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Maritime Transportation System Safety – Modeling and Identification

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ABSTRACT: The article is showing a concept of critical infrastructure systems' safety states model. Model construction is basing on: popular technical systems' safety states models, and notions specified in acts of law and other studies concerning crisis management. Paper is including some concept of proposed model usage possibilities - methods and procedures for estimating unknown basic parameters of safety states transitions process: identifying the distributions of its conditional lifetime at safety states, estimating probabilities of its staying at safety states at the initial moment, probabilities of its transitions between safety states and parameters of the distribution for the description of its conditional lifetimes at safety states.

1 INTRODUCTION

Crisis management has become last years an important part of many aspects of our everyday life. This is coming out of both: increasing menace of terrorist attacks, and increasing number of different kinds of elemental disasters taking place in the near past.

One of crisis management most important features is protection of critical infrastructure, that is defined as: *systems, and included within them, interconnected - objects, devices, installations, services, essential for state's safety and its citizens, serving for efficient functioning of public administration, institutions and business.*

Protection of critical infrastructure systems becomes even more important, if considering significant incidents, that took place last years – terrorist attacks (New York 2001, Madrid 2004, London 2005), earthquakes resulting with tsunami waves, causing huge destructions of large areas, including sensitive objects placed inside them (Japan 2011), and floods caused by tropical cyclones (Katrina – New Orleans 2005, Sandy – New York 2012).

This paper is undertaking issues connected to modeling of critical infrastructure systems safety, basing on maritime transportation system, being essential system for both: critical infrastructure, and European critical infrastructure. The model of the safety states transitions processes of critical infrastructure is introduced.

Further, paper includes a way of application of the model in the evaluation and prediction of the safety of real process, concerned with determining the unknown parameters of the proposed model.

Particularly, concerning the safety states transitions process of critical infrastructure, the probabilities of this process staying at the safety states at the initial moment, the probabilities of this process transitions between the system operation states and the distributions of the conditional lifetimes of this at the particular operation states, are also shown.

2 MARITIME TRANSPORTATION SYSTEM MODELING

2.1 *Maritime transportation system as a subsystem of critical infrastructure and European critical infrastructure*

Maritime transportation system is one of the most important components of critical infrastructure. disturbances to its functioning can cause significant negative results for surrounding systems, including natural environment.

Act of Law on Crisis Management (2007) is indicating all transport systems in general, as a part of critical infrastructure. Council Directive 2008/114/EC goes even further – indicating separately: Road, Rail, Air, Inland waterways transport, and Ocean and short-sea shipping and ports, as sectors of European critical infrastructure. European critical infrastructure is there defined as: *critical infrastructure located in Member States the disruption or destruction of which would have a significant impact on at least two Member States*.

The Directive is also demanding special efforts and activities to be undertaken to protect European critical infrastructure.

2.2 *Maritime transportation system safety states model reflecting crisis management phases*

Implementation of crisis management issues and problems into the technical systems' safety states models commonly known, has resulted in formulating of critical infrastructure systems' safety states model, illustrating processes connected to their transitions, corresponding to particular crisis management phases (Figure 1).

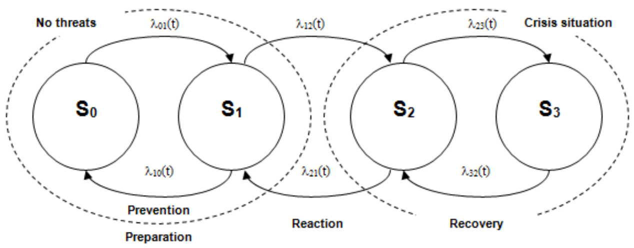

Figure 1. Critical infrastructure systems' safety states model

S_0 state is seen as corresponding to threats zero level. State S_1 stands for increased level of threats, but below level causing transition to crisis situation. States S_0 and S_1 can be understood as one aggregated state. Stay of system at one of these states can be seen as one wider *no threats* state

Aggregated *no threats* state can be interpreted as a state, covering intensive efforts of crisis management services, aiming to stand up for threats, meaning increasing rate of transition from state S_1 to S_0.

The efforts are corresponding to following crisis management phases:

– ***Prevention*** – analyzes of potentially possible crisis situations, and undertaking activities lowering probability of their appearance,
– ***Preparation*** – planning of actions (procedures), that should be performed in case of appearing of foreseen crisis situations.

