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General Approach to Modelling Operation Threats and Extreme Weather Hazards Impact on Critical Infrastructure Safety

Keywords

Modelling, operation threats, extreme weather hazards, Critical Infrastructure, safety

Abstract

The paper presents the theoretical, general approach to safety modelling of operation threats and extreme wather hazards impact on Critical Infrastructures. To achieve this aim, the scheme of the operation and climate-weather influence on CI is presented and described. Furthermore, the basic critical infrastructure safety indicators and IMCISM Model 1 are introduced.

1. Introduction

Most real complex technical critical infrastructure are strongly influenced by changing in time their operation conditions and the climate-weather conditions at their operating areas. The time dependent interactions between the operation process related to climate-weather change process states varying at the system operating area and the critical infrastructure safety structure and its components/assets safety states changing are evident features of most real technical systems including critical infrastructures [Kołowrocki 2013a, b], [Kołowrocki & Soszyńska-Budny 2011]. The common critical infrastructure safety and resilience, its operation process and the climate-weather change process at its operating area analysis is of great value in the industrial practice because of often negative impacts of operating environment threats (OET) and extreme weather hazards (EWH) on the critical infrastructure safety and resilience. In the critical infrastructure safety analysis, the determination of its safety function and its risk function which graph corresponds to the fragility curve and other proposed in the paper safety and resilience and other features' characteristics are crucial indices for its operators and users.

To make the effort of the formulated problem solution well organized, the scheme of a general approach to safety and resilience analysis of critical infrastructure giving subsequent steps in the research activity is presented in the next section.

2. Scheme of Operation and Climate-Weather Influence on Critical Infrastructure Safety and Resilience Modelling

An original and innovative general approach to operation process and climate-weather change process influence on critical infrastructure safety and resilience modelling and analysis has been created in the report [Kołowrocki K., Soszyńska-Budny J., Critical Infrastructure Impact Models for Operation Threats and Climate Hazards, Part 1, Critical Infrastructure Connections, Journal of Polish Safety and Reliability Assotiation, Special Issue on EU-CIRCLE Project. Volume 8, Number 3, 2017].

The scheme of this approach is presented below in Figure 1.

In this scheme:

- the contents of scheme items 2.1-2.10 is concerned with the critical infrastructure operation process and climate-weather change process at its operating area modelling, critical infrastructure safety modelling, with the integration of the designed models into a general joint models of critical infrastructure safety related to operation and climate-weather change processes and with the modelling safety of critical infrastructure networks and their accidents consequences (Wp2 & WP3);
- the contents of scheme items 2.11-2.16 is concerned with the critical infrastructure safety and its accident consequences optimization, business continuity, resilience and cost effectiveness modelling (WP4);
- the content of scheme item 2.17 is concerned with the case studies and the proposed models application and validation (WP6);
- the contents of scheme item 2.18 is concerned with the development of simplified procedures of critical infrastructure safety and resilience to operation and climate-weather change strengthening (WP5 & WP&);
- the contents of scheme item 2.19 is directly concerned with the critical infrastructure safety and resilience to operation and climate-weather change strengthening training system (WP8).

In this report Part1, starting from a simplest pure safety Model 0 without considering outside impacts on critical infrastructure defined as a multistate ageing system, the critical infrastructure and its components/assets safety functions and other safety indices like mean values and variances of lifetimes in the safety state subsets and in the particular safety states, a critical infrastructure risk function, its fragility curve, the moment of exceeding the critical safety state and intensities of ageing/degrading are defined. System components' independences are ignored and practically important modifications assuming inside critical infrastructure assets' dependences are introduced and developed. Moreover, the way of modification all considered critical infrastructure safety models into more general models for safety analysis and prediction of critical infrastructure networks and networks of critical infrastructure networks and for networks of critical infrastructure networks cascading effect analysing is proposed as well. In addition, a general approach to modelling, identification and prediction of critical infrastructure accident consequences is proposed.

