j)} t\Big],$$
$$\upsilon = u, u-1,\ldots,1, \ u = 1,2,3 \quad (17)$$

$$S_{i/j}(t,\upsilon) = \exp[-\lambda_i(\upsilon) t],$$
$$\upsilon = u+1,\ldots,3, \ \ u = 1,2,3. \quad (18)$$

4. Safety and resilience of Baltic Port and Shipping Critical Infrastructure Network

In this section, the safety function of the *BPSCIN* related to cascading effects and climate-weather change process are given under assumption that *BPSCIN* is a multistate series network.

4.1. Safety and resilience related to cascading effect

Assuming the series structure for *BPSCIN* and the dependence between *CINs*, expressed in (6)-(7), in case the *CINs* have exponential safety functions (3)-(4) and considering (22)-(23). the safety function of the *BPSCIN* related to cascading effects is given by the vector [Blokus-Roszkowska, Kolowrocki, 2017a-b]

$$\boldsymbol{S}_{CE}(t,\cdot) = [1, \boldsymbol{S}_{CE}(t,1), \boldsymbol{S}_{CE}(t,2), \boldsymbol{S}_{CE}(t,3), \boldsymbol{S}_{CE}(t,4)], \quad (19)$$

where

$$\boldsymbol{S}_{CE}(t,1) = \exp[-\sum_{i=1}^{3}\lambda_i(2)t] + \sum_{j=1}^{3}\frac{\lambda_j(2)-\lambda_j(1)}{\sum_{i=1}^{3}\lambda_i(2)-\sum_{i=1}^{3}\lambda_i(1)} \cdot[\exp[-\sum_{i=1}^{3}\frac{\lambda_i(1)}{1-q(1,CIN_i,CIN_j)}t] - \exp[-(\sum_{i=1}^{3}\lambda_i(2)-\sum_{i=1}^{3}\lambda_i(1) + \sum_{i=1}^{3}\frac{\lambda_i(1)}{1-q(1,CIN_i,CIN_j)})t]], \quad (20)$$

$$\boldsymbol{S}_{CE}(t,2) = \exp[-\sum_{i=1}^{3}\lambda_i(3)t] + \sum_{j=1}^{3}\frac{\lambda_j(3)-\lambda_j(2)}{\sum_{i=1}^{3}\lambda_i(3)-\sum_{i=1}^{3}\lambda_i(2)} \cdot[\exp[-\sum_{i=1}^{3}\frac{\lambda_i(2)}{1-q(2,CIN_i,CIN_j)}t] - \exp[-(\sum_{i=1}^{3}\lambda_i(3)-\sum_{i=1}^{3}\lambda_i(2) + \sum_{i=1}^{3}\frac{\lambda_i(2)}{1-q(2,CIN_i,CIN_j)})t]], \quad (21)$$

$$\boldsymbol{S}_{CE}(t,3) = \exp[-\sum_{i=1}^{3}\lambda_i(4)t] + \sum_{j=1}^{3}\frac{\lambda_j(4)-\lambda_j(3)}{\sum_{i=1}^{3}\lambda_i(4)-\sum_{i=1}^{3}\lambda_i(3)} \cdot[\exp[-\sum_{i=1}^{3}\frac{\lambda_i(3)}{1-q(3,CIN_i,CIN_j)}t] - \exp[-(\sum_{i=1}^{3}\lambda_i(4)-\sum_{i=1}^{3}\lambda_i(3) + \sum_{i=1}^{3}\frac{\lambda_i(3)}{1-q(3,CIN_i,CIN_j)})t]], \quad (22)$$

$$\boldsymbol{S}_{CE}(t,4) = \exp[-\sum_{i=1}^{3}\lambda_i(4)t], \quad (23)$$

for $t \geq 0$.
Next, applying (20)-(23) and substituting the assumed values of *CINs'* intensities (5) and the above mentioned values of coefficients of the *CINs'* impact on other networks' functioning (10)-(12), the coordinates of the *BPSCIN* safety function are

$$\boldsymbol{S}_{CE}(t,1) = \exp[-0.15t] + \frac{1}{3}[\exp[-0.10t] - \exp[-0.19t] + \exp[-0.06t] - \exp[-0.15t] + \exp[-0.07t] - \exp[-0.15t]], \quad (24)$$

$$\boldsymbol{S}_{CE}(t,2) = \exp[-0.24t] + \frac{1}{3}[\exp[-0.18t] - \exp[-0.27t] + \exp[-0.16t] - \exp[-0.25t] + \exp[-0.16t] - \exp[-0.25t]], \quad (25)$$

$$\boldsymbol{S}_{CE}(t,3) = \exp[-0.3t] + \frac{1}{3}[\exp[-0.40t] - \exp[-0.49t] + \exp[-0.31t] - \exp[-0.40t] + \exp[-0.26t] - \exp[-0.35t]], \quad (26)$$

$$\boldsymbol{S}_{CE}(t,4) = \exp[-0.3t]. \quad (27)$$

The safety function coordinates of the *BPSCIN* related to cascading effects, given by (24)-(27), are illustrated in *Figure 1*.

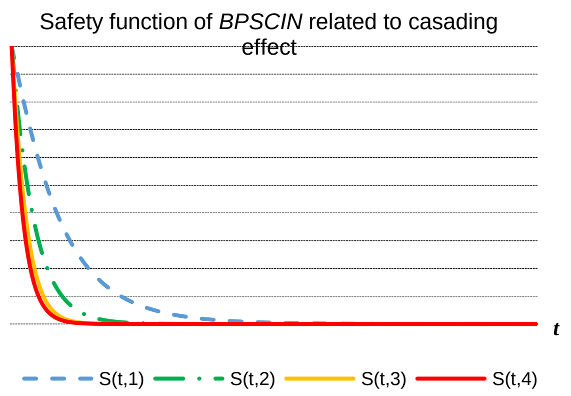

Figure 1. The graphs of the *BPSCIN* safety function coordinates.