Crisis situation state is interpreted as aggregation of two minor states shown in Figure 1: S_2 state, illustrating threats level trespassing border of crisis situation, but not causing damages to critical infrastructure systems, and S_3 state, reached when damages mentioned are taking place.

Crisis management services efforts, undertaken when crisis situation occurs, aiming to move system from *crisis situation* state into *no threats* state, are named ***Reaction***:

– ***Reaction*** – undertaking of previously planned, coordinated activities, leading to stop crisis situation expanding, support casualties, and restrict damages and losses.

Transition between states S_2 and S_3 reflects the fourth, not mentioned until now, phase of crisis management, named ***Recovery*** (***Reconstruction***):

– ***Recovery (Reconstruction)*** – restoration of previous conditions of critical infrastructure.

Thus, the model is representing all four crisis management phases.

3 PROBABILISTIC DESCRIPTION OF SAFETY STATES TRANSITIONS' PROCESS

According to outcome of chapter 2 above, critical infrastructure safety states transitions process $S(t)$, t ∈ <0,+∞), can stay at one of four particular safety states S_0, S_1, S_2, S_3, already defined. Furthermore, it can be assumed that critical infrastructure safety states transitions process $S(t)$ is a semi-Markov process, with the conditional sojourn times T_{ij} at the operation states S_i when its next operation state is S_j, $i, j = 0, 1, 2, 3$ $i \neq j$.

The critical infrastructure safety states transitions process can be described by its following basic parameters:

– the vector $[p_i(0)]_{1x4}$ of the initial probabilities

$$p_i(0) = P(S(0) = S_i), \quad i = 0,1,2,3, \tag{1}$$

of the critical infrastructure safety states transitions process $S(t)$ staying at particular safety states at the moment $t = 0$;

– the matrix $[p_{ij}]_{4x4}$ of probabilities p_{ij}, $i, j = 0, 1, 2, 3$ $i \neq j$, of the critical infrastructure safety states transitions process $S(t)$ transitions between the safety states S_i and S_j;
– the matrix $[F_{ij}(t)]_{4x4}$ of conditional distribution functions

$$F_{ij}(t) = P(T_{ij} < t), \ \ i, j = 0,1,2,3, \ \ i \neq j, \tag{2}$$

of the critical infrastructure safety states transitions process $S(t)$ conditional sojourn times T_{ij} at the operation states, and the corresponding matrix of the density functions $[f_{ij}(t)]_{4x4}$, where

$$f_{ij}(t) = \frac{d}{dt}[F_{ij}(t)], \quad i, j = 0,1,2,3, \quad i \neq j;$$

By means of above mentioned parameters following characteristics of critical infrastructure safety states transitions process can be determined:

– mean values of the critical infrastructure safety states transitions process $S(t)$ conditional sojourn times T_{ij}, at the particular safety states:

$$M_{ij} = E[T_{ij}] = \int_0^\infty t dF_{ij}(t) = \int_0^\infty t f_{ij}(t),$$
$$i, j = 0,1,2,3, \ i \neq j; \tag{3}$$

– rates of critical infrastructure safety states transitions process $S(t)$ between the safety states:

$$\lambda_{ij}(t) = \frac{f_{ij}(t)}{1 - F_{ij}(t)}, \ i, j = 0,1,2,3, \quad i \neq j; \tag{4}$$

– unconditional distribution functions of the critical infrastructure safety states transitions process $S(t)$ stay time T_i at particular safety states:

$$F_i(t) \ = \ \sum_{j=0}^{3} p_{ij} F_{ij}(t), \quad i = 0,1,2,3; \tag{5}$$

– the mean values of the critical infrastructure safety states transitions process $S(t)$ unconditional sojourn times T_i at the safety states:

$$M_i = E[T_i] = \sum_{j=0}^{3} p_{ij} M_{ij}, \ i = 0,1,2,3, \tag{6}$$

where M_{ij} is given by (3);

– the limit values of the critical infrastructure safety states transitions process $S(t)$ transient probabilities at the particular safety states

$$p_i(t) = P(Z(t) = z_i), \ t \in < 0, +\infty), \ i = 0,1,2,3, \tag{7}$$

are given by:

$$p_i = \lim_{t \to \infty} p_i(t) = \frac{\pi_i M_i}{\sum_{j=1}^{3} \pi_j M_j}, \ i = 0,1,2,3, \tag{8}$$

where M_i, $i = 0, 1, 2, 3$, are given by (6), while the steady probabilities π_i of the vector $[\pi_i]_{1x4}$ satisfy the system of equations

$$\begin{cases} [\pi_i] = [\pi_i][p_{ij}] \\ \sum_{j=1}^{j} \pi_j = 1; \end{cases} \tag{9}$$