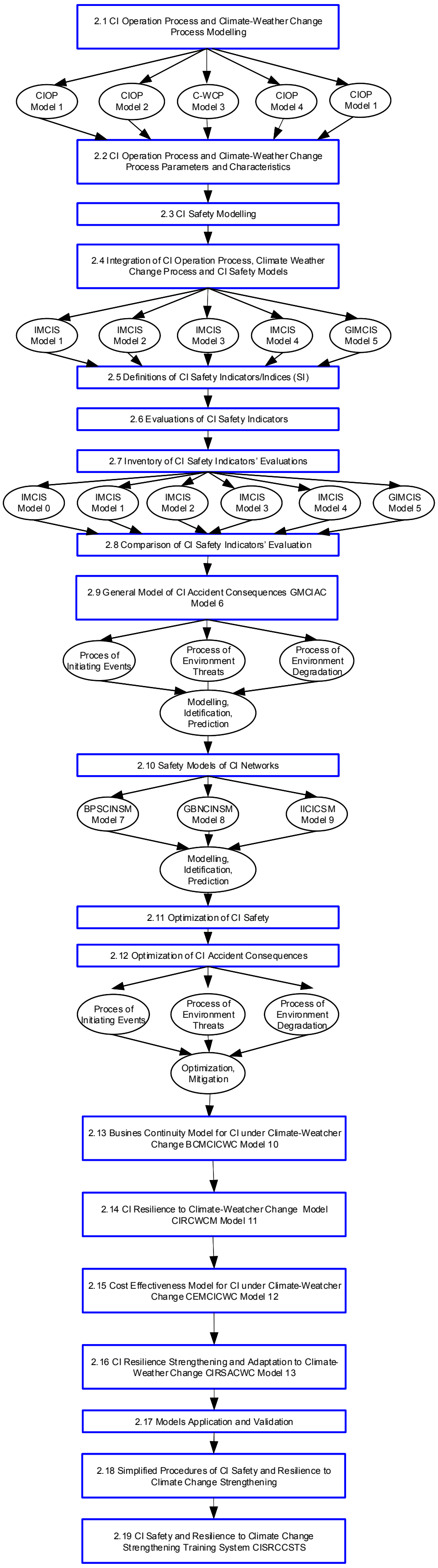

Figure 1. The scheme of general approach to operation and climate-weather change influence on critical infrastructure safety and resilience modelling

Details of theoretical backgrounds of this report Part 1 are given in [Kołowrocki K., Soszyńska-Budny J., Critical Infrastrutcture Impact Models for Operation Threats and Climate Hazards, Part 1, Critical Infrastructure Connections, Journal of Polish Safety and Reliability Assotiation, Special Issue on EU-CIRCLE Project. Volume 8, Number 3, 2017].