If $r = 2$ is the critical safety state, then the second safety indicator of the *BPSCIN* related to cascading effects is a probability that the *BPSCIN* related to cascading effects is in the subset of safety states worse than the critical safety state $r = 2$ while it was in the best safety state $z = 4$ at the moment $t = 0$ [Kołowrocki 2014], [Kołowrocki, Soszyńska-Budny, 2011] known as the risk function

$$\boldsymbol{r}_{CE}(t) = P(T(r) \leq t), \quad t \in <0,\infty), \quad (28)$$

and given by

$$\boldsymbol{r}_{CE}(t) = 1 - \boldsymbol{S}_{CE}(t,2), \quad t \in <0,\infty), \quad (29)$$

where $\boldsymbol{S}_{CE}(t,2)$ is the coordinate of the *BPSCIN* safety function given by (25).
Thus, the moment when the Baltic Port and Shipping Critical Infrastrucutre Network risk function exceeds a permitted level δ, is

$$\tau_{CE} = \boldsymbol{r}_{CE}^{\ -1}(\delta), \qquad (30)$$

where $\boldsymbol{r}_{CE}^{\ -1}(t)$, if exists, is the inverse function of the *BPSCIN* risk function $\boldsymbol{r}_{CE}(t)$, given by (29). For the assumed value $\delta = 0.2$, the moment of exceeding an acceptable level equals

$$\tau_{CE} \cong 1.075 \text{ years} \cong 393 \text{ days} \cong 9432 \text{ hours}. \qquad (31)$$

The graph of the *BPSCIN* risk function, called the fragility curve, is illustrated in *Figure 2*.

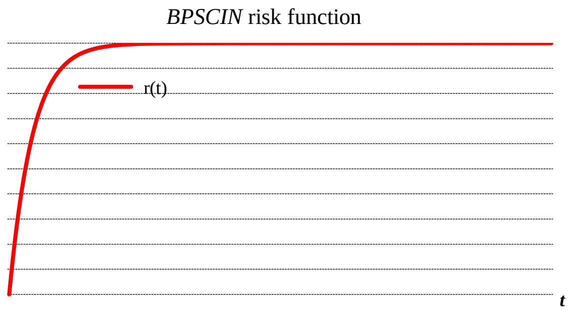

Figure 2. The graph of the *BPSCIN* risk function.

Other safety characteristics of the *BPSCIN* network related to cascading effects are the mean values and the standard deviations of this network lifetime in the safety state subsets {1,2,3,4}, {2,3,4}, {3,4}, {4}. In case the *BCIN* networks have exponential safety functions (3)-(4) and considering (22)-(23) for assumed model of dependency, the mean values can be counted from the formulae

$$\mu_{CE}(1) = \frac{1}{\sum_{i=1}^{3}\lambda_i(2)} + \sum_{j=1}^{3}\frac{\lambda_j(2)-\lambda_j(1)}{\sum_{i=1}^{3}\lambda_i(2)-\sum_{i=1}^{3}\lambda_i(1)}$$
$$\cdot[1/\sum_{i=1}^{3}\frac{\lambda_i(1)}{1-q(1,CIN_i,CIN_j)} - 1/[\sum_{i=1}^{3}\lambda_i(2)-\sum_{i=1}^{3}\lambda_i(1)$$
$$+\sum_{i=1}^{3}\frac{\lambda_i(1)}{1-q(1,CIN_i,CIN_j)}]], \qquad (32)$$

$$\mu_{CE}(2) = \frac{1}{\sum_{i=1}^{3}\lambda_i(3)} + \sum_{j=1}^{3}\frac{\lambda_j(3)-\lambda_j(2)}{\sum_{i=1}^{3}\lambda_i(3)-\sum_{i=1}^{3}\lambda_i(2)}$$
$$\cdot[1/\sum_{i=1}^{3}\frac{\lambda_i(2)}{1-q(2,CIN_i,CIN_j)} - 1/[\sum_{i=1}^{3}\lambda_i(3)-\sum_{i=1}^{3}\lambda_i(2)$$
$$+\sum_{i=1}^{3}\frac{\lambda_i(2)}{1-q(2,CIN_i,CIN_j)}]], \qquad (33)$$

$$\mu_{CE}(3) = \frac{1}{\sum_{i=1}^{3}\lambda_i(4)} + \sum_{j=1}^{3}\frac{\lambda_j(4)-\lambda_j(3)}{\sum_{i=1}^{3}\lambda_i(4)-\sum_{i=1}^{3}\lambda_i(3)}$$
$$\cdot[1/\sum_{i=1}^{3}\frac{\lambda_i(3)}{1-q(3,CIN_i,CIN_j)} - 1/[\sum_{i=1}^{3}\lambda_i(4)-\sum_{i=1}^{3}\lambda_i(3)$$
$$+\sum_{i=1}^{3}\frac{\lambda_i(3)}{1-q(3,CIN_i,CIN_j)}]], \qquad (34)$$