Other interesting characteristics of the process $S(t)$ possible to obtain are:

– total sojourn times T_i at the particular safety states S_i, $i = 0, 1, 2, 3$, during the fixed system opetation time Θ, having approximately normal distributions with the expected value given by

$$\hat{M}_i = E[\hat{T}_i] = p_i \theta, \ i = 0,1,2,3, \tag{10}$$

where p_i, $i = 0, 1, 2, 3$, are given by (7);

– the total cost (loss) $\hat{C}$ concerned with critical infrastructure exploitation at fixed exploitation time Θ, that are aproximately

$$\hat{C} = \sum_{i=0}^{3} p_i C_i \theta, \tag{11}$$

where p_i, $i = 0, 1, 2, 3$, are given by (7), while C_i, $i = 0, 1, 2, 3$, are average costs (losses) of exploitation at particular safety states S_i, $i = 0, 1, 2, 3$, within the time frame, at which exploitation time Θ is measured.

In special circumstances, when critical infrastructure safety states transitions process conditional sojourn times T_{ij} at the particular safety states, are having Weibull's distribution with the density function

$$f_{ij}(t) = \begin{cases} 0, & t < x_{ij} \\ \alpha_{ij}\beta_{ij}(t - x_{ij})^{\beta_{ij}-1} \exp[-\alpha_{ij}(t - x_{ij})^{\beta_{ij}}], & t \geq x_{ij}, \end{cases} \tag{12}$$

where $0 \leq \alpha_{ij} < +\infty$, $0 \leq \beta_{ij} < +\infty$, $i, j = 0,1,2,3$, $i \neq j$, its two main characteristics given by (3) and (4) are:

– the mean values of critical infrastructure safety states transitions process $S(t)$ conditional sojourn times T_{ij} at the particular safety states

$$M_{ij} = E[T_{ij}] = x_{ij} + \alpha_{ij}^{-\frac{1}{\beta_{ij}}} \Gamma(1 + \frac{1}{\beta_{ij}}), \tag{13}$$

where $\Gamma(u) = \int_0^{+\infty} t^{u-1} e^{-t} dt, \quad u > 0$, is the gamma function;

– rates of critical infrastructure safety states transitions process $S(t)$ between the safety states:

$$\lambda_{ij}(t) = \alpha_{ij}\beta_{ij}(t - x_{ij})^{\beta_{ij}-1}, \ t > x_{ij}, \ i, j = 0,1,2,3, \ i \neq j \tag{14}$$

Described above determination of critical infrastructure safety states transitions process' basic parameters, can be used for maritime transportation system (treated as part of critical infrastructure) safety states transition process' description. Further evaluation of formulated relations is however needed, leading to: obtain ratings of actual system parameters' influence on crisis situation appearance probability; possibilities of crisis situation expansion inhibiting, in case if its appearance; and backward system transition to the state from before crisis situation.

4 SAFETY STATES TRANSITIONS MODEL PARAMETERS IDENTIFICATION

Below chapter is showing general methodology of critical infrastructure safety states transitions process' parameters identification. This will be used in further research works for maritime transportation system safety states process' parameters identification. Then it will make possible diagnosing of system parameters influence on transitions' rates between particular system safety states, consequently allowing to investigate studies possibilities on influencing on maritime transportation system in crisis situations.

4.1 *Basic assumptions*

To make the estimation of the unknown parameters of the critical infrastructure safety states transitions process, the experiment delivering the necessary statistical data should be precisely planned.

First, before the experiment, following preliminary steps should be performed:

1 to analyze the process;

2 to fix or to define the process following general parameters:
- the number of the safety states of the process v;
- the safety states of the system operation process $z_1, z_2, \ldots, z_v$;

3 to fix the possible transitions between the safety states;

4 to fix the set of the unknown parameters of the process semi-Markov model.