In this report Part 2, considered in its Part 1 Model 0 is joined with the critical infrastructure operation process model to create Model 1 devoted to safety modelling and prediction of critical infrastructure defined as a complex system in its operating environment that significant features are inside-system dependencies and outside-system dependencies. This is a general safety analytical model of a critical infrastructure related to its operation process, linking its multistate safety model and its operation process model and considering variable at different operation states its safety structure and its components' safety parameters. In this model, additional safety indices typical for the critical infrastructure related to its varying in time safety structures and its components' safety parameters caused by its operation process are introduced extending the Model 0 set of safety indicators by the components and critical infrastructure conditional intensities of ageing at particular operation states and conditional and unconditional coefficients of the operation process impact on intensities of ageing. A slight generalization of Model 1 is Model 2 devoted to safety of a critical infrastructure related to its operation process including operating environment threats. It is the integrated general model of critical infrastructure linking its multistate safety model and the model of its operation process including operating environment threats and considering variable at the different operation states safety structures and their components safety parameters. Other practically significant discussed in this report critical infrastructure safety indicators are the critical infrastructure and its components intensities of degradation and the coefficients of operation process including operating environment threats influence on the critical infrastructure and its components intensities of degradation. Next, a general safety analytical Model 3 of critical infrastructure safety related to the climate-weather change process in its operating area is proposed. It is the integrated model of critical infrastructure safety, linking its multistate safety model and the model of the climate-weather change process at its operating area, considering variable at the different climate-weather states and impacted by them system components safety parameters. The conditional safety functions at the climate-weather particular states, the unconditional safety function and the risk function of the critical infrastructure at changing in time climate-weather conditions are defined. Other, practically significant, critical infrastructure safety indices introduced in the model are its mean lifetime up to the exceeding a critical safety state, the moment when its risk function value exceeds the acceptable safety level, the intensities of ageing of the critical infrastructure related to the climate-weather change process at its operating area and its components and the coefficients of the climate-weather change process impact on the critical infrastructure and its components intensities of ageing. More general Model 4 considering together the operation process and the climate-weather change process influence on the safety of a critical infrastructure, i.e. the safety analytical model of a critical infrastructure under the influence of the operation process related to climate-weather change process is proposed. It is the integrated model of a critical infrastructure safety, linking its multistate safety model and the model of its operation process related to climate-weather change process at its operating area, considering variable at the different operation and climate-weather states impacted by them the system safety structures and its components safety parameters. The conditional safety functions at the operation process related to climate-weather change process particular states, the unconditional safety function and the risk function of a critical infrastructure at changing in time operation and climate-weather conditions are defined. Other, practically significant, critical infrastructure safety indices introduced in the model are its mean lifetime up to the exceeding a critical safety state, the moment when its risk function value exceeds the acceptable safety level, the intensities of ageing of the critical infrastructure and its components impacted by the operation process related to the climate-weather change process at its operating area and the coefficients of the operation process related to the climate-weather change process impact on the critical infrastructure and its components intensities of ageing. Most general Model 5 covers the operating environment threats and climate-weather hazards influence on the safety of a critical infrastructure. A general safety analytical model of a critical infrastructure under the influence of its operation process including operating environment threats (OET) related to climate-weather change process including extreme weather hazards (EWH) is proposed. It is the integrated model of a critical infrastructure safety, linking its multistate safety model and the joint model of its operation process including OET and the climate-weather change process including EWH at its operating area, considering variable at the different operation and climate-weather states impacted by them the critical infrastructure safety structures and its components safety parameters. The conditional safety functions at the operation process including operating environment threats and climate-weather hazards particular states, the unconditional safety function and the risk function of the critical infrastructure at changing in time its operation conditions including OET and climate-weather conditions including EWH are defined. Other, practically significant, critical infrastructure safety indices introduced in the paper are its mean lifetime up to the exceeding a critical safety state, the moment when its risk function value exceeds the acceptable safety level, the intensities of ageing of the critical infrastructure and its components impacted by the operation process including operating environment threats related to the climate-weather change process including extreme weather hazards and the coefficients of the operation process including operating environment threats related to the climate-weather change process including extreme weather hazards impact on the critical infrastructure and its components intensities of ageing.

These all safety indices, proposed in Models 0-5, are defined in general for any critical infrastructures varying in time their safety structures and components safety parameters influenced by changing in time operation conditions including environment threats and climate-weather conditions including climate-weather extreme weather hazards at their operating areas.

Details of theoretical backgrounds of this report Part 2 are given in [Kołowrocki K., Soszyńska-Budny J., Critical Infrastructure Impact Models for Operation Threats and Climate Hazards, Part 2, Impact Assessment Models, Journal of Polish Safety and Reliability Assotiation, Special Issue on EU-CIRCLE Project. Volume 8, Number 4, 2017].