$$\mu_{CE}(4) = \frac{1}{\sum_{i=1}^{3}\lambda_i(4)} = 0.125 \qquad (35)$$

and the standard deviations from

$$\sigma_{CE}(u) = \sqrt{n_{CE}(u) - [\mu_{CE}(u)]^2} \qquad (36)$$

for $u = 1,2,3$, where

$$n_{CE}(1) = \frac{2}{[\sum_{i=1}^{3}\lambda_i(2)]^2} + 2\sum_{j=1}^{3}\frac{\lambda_j(2)-\lambda_j(1)}{\sum_{i=1}^{3}\lambda_i(2)-\sum_{i=1}^{3}\lambda_i(1)}$$
$$\cdot[1/[\sum_{i=1}^{3}\frac{\lambda_i(1)}{1-q(1,CIN_i,CIN_j)}]^2 - 1/[\sum_{i=1}^{3}\lambda_i(2)-\sum_{i=1}^{3}\lambda_i(1)$$
$$+\sum_{i=1}^{3}\frac{\lambda_i(1)}{1-q(1,CIN_i,CIN_j)}]^2], \qquad (37)$$

$$n_{CE}(2) = \frac{2}{[\sum_{i=1}^{3}\lambda_i(3)]^2} + 2\sum_{j=1}^{3}\frac{\lambda_j(3)-\lambda_j(2)}{\sum_{i=1}^{3}\lambda_i(3)-\sum_{i=1}^{3}\lambda_i(2)}$$
$$\cdot[1/[\sum_{i=1}^{3}\frac{\lambda_i(2)}{1-q(2,CIN_i,CIN_j)}]^2 - 1/[\sum_{i=1}^{3}\lambda_i(3)-\sum_{i=1}^{3}\lambda_i(2)$$
$$+\sum_{i=1}^{3}\frac{\lambda_i(2)}{1-q(2,CIN_i,CIN_j)}]^2], \qquad (38)$$

$$n_{CE}(3) = \frac{2}{[\sum_{i=1}^{3}\lambda_i(4)]^2} + 2\sum_{j=1}^{3}\frac{\lambda_j(4)-\lambda_j(3)}{\sum_{i=1}^{3}\lambda_i(4)-\sum_{i=1}^{3}\lambda_i(3)}$$
$$\cdot[1/[\sum_{i=1}^{3}\frac{\lambda_i(3)}{1-q(3,CIN_i,CIN_j)}]^2 - 1/[\sum_{i=1}^{3}\lambda_i(4)-\sum_{i=1}^{3}\lambda_i(3)$$

$$+\sum_{i=1}^{3}\frac{\lambda_i(3)}{1-q(3,CIN_i,CIN_j)}]^2], \quad (39)$$

and

$$\sigma_{CE}(4)=\frac{1}{\sum_{i=1}^{3}\lambda_i(4)}. \quad (40)$$

According to (37)-(40) and substituting the values of coefficients given in (10)-(17) and intensities (5), the mean lifetimes of the *BPSCIN* network in the subsets {1,2,3,4}, {2,3,4}, {3,4}, {4} in years, are:

$$\mu_{CE}(1)\cong 13.938,\ \ \mu_{CE}(2)\cong 6.343,$$
$$\mu_{CE}(3)\cong 3.862\ \ \mu_{CE}(4)\cong 0.033. \quad (41)$$

Similarly, applying (37)-(41), the standard deviations of the *GBNCIN* network lifetimes can be determined and their values in years are:

$$\sigma_{CE}(1)\cong 13.616,\ \ \sigma_{CE}(2)\cong 6.201,$$
$$\sigma_{CE}(3)\cong 3.971,\ \sigma_{CE}(4)\cong 0.033. \quad (42)$$

The mean values of the *BPSCIN* network lifetimes in the particular states 1,2,3,4 by (41), in years are:

$$\bar{\mu}_{CE}(1)\cong 7.595,\ \ \bar{\mu}_{CE}(2)\cong 2.481,$$
$$\bar{\mu}_{CE}(3)\cong 3.829,\ \bar{\mu}_{CE}(4)\cong 0.0333. \quad (43)$$

Other *BPSCIN* safety indices are the intensities of *BPSCIN* departure from the safety state subsets {1,2,3,4}, {2,3,4}, {3,4}, {4}, i.e. the coordinates of the vector

$$\boldsymbol{\lambda}_{CE}(t,\cdot)=[0,\boldsymbol{\lambda}_{CE}(t,1),\ \boldsymbol{\lambda}_{CE}(t,2),\ \boldsymbol{\lambda}_{CE}(t,3),\ \boldsymbol{\lambda}_{CE}(t,4)],$$
$$t\geq 0. \quad (44)$$

These intensities can be determined from the formula

$$\boldsymbol{\lambda}_{CE}(t,u)=\frac{-\frac{d\boldsymbol{S}_{CE}(t,u)}{dt}}{\boldsymbol{S}_{CE}(t,u)},\ u=1,2,3,4, \quad (45)$$

where $\boldsymbol{S}_{CE}(t,u)$, $u=1,2,3,4$, are given by (24)-(27), and after some transformation they take form

$$\boldsymbol{\lambda}_{CE}(t,1)=$$
$$\{0.15+0.333\cdot[\exp[0.05t]-0.1\exp[-0.04t]$$
$$+0.19\exp[0.09t]-0.06\exp[-0.004t]$$
$$+0.15\exp[0.08t]-0.07\exp[-0.01t]]\}$$
$$/\{1+0.333\cdot[\exp[0.05t]-\exp[-0.04t]+\exp[0.09t]$$
$$-\exp[-0.004t]+\exp[0.08t]-\exp[-0.01t]]\},$$
$$t\geq 0, \quad (46)$$