Next, to estimate the unknown parameters of the process, based on the experiment, necessary statistical data should be collected, performing the following steps:

1 to fix and to collect the following statistical data necessary to evaluating the probabilities $p_i(0)$ of the process staying at the safety states at the initial moment $t = 0$:
- the duration time of the experiment Θ,
- the number of the investigated (observed) realizations of the process $n(0)$,
- the vector of the realizations $n_i(0)$, $i = 1, 2, \ldots, v$, of the numbers of staying of the process respectively at the safety states $z_1, z_2, \ldots, z_v$, at the initial moments $t = 0$ of all $n(0)$ observed realizations of the process

$$[n_i(0)] = [n_1(0), n_2(0), \ldots, n_v(0)] \tag{15}$$

where $n_1(0) + n_2(0) + n_v(0) = n(0)$;

2 to fix and to collect the following statistical data necessary to evaluating the probabilities $p_{ij}(0)$ of the process transitions between the safety states:
- the matrix of the realizations of the numbers n_{ij}, $i, j = 1,2,\ldots, v$, $i \neq j$, of the transitions of the process from the safety state z_i into the safety state z_j at all observed realizations of the process

$$[n_{ij}] = \begin{bmatrix} n_{11}\ n_{12} \ldots n_{1v} \\ n_{21}\ n_{22} \ldots n_{2v} \\ \ldots \\ n_{v1}\ n_{v2} \ldots n_{vv} \end{bmatrix} \tag{16}$$

where $n_{ii} = 0$ for $i = 1, 2, \ldots, v$;

- the vector of the realizations of the numbers n_i, $i = 1, 2, \ldots, v$, of departures of the process from the safety states z_i (the sums of the numbers of the i-the rows of the matrix $[n_{ij}]$)

$$[n_i] = [n_1, n_2, \ldots, n_v] \tag{17}$$

where $n_1 = n_{11} + n_{12} + \ldots + n_{1v}$, $n_2 = n_{21} + n_{22} + \ldots + n_{2v}$, …, $n_v = n_{v1} + n_{v2} + \ldots + n_{vv}$;

3 to fix and to collect the following statistical data necessary to evaluating the unknown parameters of the distributions $F_{ij}(t)$ of the conditional lifetimes T_{ij} of the system operation process at the particular safety states:
- the numbers n_{ij}, $i, j = 1,2,\ldots,v$, $i \neq j$, of realizations of the conditional sojourn times Θ_{ij}, $i, j = 1,2,\ldots,v$, $i \neq j$, of the system operation process at the safety state z_i when the next transition is to the safety state z_j during the observation time Θ,
- the realizations θ_{ij}^k, $k = 1,2, \ldots, n_{ij}$, of the conditional sojourn times Θ_{ij} of the system operation process at the safety state z_i when the next transition is to the safety state z_j during the observation time Θ for each $i, j = 1,2,\ldots,v$, $i \neq j$.

4.2 *Critical infrastructure safety states transitions process' basic parameters estimating*

After collecting the statistical data, it is possible to estimate the unknown parameters of the system operation process performing the following steps:

1 to determine the vector

$$[p(0)] = [p_1(0), p_2(0), \ldots, p_v(0)] \tag{18}$$

of the realizations of the probabilities $p_i(0)$, $i = 1, 2, \ldots, v$, of the system operation process staying at the safety states at the initial moment $t = 0$, according to the formula

$$p_i(0) = \frac{n_i(0)}{n(0)} \quad \text{for} \quad i = 1,2,\ldots,v, \tag{19}$$

where

$$n(0) = \sum_{i=1}^{v} n_i(0), \tag{20}$$

is the number of the realizations of the system operation process starting at the initial moment $t = 0$;

2 to determine the matrix

$$[p_{ij}] = \begin{bmatrix} p_{11} \; p_{12} \cdots p_{1v} \\ p_{21} \; p_{22} \cdots p_{2v} \\ \cdots \\ p_{v1} \; p_{v2} \cdots p_{vv} \end{bmatrix}, \qquad (21)$$

of the realizations of the probabilities p_{ij}, $i, j = 1,2,...,v$, of the system operation process transitions from the safety state z_i to the safety state z_j according to the formula

$$p_{ij} = \frac{n_{ij}}{n_i} \text{ for } i, j = 1, 2, ..., v, \; i \neq j,$$

$$p_{ii} = 0 \text{ for } i, j = 1, 2, ..., v, \qquad (22)$$

where

$$n_i = \sum_{i \neq j}^{v} n_{ij}, \; i = 1,2,...,v, \qquad (23)$$

is the realization of the total number of the system operation process departures from the safety state z_i during the experiment time Θ.