After finalising tasks of scheme items 2.1-2.10, the next step can be done to perform the tasks formulated in scheme items 2.11-2.16, terminating methodological framework, where the devised risk and impact assessment framework on interconnected and interdependent critical infrastructures may be transformed into a resilience and adaptation framework. Thus, the way we should go in the research further activity is investigating and solving the problems of optimization of critical infrastructure safety (finding optimal values of safety indictors), critical infrastructure accident consequences optimisation and mitigation, critical infrastructure resilience to climate-weather change analysis and strengthening critical infrastructure resilience to climate-weather change, pointed out in the scheme of the general approach to safety and resilience analysis presented in Figure 1.1. This activity will results in business continuity models for critical infrastructure under climate pressures elaboration, critical infrastructure resilience indicators defining, cost-effectiveness analysis and modelling and finally in Framework for critical infrastructure adaptation to climate change creation expected to be done in the scope of WP 4 activity.

All the above Models 0-13, presented in [Kołowrocki K., Soszyńska-Budny J., Critical Infrastrutcture Impact Models for Operation Threats and Climate Hazards, Part 1, Critical Infrastructure Connections, Journal of Polish Safety and Reliability Assotiation, Special Issue on EU-CIRCLE Project. Volume 8, Number 3, 2017] and [Kołowrocki K., Soszyńska-Budny J., Critical Infrastructure Impact Models for Operation Threats and Climate Hazards, Part 2, Impact Assessment Models, Journal of Polish Safety and Reliability Assotiation, Special Issue on EU-CIRCLE Project. Volume 8, Number 4, 2017], can be the basis for preparation of significantly simplified models and procedures that are very easy to use by the practitioners and operators of the critical infrastructures in their safety analysis, what is intended to be done in this report Part 1 and Part 2. The use of these simplified procedures is presented in details in this report for real critical infrastructures.

These simplified procedures are also expected to be modified and developed for other than safety features of critical infrastructure analysis, modelling and prediction.

These procedures can be the basis for preparing algorithms and computer software allowing to apply by practitioners these procedures automatically.

All created models and based of them simplified procedures for determining the critical infrastructure safety indicators supported by suitable computer software can be very important and useful practical tools.

They also can be used to generate the Critical Infrastructure Safety and Resilience to Climate Change Strengthening Training System (CISCCSTS) in the form of the package of training courses based on the e-learning concept.

3. Critical Infrastructure Safety Indicators

3.1. Basic Definitions

In the multistate safety analysis to define the critical infrastructure with degrading/ageing components/assets, we assume that:

- all components/assets and a critical infrastructure have the safety state set $\{0,1,...,z\}$, $z \geq 1$,
- the safety states are ordered, the safety state 0 is the worst and the safety state z is the best,
- $T(u)$ is a random variable representing the lifetime of a critical infrastructure in the safety state subset $\{u,u+1,...,z\}$ while it was in the safety state z at the moment $t = 0$,
- the critical infrastructure and its assets safety states degrades with time t,
- $s(t)$ is a critical infrastructure safety state 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 critical infrastructure with ageing components/assets may be changed in time only from better to worse [Kolowrocki & Soszynska-Budny 2011]. The way in which the assets and the critical infrastructure safety states are changing is illustrated in Figure 2 and Figure 3.