$$\boldsymbol{\lambda}_{CE}(t,2)=\{0.24+0.333\cdot[0.18\exp[0.065t]$$
$$-0.27\exp[-0.025t]+0.16\exp[-0.08t]$$
$$-0.25\exp[-0.005t]+0.16\exp[0.08t]$$
$$-0.25\exp[-0.01t]]\}\ /\{1+0.333\cdot[\exp[0.065t]$$
$$-\exp[-0.025t]+\exp[0.08t]-\exp[-0.005t]$$
$$+\exp[0.08t]-\exp[-0.025t]]\},\ \ t\geq 0, \quad (47)$$

$$\boldsymbol{\lambda}_{CE}(t,3)=\{0.3+0.333\cdot[0.4\exp[-0.1t]$$
$$-0.46\exp[-0.16t]+0.031\exp[-0.009t]$$
$$-0.37\exp[-0.069t]+0.26\exp[0.042t]$$
$$-0.32\exp[-0.018t]]\}\ /\{1+0.333\cdot[\exp[-0.1t]$$
$$-\exp[-0.16t]+\exp[-0.009t]-\exp[-0.069t]$$
$$+\exp[0.042t]-\exp[-0.018t]]\},\ \ t\geq 0, \quad (48)$$

$$\boldsymbol{\lambda}_{CE}(t,4)=0.3,\ \ t\geq 0. \quad (49)$$

The graph of the *BPSCIN* intensities are illustrated in *Figure 3*.

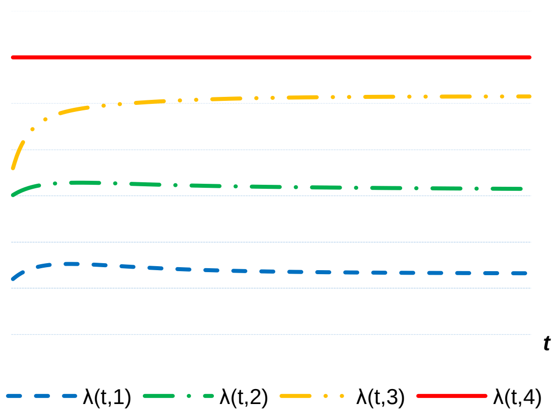

Figure 3. The intensities of BPSCIN related to cascading effect

Using these intensities, the coefficients of cascading effect impact on the *BPSCIN* intensities of departure from the safety state subsets {1,2,3,4}, {2,3,4}, {3,4}, {4} can be estimated. Then, the coordinates of the vector

$$\boldsymbol{\rho}_{CE}(t,\cdot)=[0,\boldsymbol{\rho}_{CE}(t,1),\ \boldsymbol{\rho}_{CE}(t,2),\ \ \boldsymbol{\rho}_{CE}(t,3),$$
$$\boldsymbol{\rho}_{CE}(t,4)],\ t\geq 0, \quad (50)$$

are given by

$$\boldsymbol{\rho}_{CE}(t,u) = \frac{\boldsymbol{\lambda}_{CE}(t,u)}{\boldsymbol{\lambda}^0(t,u)},\ u = 1,2,3, \tag{51}$$

where $\boldsymbol{\lambda}_0(t,u),\ u = 1,2,3,$ are the intensities of the *BPSCIN* network departure from the safety state subset {1,2,3,4}, {2,3,4}, {3,4}, {4}, without of cascading effect impact.

We assumed before, that the *BPSCIN* is considered as a series network. Thus, the intensities of the Baltic Port and Shipping Critical Infrastructure Network departure without of cascading effect impact are given by

$$\boldsymbol{\lambda}^0(t,u) = 3\cdot\lambda_i(u),\ t \ge 0,\ u = 1,2,3,4, \tag{52}$$

and from formula (5) they take following values

$$\boldsymbol{\lambda}^0(t,1) = 0.06,\ \boldsymbol{\lambda}^0(t,2) = 0.15,$$
$$\boldsymbol{\lambda}^0(t,2) = 0.24,\ \boldsymbol{\lambda}^0(t,4) = 0.3. \tag{53}$$

When we apply formula (51) and from (46)-(49) and (53), the coefficients of the cascading effect impact on the *BPSCIN* are as follows:

$$\boldsymbol{\rho}_{CE}(t,1) = 16.667\boldsymbol{\lambda}_{CE}(t,1),$$
$$\boldsymbol{\rho}_{CE}(t,2) = 6.667\boldsymbol{\lambda}_{CE}(t,2),$$
$$\boldsymbol{\rho}_{CE}(t,3) = 4.167\boldsymbol{\lambda}_{CE}(t,3),$$
$$\boldsymbol{\rho}_{CE}(t,4) = 3,333,\ t \ge 0, \tag{54}$$

where $\boldsymbol{\lambda}_{CE}(t,1),\ \boldsymbol{\lambda}_{CE}(t,2),\ \boldsymbol{\lambda}_{CE}(t,3),\ \boldsymbol{\lambda}_{CE}(t,4),$ are given by (46) and (49).

Thus, the indicator of the *BPSCIN* resilience to cascading effect impact is defined by

$$\boldsymbol{RI}_{CE}(t,r) = \frac{1}{\boldsymbol{\rho}_{CE}(t,r)},\ t \ge 0, \tag{55}$$

where $\boldsymbol{\rho}_{CE}(t,r)$ is the coefficient of cascading effect impact on the *BPSCIN* intensities of degradation given by (54) and the *BPSCIN* critical safety state is $r = 2$.

4.2. Safety and resilience related to cascading effect and climate-weather change process

In this section, we consider the critical infrastructure related to the climate-weather change process *C*(*t*), $t \in < 0,\infty)$, and impacted in a various way at the climate-weather states $c_b,\ b = 1,2,...,w.$ We assume that the changes of the climate-weather states of the climate-weather change process *C*(*t*), $t \in < 0,\infty)$, at the critical infrastructure operating area have an influence on the critical infrastructure safety structure and on the safety of the critical infrastructure assets $A_i,\ i = 1,2,...,n,$ as well.

The following climate-weather change process parameters at the critical infrastructure operating area can be identified either statistically using the methods given in [Kołowrocki, Soszyńska-Budny, Torbicki 2017b] or evaluated approximately by experts:

- the number of climate-weather states w;
- the vector of the initial probabilities $[q_b(0)]_{1\text{x}w}$;
- the matrix $[q_{bl}]_{w\text{x}w}$ of probabilities of transition of the climate-weather change process *C*(*t*) between the climate-weather states c_b and c_l;
- the matrix $[N_{bl}]_{w\text{x}w}$ of mean values of conditional sojourn times of the climate-weather change process *C*(*t*) conditional sojourn times C_{bl} at the climate-weather state c_b when the next state is c_l.

The vector of limit values of transient probabilities $[q_b]_{1\text{x}w}$ is the climate-weather change process characteristic at the critical infrastructure operating area. It can be either calculated analytically using the above parameters of the climate-weather change process or evaluated approximately by experts [Kołowrocki, Soszyńska-Budny, Torbicki 2017b].

In this paper, taking into account the historical hydro-meteorological data and expert's opinion and academic assumptions, we distinguish the following *w=4* climate-weather states:

- climate-weather state c_1 – the air temperature from -25 up to -15 or 25 up to 35 and the soil temperature from -30 up to -5 or 20 up to 37;
- climate-weather state c_2 – the air temperature from -25 up to -15 or 25 up to 35 and the soil temperature from -30 up to -5 or 20 up to 37 and strong wind;
- climate-weather state c_3 – the air temperature from -15 up to 5 or 5 up to 25 and the soil temperature from -5 up to 5 or 5 up to 20 and strong wind;
- climate-weather state c_4 – the air temperature from -15 up to 5 or 5 up to 25 and the soil temperature from -5 up to 5 or 5 up to 20.

Next, in the same way, the values of the climate-weather change process *C(t)* limit transient probabilities $[q_b]_{1\text{x}4}$ at the climate-weather states c_b, *b=1,2,3,4* are given based on academic assumptions and expert's opinions:

q_1=0.011, q_2=0.002, q_3=0.019, q_4=0.968. (56)

Moreover, the coefficients of climate-weather impact on the *CINs* intensities of ageing at the climate-weather change process operating area are assumed as:

$$[\rho(u)]^{(1)} = 1.2,\ [\rho(u)]^{(2)} = 1.2,$$
$$[\rho(u)]^{(3)} = 1,\ [\rho(u)]^{(4)} = 1,\ u = 1,2,3,4. \quad (57)$$

The Baltic Port and Shipping Critical Infrastructure Network at the climate-weather state c_b, $b = 1,2,3,4$, *CINs* are dependent according to the local load sharing rule and have safety functions given by (19)-(27), then its conditional safety function is given by the vector [Report]

$$[\boldsymbol{S}^3_{CE}(t,\cdot)]^{(b)} = [1,[\boldsymbol{S}^3_{CE}(t,1)]^{(b)}, \boldsymbol{S}^3_{CE}(t,2)]^{(b)},$$
$$\boldsymbol{S}^3_{CE}(t,3)]^{(b)},[\boldsymbol{S}^3_{CE}(t,4)]^{(b)}],$$
$$t \in <0,\infty),\ b = 1,2,3,4, \quad (58)$$

with exponential coordinates given as follows:

$$[\boldsymbol{S}^3_{CE}(t,1)]^{(b)} = \exp[-3\cdot[\rho(2)]^{(b)}\cdot\lambda^0(2)t]$$
$$+\frac{1}{3}\sum_{j=1}^{3}[\exp[-[\rho(1)]^{(b)}\cdot\lambda^0(1)\sum_{i=1}^{3}\frac{1}{1-[q(1,CIN_i,CIN_j)]^{(b)}}t]$$
$$-\exp[-(3\cdot[\rho(2)]^{(b)}\cdot\lambda^0(2)\ -3\cdot[\rho(1)]^{(b)}\cdot\lambda^0(1)$$
$$+[\rho(1)]^{(b)}\cdot\lambda^0(1)\sum_{i=1}^{3}\frac{1}{1-[q(1,CIN_i,CIN_j)]^{(b)}})t]], \quad (59)$$

$$[\boldsymbol{S}^3_{CE}(t,2)]^{(b)} = \exp[-3\cdot[\rho(3)]^{(b)}\cdot\lambda^0(3)t]$$
$$+\frac{1}{3}\sum_{j=1}^{3}[\exp[-[\rho(2)]^{(b)}\cdot\lambda^0(1)\sum_{i=1}^{3}\frac{1}{1-[q(2,CIN_i,CIN_j)]^{(b)}}t]$$
$$-\exp[-(3\cdot[\rho(3)]^{(b)}\cdot\lambda^0(3)\ -3\cdot[\rho(2)]^{(b)}\cdot\lambda^0(2)$$
$$+[\rho(2)]^{(b)}\cdot\lambda^0(1)\sum_{i=1}^{3}\frac{1}{1-[q(2,CIN_i,CIN_j)]^{(b)}})t]], \quad (60)$$

$$[\boldsymbol{S}^3_{CE}(t,3)]^{(b)} = \exp[-3\cdot[\rho(4)]^{(b)}\cdot\lambda^0(4)t]$$
$$+\frac{1}{3}\sum_{j=1}^{3}[\exp[-[\rho(3)]^{(b)}\cdot\lambda^0(3)\sum_{i=1}^{3}\frac{1}{1-[q(3,CIN_i,CIN_j)]^{(b)}}t]$$
$$-\exp[-(3\cdot[\rho(4)]^{(b)}\cdot\lambda^0(4)\ -3\cdot[\rho(3)]^{(b)}\cdot\lambda^0(3)$$
$$+[\rho(3)]^{(b)}\cdot\lambda^0(1)\sum_{i=1}^{3}\frac{1}{1-[q(3,CIN_i,CIN_j)]^{(b)}})t]], \quad (61)$$

$$[\boldsymbol{S}^3_{CE}(t,4)]^{(b)} = \exp[-3\cdot[\rho(4)]^{(b)}\cdot\lambda^0(4)t], \quad (62)$$

for $b = 1,2,3,4$.