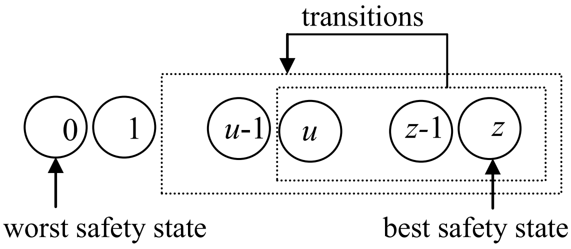

Figure 2. Illustration of a critical infrastructure safety states changing

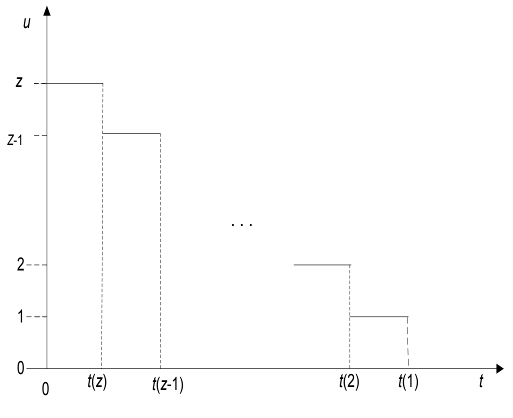

Figure 3. The relationship between the realizations $t(u)$, $u = 1, 2, \ldots, z$, of the critical infrastructure lifetime $T(u)$, $u = 1, 2, \ldots, z$, in the safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1, 2, \ldots, z$

We denote the critical infrastructure unconditional lifetime in the safety state subset $\{u, u+1,...,z\}$ by $T(u)$ and define the critical infrastructure safety function (SI1) by the vector [Blokus-Roszkowska et all 2016b]

$$\boldsymbol{S}(t,\cdot) = [1, \boldsymbol{S}(t,1),..., \boldsymbol{S}(t,z)], \tag{1}$$

with the coordinates defined by

$$\boldsymbol{S}(t,u) = P(T(u) > t) \text{ for } t \in <0,\infty), \quad u = 1,2,...,z. \tag{2}$$

The exemplary graph of a five-state (z = 4) critical infrastructure safety function

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

is shown in Figure 4.

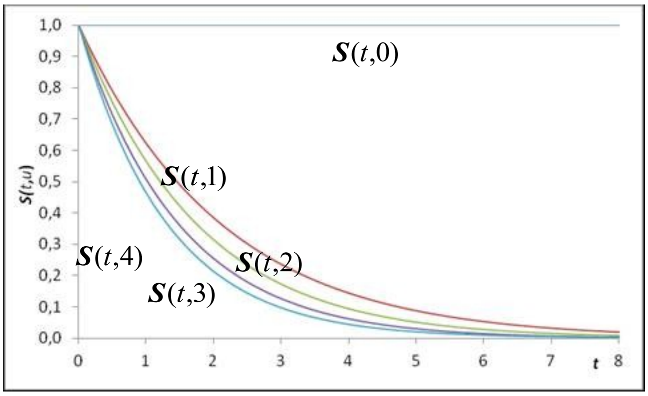

Figure 4. The graphs of a four-state critical infrastructure safety function $\boldsymbol{S}(t,\cdot)$ coordinates

Critical Infrastructure risk function (SI2)

$$\boldsymbol{r}(t) = P(S(t) < r \mid S(0) = z) = P(T(r) \leq t), \quad t \in <0,\infty), \tag{3}$$

is defined as a probability that the critical infrastructure in the subset of safety states worse than the critical safety state r, $r \in \{1,...,z\}$ while it was in the best safety state z at the moment t = 0 [Kołowrocki & Soszyńska-Budny, 2011] and given by

$$\boldsymbol{r}(t) = 1 - \boldsymbol{S}(t,r), \quad t \in <0,\infty), \tag{4}$$

where $\boldsymbol{S}(t,r)$ is the coordinate of the critical infrastructure unconditional safety function given by (2) for $u=r$.

The graph of the system risk function presented in Figure 5 is called the critical infrastructure fragility curve (SI3) [Ben, Gouldby, Schultz, Simm & Wibowo 2010].

The critical infrastructure safety function (SI1), the critical infrastructure risk function (SI2) and the critical infrastructure fragility curve (SI3) are proposed as main critical infrastructure Safety Indicators (SI).