Next, applying (59)-(62) and substituting the assumed values of *CINs'* intensities (52)–(53) and the above mentioned values of coefficients given by (57)-(12), the coordinates of the *BPSCIN* safety function are

- for *b=1,2* as follows:

$$[\boldsymbol{S}^3_{CE}(t,1)]^{(1)} = [\boldsymbol{S}^3_{CE}(t,1)]^{(2)} = \exp[-0.18t]$$
$$+\frac{1}{3}[\exp[-0.12t]\ -\exp[-0.228t]$$
$$+\exp[-0.186t]\ -\exp[-0.185t]$$
$$+\exp[-0.084t]-\exp[-0.192t]], \quad (63)$$

$$[\boldsymbol{S}^3_{CE}(t,2)]^{(1)} = [\boldsymbol{S}^3_{CE}(t,2)]^{(2)} = \exp[-0.288t]$$
$$+\frac{1}{3}[\exp[-0.21t]-\exp[-0.318t]$$
$$+\exp[-0.186t]-\exp[-0.294t]$$
$$+\exp[-0.193t]-\exp[-0.301t]], \quad (64)$$

$$[\boldsymbol{S}^3_{CE}(t,3)]^{(1)} = [\boldsymbol{S}^3_{CE}(t,3)]^{(2)} = \exp[-0.36t]$$
$$+\frac{1}{3}[\exp[-0.48t]-\exp[-0.552t]$$
$$+\exp[-0.370t]-\exp[-0.442t]$$
$$+\exp[-0.309t]-\exp[-0.381t]], \quad (65)$$

$$[\boldsymbol{S}^3_{CE}(t,4)]^{(1)} = [\boldsymbol{S}^3_{CE}(t,4)]^{(2)} = \exp[-0.36t]. \quad (66)$$

- for *b=3,4* as follows:

$$[\boldsymbol{S}^3_{CE}(t,1)]^{(3)} = [\boldsymbol{S}^3_{CE}(t,1)]^{(4)} = \exp[-0.15t]$$
$$+\frac{1}{3}[\exp[-0.1t]-\exp[-0.19t]$$
$$+\exp[-0.155t]\ -\exp[-0.154t]$$
$$+\exp[-0.07t]-\exp[-0.16t]], \quad (67)$$

$$[\boldsymbol{S}^3_{CE}(t,2)]^{(3)} = [\boldsymbol{S}^3_{CE}(t,2)]^{(4)} = \exp[-0.24t]$$

$$+\frac{1}{3}[\exp[-0.175t]-\exp[-0.265t]$$
$$+\exp[-0.155t]-\exp[-0.245t]$$
$$+\exp[-0.161t]-\exp[-0.251t]], \qquad (68)$$

$$[\boldsymbol{S}^{3}_{CE}(t,3)]^{(3)}=[\boldsymbol{S}^{3}_{CE}(t,3)]^{(4)}=\exp[-0.3t]$$
$$+\frac{1}{3}[\exp[-0.4t]-\exp[-0.46t]$$
$$+\exp[-0.309t]-\exp[-0.369t]$$
$$+\exp[-0.258t]-\exp[-0.318t]], \qquad (69)$$

$$[\boldsymbol{S}^{3}_{CE}(t,4)]^{(3)}=[\boldsymbol{S}^{3}_{CE}(t,4)]^{(4)}=\exp[-0.3t]. \qquad (70)$$

Next, we denote the critical infrastructure related to the climate-weather change process $C(t)$, $t\in<0,\infty)$, unconditional lifetime in the safety state subset $\{u, u+1,\dots,4\}$, $u=1,2,3,4$, by $T(u)$. Then, the unconditional safety function of a Baltic Port and Shipping Critical Infrastructure Network related to the climate-weather change process $C(t)$, $t\in<0,\infty)$, with *CINs* dependent according to LLS rule is given by the vector (58) where particular coordinates can be determined from following formula according to (57) and (59) – (62)

$$\boldsymbol{S}^{3}_{CE}(t,u)\cong\sum_{b=1}^{4}q_b[\boldsymbol{S}^{3}_{CE}(t,u)]^{(b)} \text{ for } t\geq 0,$$
$$u=1,2,3,4, \qquad (71)$$

and $[\boldsymbol{S}^{3}_{CE}(t,u)]^{(b)}$, $u=1,2,3,4$, $b=1,2,3,4$, are the coordinates of the critical infrastructure conditional safety functions given by (59)-(62) and q_b are the climate-weather change process $C(t)$ at the critical infrastructure operating area limit transient probabilities at the state c_b, $b=1,2,3,4$, given by (57).
The unconditional safety function coordinates of the *BPSCIN* related to cascading effects and climate-weather change process, given by (71), are illustrated in *Figure 4*.