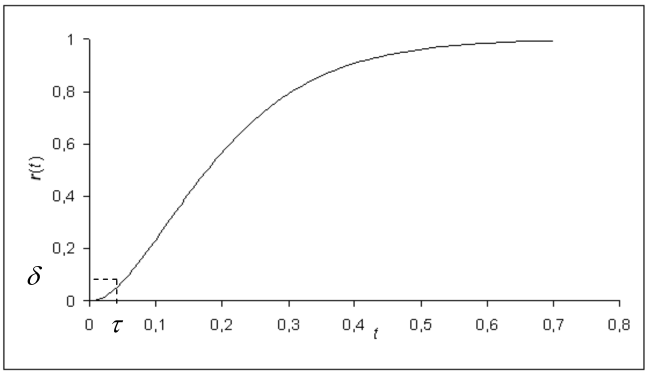

Figure 5. The graph (The fragility curve) of a system risk function $\boldsymbol{r}(t)$

To introduce other safety and resilience indicators concerned with impact models (Report Part 2), we define them exemplarily in the next section for Model 1.

3.2. Critical Infrastructure Safety Safety Model – IMCISM Model 1

We denote the system conditional lifetime in the safety state subset $\{u,u+1,...,z\}$ while the system is at the operation state z_b, $b=1,2,...,v$, by $T'^{(b)}(u)$ and the conditional safety function of the system by the vector [Kołowrocki & Soszyńska-Budny 2011]

$$[\boldsymbol{S}(t,\cdot)]^{(b)} = [1,\ [\boldsymbol{S}(t,1)]^{(b)}, ...,\ [\boldsymbol{S}(t,z)]^{(b)}], \qquad (5)$$

with the coordinates defined by

$$[\boldsymbol{S}(t,u)]^{(b)} = P(T^{(b)}(u) > t | Z(t) = z_b) \qquad (6)$$

for $t \in <0,\infty)$, $u=1,2,...,z$, $b=1,2,...,v$.

The safety function $[\boldsymbol{S}(t,u)]^{(b)}$ is the conditional probability that the system lifetime $T'^{(b)}(u)$ in the safety state subset $\{u,u+1,...,z\}$ is greater than t, while the system operation process $Z(t)$ is at the operation state z_b.

In the case when the system operation time θ is large enough, the coordinates of the unconditional safety function of the system defined by (1.1) are given by

$$\boldsymbol{S}(t,u) \cong \sum_{b=1}^{v} p_b [\boldsymbol{S}(t,u)]^{(b)} \text{ for } t \geq 0,$$
$$u = 1,2,...,z, \qquad (7)$$

where $[\boldsymbol{S}(t,u)]^{(b)}$, $u=1,2,...,z$, $b=1,2,...,v$, are the coordinates of the system conditional safety functions defined by (5)-(6) and p_b, $b=1,2,...,v$, are the system operation process limit transient probabilities at the particular operation states [Kołowrocki & Soszyńska-Budny 2011].

The mean value of the system unconditional lifetime $T(u)$ in the safety state subset $\{u,u+1,...,z\}$ is given by

$$\mu(u) \cong \sum_{b=1}^{v} p_b \mu_b(u), \ u=1,2,...,z, \qquad (8)$$

where $\mu_b(u)$ are the mean values of the system conditional lifetimes $T^{(b)}(u)$ in the safety state subset $\{u,u+1,...,z\}$ at the operation state z_b, $b=1,2,...,v$, given by

$$\mu_b(u) = \int_0^\infty [\boldsymbol{S}(t,u)]^{(b)} dt, \ u=1,2,...,z, \qquad (9)$$

$[\boldsymbol{S}(t,u)]^{(b)}$, $u=1,2,...,z$, $b=1,2,...,v$, are defined by (5)-(6) and p_b are given by (2.4) in (Kołowrocki & Soszyńska-Budny 2011). Whereas, the variance of the system unconditional lifetime $T(u)$ is given by

$$\sigma^2(u) = 2\int_0^\infty t\ \boldsymbol{S}(t,u)dt - [\mu(u)]^2, \ u=1,2,...,z, \qquad (10)$$

where $\boldsymbol{S}(t,u)$, $u=1,2,...,z$, are given by (7) and $\mu(u)$, $u=0,1,...,z$, are given by (8).