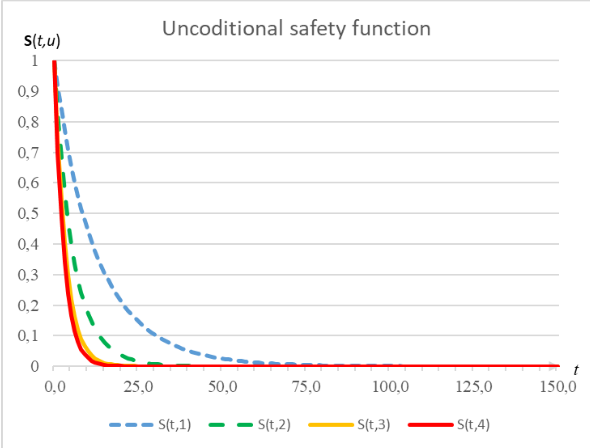

Figure 4. The graphs of the *BPSCIN* unconditional safety function coordinates.

Similarly to Section 4.1, we assume that *r=2* is the critical safety state. Then the second safety indicator of the *BPSCIN* related to cascading effects and climate-weather change process is a probability that the *BPSCIN* related to cascading effects and climate-weather change process is in the subset of safety states worse than the critical safety state $r=2$ while it was in the best safety state $z=4$ at the moment $t = 0$ [Kołowrocki 2014], [Kołowrocki, Soszyńska-Budny, 2011] given by

$$\boldsymbol{r}^{3}_{CE}(t)=1-\boldsymbol{S}^{3}_{CE}(t,2),\ t\in<0,\infty), \qquad (72)$$

where $\boldsymbol{S}^{3}_{CE}(t,2)$ is the coordinate of the *BPSCIN* unconditional safety function given by (58).
Thus, the moment when the Baltic Port and Shipping Critical Infrastrucutre Network risk function exceeds a permitted level δ, is

$$\tau^{3}_{CE}=\boldsymbol{r}^{3\ -1}_{CE}(\delta), \qquad (73)$$

where $\boldsymbol{r}^{3\ -1}_{CE}(t)$, if exists, is the inverse function of the *BPSCIN* risk function $\boldsymbol{r}^{3}_{CE}(t)$, given by (72). For the assumed value $\delta=0.2$, the moment of exceeding an acceptable level equals

$$\tau_{CE}\cong 1.072 \text{ years} \cong 392 \text{ days} \cong 9408 \text{ hours}. \qquad (74)$$

The graph of the *BPSCIN* risk function, called the fragility curve, is illustrated in *Figure 5*.

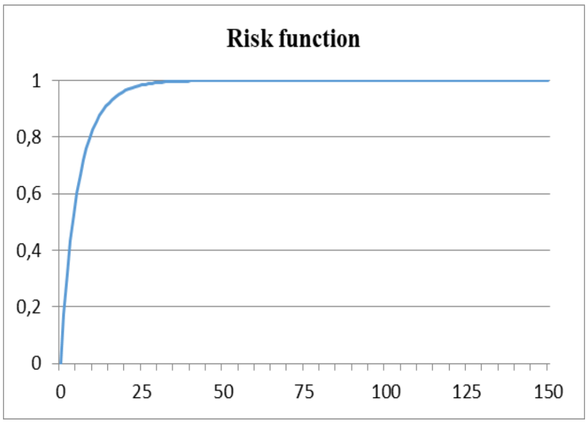

Figure 5. The graph of the *BPSCIN* unconditional risk function.

According to (37)-(40) and substituting the values of coefficients given in (10)-(17) and intensities (5), the mean value of the *BPSCIN* unconditional lifetimes $T(u)$ in the subsets {1,2,3,4}, {2,3,4}, {3,4}, {4} in years, are:

$$\mu^3_{CE}(1) \cong 13.923, \;\; \mu^3_{CE}(2) \cong 6.338,$$
$$\mu^3_{CE}(3) \cong 3.861 \;\; \mu^3_{CE}(4) \cong 0.033. \quad (75)$$

Similarly, applying (37)-(41), the standard deviations of the *BPSCIN* unconditional lifetimes can be determined and their values in years are:

$$\sigma^3_{CE}(1) \cong 13.587, \;\; \sigma^3_{CE}(2) \cong 6.191,$$
$$\sigma^3_{CE}(3) \cong 3.968, \; \sigma^3_{CE}(4) \cong 0.033. \quad (76)$$

The mean values of the *BPSCIN* unconditional lifetimes in the particular states 1,2,3,4 by (41), in years are:

$$\bar{\mu}^3_{CE}(1) \cong 7.585, \;\; \bar{\mu}^3_{CE}(2) \cong 2.477,$$
$$\bar{\mu}^3_{CE}(3) \cong 0.099, \; \bar{\mu}^3_{CE}(4) \cong 0.033. \quad (77)$$

Other *BPSCIN* safety indices are the intensities of *BPSCIN* departure from the safety state subsets {1,2,3,4}, {2,3,4}, {3,4}, {4}, i.e. the coordinates of the vector

$$\lambda^3_{CE}(t,\cdot) = [0, \lambda^3_{CE}(t,1), \; \lambda^3_{CE}(t,2), \; \lambda^3_{CE}(t,3), \; \lambda^3_{CE}(t,4)],$$
$$t \ge 0. \quad (78)$$

These intensities can take form as follows

$$\lambda^3_{CE}(t,1) \cong \sum_{b=1}^{4} q_b [\lambda^3_{CE}(t,1)]^{(b)}, \; t \ge 0, \quad (79)$$

$$\lambda^3_{CE}(t,2) \cong \sum_{b=1}^{4} q_b [\lambda^3_{CE}(t,2)]^{(b)}, \;\; t \ge 0, \quad (80)$$

$$\lambda^3_{CE}(t,3) \cong \sum_{b=1}^{4} q_b [\lambda^3_{CE}(t,3)]^{(b)}, \;\; t \ge 0, \quad (81)$$

$$\lambda^3_{CE}(t,4) \;\; \cong \sum_{b=1}^{4} q_b [\lambda^3_{CE}(t,4)]^{(b)}, \; t \ge 0. \quad (82)$$

The graph of the *BPSCIN* unconditional intensities are illustrated in *Figure 6*.