Hence, according to (1.19) in [Kołowrocki & Soszyńska-Budny 2011], we get the following formulae for the mean values of the unconditional lifetimes of the system in particular safety states

$$\bar{\mu}(u) = \mu(u) - \mu(u+1), \ u=0,1,...,z-1,$$
$$\bar{\mu}(z) = \mu(z), \qquad (11)$$

where $\mu(u)$, $u=0,1,...,z$, are given by (8).

Other practically useful system safety factors are:

- the mean value of the unconditional system lifetime $T(r)$ up to the exceeding the critical safety state r (SI4) given by

$$\mu(r) \cong \sum_{b=1}^{\nu} p_b \mu_b(r), \tag{12}$$

where $\mu_b(r)$ are the mean values of the system conditional lifetimes $T^{(b)}(r)$ in the safety state subset $\{r, r+1, ..., z\}$ at the operation state z_b, $b = 1,2,...,\nu$, given by

$$\mu_b(r) = \int_0^\infty [\boldsymbol{S}(t,r)]^{(b)} dt, \ \ b = 1,2,...,\nu, \tag{13}$$

$[\boldsymbol{S}(t,r)]^{(b)}$, $u = 1,2,...,z$, $b = 1,2,...,\nu$, are defined by (7) and p_b are given by (2.4) in [Kołowrocki & Soszyńska-Budny 2011];

- the standard deviation of the system lifetime $T(r)$ up to the exceeding the critical safety state r (SI5) given by

$$\sigma(r) = \sqrt{n(r) - [\mu\mu(r)]^2}\ , \tag{14}$$

where

$$n(r) = 2\int_0^\infty t\, \boldsymbol{S}\,(t,r) dt, \tag{15}$$

where $\boldsymbol{S}(t,r)$ is given by (7) and $\mu(r)$ is given by (12) for $u = r$.

- the moment τ the system risk function exceeds a permitted level δ (SI6) given by

$$\tau = \boldsymbol{r}^{-1}(\delta), \tag{16}$$

and illustrated in Figure 5, where $\boldsymbol{r}'^{-1}(t)$, if it exists, is the inverse function of the risk function $\boldsymbol{r}(t)$ given by (4).

Other critical infrastructure safety indices are:

- the intensities of ageing/degradation of the critical infrastructure (the intensities of critical infrastructure departure from the safety state subset $\{u, u+1, ..., z\}$) related to the operation process impact (SI7), i.e. the coordinates of the vector

$$\boldsymbol{\lambda}(t,\cdot) = [0,\ \boldsymbol{\lambda}(t,1), \ldots, \boldsymbol{\lambda}(t,z)\ ],\ t \in <0,+\infty), \tag{17}$$

where

$$\boldsymbol{\lambda}(t,u) = \frac{-\frac{d\boldsymbol{S}(t,u)}{dt}}{\boldsymbol{S}(t,u)},\ \ t \in <0,+\infty),$$
$$u = 1,2,...,z; \tag{18}$$

– the coefficients of operation process impact on the critical infrastructure intensities of ageing (the coefficients of operation process impact on critical infrastructure intensities of departure from the safety state subset $\{u, u+1, ..., z\}$) (SI8), i.e. the coordinates of the vector

$$\boldsymbol{\rho}(t,\cdot) = [0,\ \boldsymbol{\rho}(t,1), \ldots, \boldsymbol{\rho}(t,z)\ ],\ t \in <0,+\infty), \tag{19}$$

where

$$\boldsymbol{\lambda}(t,u) = \boldsymbol{\rho}(t,u) \cdot \boldsymbol{\lambda}^0(t,u),\ \ t \in <0,+\infty),$$
$$u = 1,2,...,z, \tag{20}$$

and $\boldsymbol{\lambda}^0(t,u)$ are the intensities of ageing of the critical infrastructure (the intensities of the critical infrastructure departure from the safety state subset $\{u, u+1, ..., z\}$) without of operation impact, i.e. the coordinate of the vector

$$\boldsymbol{\lambda}^0(t,\cdot) = [0,\ \lambda^0(t,1),, \ldots, \boldsymbol{\lambda}^0(t,z)\ ],$$
$$t \in <0,+\infty). \tag{21}$$

In the case, the critical infrastructure have the exponential safety functions, i.e.

$$\boldsymbol{S}(t,\cdot) = [0,\ \boldsymbol{S}(t,1), \ldots, \boldsymbol{S}(t,z)\ ],\ t \in <0,+\infty), \tag{22}$$

where

$$\boldsymbol{S}(t,u) = \exp[-\boldsymbol{\lambda}(u)t],\ \ t \in <0,+\infty),\ \ \boldsymbol{\lambda}(u) \ge 0,$$
$$u = 1,2,\ldots,z, \tag{23}$$

the critical infrastructure safety indices defined by (17)-(21) take forms:

- the intensities of ageing of the critical infrastructure (the intensities of critical infrastructure departure from the safety state subset $\{u, u+1, ..., z\}$) related to the operation impact, i.e. the coordinates of the vector

$$\boldsymbol{\lambda}(\cdot) = [0,\ \boldsymbol{\lambda}(1), \ldots, \boldsymbol{\lambda}(z)\ ], \tag{24}$$

- the coefficients of the operation impact on the critical infrastructure intensities of ageing (the coefficients of the operation impact on critical infrastructure intensities of departure from the safety state subset $\{u, u+1, \ldots, z\}$), i.e. the coordinate of the vector

$$\boldsymbol{\rho}(\cdot) = [0,\ \boldsymbol{\rho}(1),\ \ldots,\ \boldsymbol{\rho}(z)], \qquad (25)$$

where

$$\lambda(u) = \boldsymbol{\rho}(u) \cdot \lambda^{0}(u),\ \ u = 1,2,\ldots,z. \qquad (26)$$

and $\lambda^{0}(u)$ are the intensities of ageing of the critical infrastructure (the intensities of the critical infrastructure departure from the safety state subset $\{u, u+1, \ldots, z\}$) without of operation impact, i.e. the coordinate of the vector

$$\lambda^{0}(u) = [0,\ \lambda^{0}(1),\ \ldots,\ \lambda^{0}(z)]. \qquad (27)$$

Additionally, we propose to introduce the critical infrastructure resilence indicaator (RI1), i.e. the coefficient of critical infrastructure resilience to operation process impact

$$RI1(t) = 1/\boldsymbol{\rho}(t,r),\ \ t \in <0,+\infty), \qquad (28)$$

where $\boldsymbol{\rho}(t,r)$ is the coefficients of the operation process impact on the critical infrastructure intensity of ageing $\lambda(t,r)$, i.e. the coefficients of operation process impact on critical infrastructure intensities of departure from the safety state subset $\{r, r+1, \ldots, z\}$ of states not worse than the critical safety state r.
Similarly, we can define other critical infrastructure resilence indicaators, respectively for Models 2-5, i.e.:

- the coefficient of critical infrastructure resilience to operation process including operating threats impact,
- the coefficient of critical infrastructure resilience to climate-weather hazards impact,
- the coefficient of critical infrastructure resilience to operation process and climate-weather impacts,
- the coefficient of critical infrastructure resilience to operation process threats and climate-weather hazards impacts.

4. Conclusions

All created models and based of them simplified procedures for determining the critical infrastructure safety indicators supported by suitable computer software can be very important and useful practical tools. They also can be used to generate the Critical Infrastructure Safety and Resilience to Climate Change Strengthening Training System (CISCCSTS) in the form of the package of Training Courses based on the e-learning concept.

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