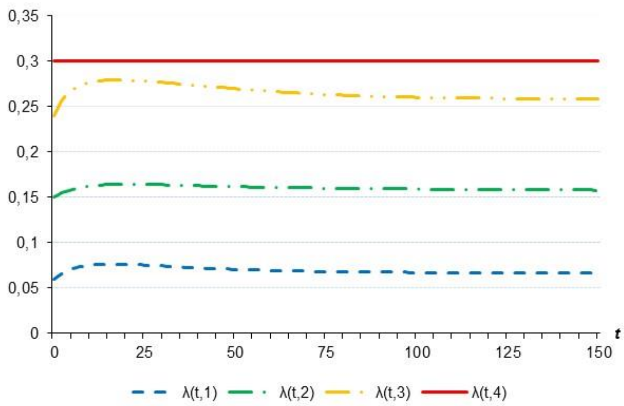

Figure 6. The intensities of *BPSCIN* related to cascading effect

Using these intensities, the coefficients of cascading effect and climate-weather change process impact on the *BPSCIN* intensities of departure from the safety state subsets {1,2,3,4}, {2,3,4}, {3,4}, {4} can be estimated. Then, the coordinates of the vector

$$\boldsymbol{\rho}^3_{CE}(t,\cdot) = [0, \boldsymbol{\rho}^3_{CE}(t,1), \; \boldsymbol{\rho}^3_{CE}(t,2), \;\; \boldsymbol{\rho}^3_{CE}(t,3),$$
$$\boldsymbol{\rho}^3_{CE}(t,4)], \; t \ge 0, \quad (83)$$

are given by

$$\boldsymbol{\rho}^3_{CE}(t,u) = \frac{\boldsymbol{\lambda}^3_{CE}(t,u)}{\boldsymbol{\lambda}^0(t,u)}, \; u = 1,2,3, \quad (84)$$

where $\lambda^0(t,u)$, $u = 1,2,3$, are the intensities of the *BPSCIN* departure from the safety state subset {1,2,3,4}, {2,3,4}, {3,4}, {4}, without of cascading effect and climate-weather change process impact.

The intensities of the Baltic Port and Shipping Critical Infrastructure Network departure without of cascading effect and climate-weather change process impact are given by (53).

$$\boldsymbol{\lambda}^{0}(t,u) = 3 \cdot \lambda_i(u),\ t \geq 0,\ u = 1,2,3,4, \tag{85}$$

and from formula (5) they take following values

$$\boldsymbol{\lambda}^{0}(t,1) = 0.06,\ \boldsymbol{\lambda}^{0}(t,2) = 0.15,$$
$$\boldsymbol{\lambda}^{0}(t,2) = 0.24,\ \boldsymbol{\lambda}^{0}(t,4) = 0.3. \tag{86}$$

When we apply formula (51) and from (46)-(49) and (53), the coefficients of the cascading effect and climate-weather change impact on the *BPSCIN* are as follows:

$$\boldsymbol{\rho}^{3}_{CE}(t,1) = 16.667\boldsymbol{\lambda}^{3}_{CE}(t,1),$$
$$\boldsymbol{\rho}^{3}_{CE}(t,2) = 6.667\boldsymbol{\lambda}^{3}_{CE}(t,2),$$
$$\boldsymbol{\rho}^{3}_{CE}(t,3) = 4.167\boldsymbol{\lambda}^{3}_{CE}(t,3),$$
$$\boldsymbol{\rho}^{3}_{CE}(t,4) = 3{,}333,\ t \geq 0, \tag{87}$$

where $\boldsymbol{\lambda}^{3}_{CE}(t,1)$, $\boldsymbol{\lambda}^{3}_{CE}(t,2)$, $\boldsymbol{\lambda}^{3}_{CE}(t,3)$, $\boldsymbol{\lambda}^{3}_{CE}(t,4)$, are given by (79) and (82).
Thus, the indicator of the *BPSCIN* resilience to cascading effect and climate-weather change process impact is defined by

$$\boldsymbol{RI}^{3}_{CE}(t,r) = \frac{1}{\boldsymbol{\rho}^{3}_{CE}(t,r)},\ t \geq 0, \tag{88}$$

where $\boldsymbol{\rho}^{3}_{CE}(t,r)$ is the coefficient of cascading effect and climate-weather change impact on the *BPSCIN* intensities of degradation given by (87) and the *BPSCIN* critical safety state is $r = 2$.

5. Conclusions

In the paper, the indicators of safety and resilience of the *BPSCIN* related to cascading effect and climate-weather change process have been presented.
In the beginning, the interactions between Baltic Port Critical Infrastructure Network, Baltic Shipping Critical Infrastructure Network and Baltic Ship Traffic and Port Operation Information Critical Infrastructure Network have been defined. The necessary data to describe these interactions has been given. Moreover, the *BPSCIN* and its safety parameters are introduced.
Furthermore, the climate-weather change process states have been defined for the *BPSCIN*.
Finally, the safety, resilience and risk analysis of the *BPSCIN* have been presented according to arbitrary assumptions and exemplary data.

Acknowledgements

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/

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