4.3 *Estimating distribution parameters of critical infrastructure safety states transitions process' lifetimes at safety states*

Prior to estimating the parameters of the safety states transitions process' conditional lifetimes distributions at the particular safety states, the following empirical characteristics of the realizations of the lifetimes of the critical infrastructure safety states transitions process at the particular safety states have to be determined:

– the realizations of the empirical mean values $\bar{T}_{ij}$ of the conditional lifetimes T_{ij} of the process at the safety state z_i when the next transition is to the safety state z_j, according to the formula

$$\bar{T}_{ij} = \frac{1}{n_{ij}} \sum_{k=1}^{n_{ij}} \theta_{ij}^k, \; i, j = 1,2,...,v, i \neq j, \qquad (24)$$

– the number $\bar{r}_{ij}$ of the disjoint intervals $I_j = < a_{ij}^j, b_{ij}^j)$, $j = 1,2,...,\bar{r}_{ij}$, that include the realizations θ_{ij}^k, $k = 1,2,...,n_{ij}$, of the conditional sojourn times θ_{ij} at the safety state z_i when the next transition is to the safety state z_j, according to the formula

$$\bar{r}_{ij} \cong \sqrt{n_{ij}},$$

– the length d_{ij} of the intervals $I_j = < a_{ij}^j, b_{ij}^j)$, , $j = 1,2,...,\bar{r}_{ij}$, according to the formula

$$d_{ij} = \frac{\bar{R}_{ij}}{\bar{r}_{ij} - 1},$$

where

$$\bar{R}_{ij} = \max_{1 \le k \le n_{ij}} \theta_{ij}^k - \min_{1 \le k \le n_{ij}} \theta_{ij}^k,$$

– the ends a_{ij}^j, b_{ij}^j, of the intervals $I_j = < a_{ij}^j, b_{ij}^j)$, $j = 1, 2,...,\bar{r}_{ij}$, according to the formulae

$$a_{ij}^1 = \max\{\min_{1 \le k \le n_{ij}} \theta_{ij}^k - \frac{d_{ij}}{2}, 0\},$$

$$b_{ij}^j = a_{ij}^1 + j d_{ij}, \quad j = 1,2,...,\bar{r}_{ij},$$

$$a_{ij}^j = b_{ij}^{j-1}, \; j = 2,3...,\bar{r}_{ij},$$

in such a way that

$$I_1 \cup I_2 \cup ... \cup I_{\bar{r}_{ij}} = < a_{ij}^1, b_{ij}^{\bar{r}_{ij}})$$

and

$$I_i \cap I_j = \emptyset \text{ for all } i \neq j, \quad i, j \in \{1,2,...,\bar{r}_{ij}\},$$

– the numbers n_{ij}^j of the realizations θ_{ij}^k in the intervals $I_j = < a_{ij}^j, b_{ij}^j)$, $j = 1,2,...,\bar{r}_{ij}$, according to the formula

$$n_{ij}^j = \#\{k : \theta_{ij}^k \in I_j, k \in \{1,2,...,n_{ij}\}\}, \quad j = 1,2,...,\bar{r}_{ij},$$

where

$$\sum_{j=1}^{\bar{r}_{ij}} n_{ij}^j = n_{ij},$$

whereas the symbol # means the number of elements of the set;

To estimate the parameters of the distributions of the conditional lifetimes of the process at the particular safety states, it has to be proceeded respectively in the following way:

– for the exponential distribution with the density function, the estimates of the unknown parameters are:

$$x_{ij} = a_{ij}^1, \alpha_{ij} = \frac{1}{\bar{T}_{ij} - x_{ij}}; \qquad (25)$$

– for the Weibull's distribution with the density function, the estimates of the unknown parameters are (the expressions for estimates of parameters α_{bl} and β_{bl} are not explicit):

$$x_{bl} = a_{bl}^1, \alpha_{bl} = \frac{n_{bl}}{\sum_{k=1}^{n_{bl}} (\theta_{bl}^k)^{\beta_{bl}}}, \alpha_{bl} = \frac{\frac{n_{bl}}{\beta_{bl}} + \sum_{k=1}^{n_{bl}} \ln(\theta_{bl}^k - x_{bl})}{\sum_{k=1}^{n_{bl}} (\theta_{bl}^k)^{\beta_{bl}} \ln(\theta_{bl}^k - x_{bl})}; \qquad (26)$$

4.4 Distribution functions identification of critical infrastructure safety states transitions process' conditional lifetimes at safety states

To formulate and next to verify the non-parametric hypothesis concerning the form of the distribution of the critical infrastructure safety process conditional lifetimes Θ_{ij} at the safety state z_i when the next transition is to the safety state z_j, on the basis of at least 30 its realizations θ_{ij}^k, $k = 1,2,...,n_{ij}$, it is due to proceed according to the following scheme:

- to construct and to plot the realization of the histogram of the process conditional lifetimes T_{ij} at the safety state z_i (Figure 2), defined by the following formula

$$\bar{h}_{n_{ij}}(t) = \frac{n_{ij}^j}{n_{ij}} \text{ for } t \in I_j, \quad (27)$$

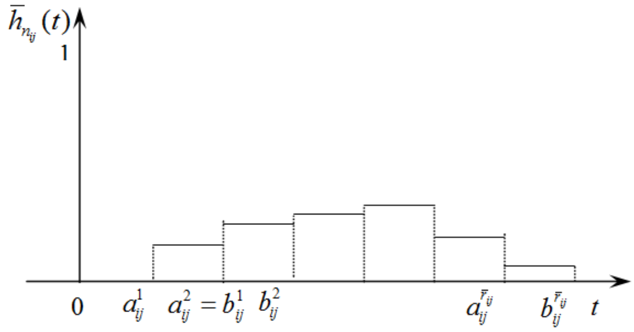

Figure 2. The graph of the realization of the histogram of the system operation process conditional sojourn time T_{ij} at the operation state z_i

- to analyze the realization of the histogram $\bar{h}_{n_{ij}}(t)$, comparing it with the graphs of the density functions $h_{ij}(t)$ of the previously distinguished distributions, to select one of them and to formulate the null hypothesis H_0, concerning the unknown form of the distribution of the conditional sojourn time T_{ij} in the following form:
- H_0: The system operation process conditional sojourn time T_{ij} at the safety state z_i when the next transition is to the safety state z_j, has the distribution with the density function $h_{ij}(t)$;
- to join each of the intervals I_j that has the number n_{ij}^j of realizations less than 4 either with the neighbor interval I_{j+1} or with the neighbor interval I_{j-1} this way that the numbers of realizations in all intervals are not less than 4;
- to fix a new number of intervals $\bar{\bar{r}}_{ij}$;
- to determine new intervals

$$\bar{I}_j = < \bar{a}_{ij}^j, \bar{b}_{ij}^j), \quad j = 1,2,..,\bar{\bar{r}}_{ij};$$

- to fix the numbers $\bar{\bar{n}}_{ij}^j$ of realizations in new intervals $\bar{I}_j$, $j = 1,2,..,\bar{\bar{r}}_{ij}$;
- to calculate the hypothetical probabilities that the variable T_{ij} takes values from the interval $\bar{I}_j$, under the assumption that the hypothesis H_0 is true, i.e. the probabilities

$$p_j = P(T_{ij} \in \bar{I}_j) = P(\bar{a}_{ij}^j \le T_{ij} < \bar{b}_{ij}^j) = H_{ij}(\bar{b}_{ij}^j) - H_{ij}(\bar{a}_{ij}^j), \quad j = 1,2,..,\bar{\bar{r}}_{ij}, \quad (28)$$

where $H_{ij}(\bar{b}_{ij}^j)$ and $H_{ij}(\bar{a}_{ij}^j)$ are the values of the distribution function $H_{ij}(t)$ of the random variable T_{ij} corresponding to the density function $H_{ij}(t)$ assumed in the null hypothesis H_0;

- to calculate the realization of the χ^2 (chi-square)-Pearson's statistics $U_{n_{ij}}$, according to the formula

$$u_{n_{ij}} = \sum_{j=1}^{\bar{\bar{r}}_{ij}} \frac{(\bar{n}_{ij}^j - n_{ij} p_j)^2}{n_{ij} p_j}; \quad (29)$$

- to assume the significance level α ($\alpha = 0.01$, $\alpha = 0.02$, $\alpha = 0.05$ or $\alpha = 0.10$) of the test;
- to fix the number $\bar{\bar{r}}_{ij} - l - 1$ of degrees of freedom, substituting for l for the distinguished distributions respectively the following values: $l = 0$ for the uniform, triangular, double trapezium, quasi-trapezium and chimney distributions, $l = 1$ for the exponential distribution and $l = 2$ for the Weibull's distribution;
- to read from the Tables of the χ^2 – Pearson's distribution the value u_α for the fixed values of the significance level α and the number of degrees of freedom $\bar{\bar{r}}_{ij} - l - 1$ such that the following equality holds

$$P(U_{n_{ij}} > u_\alpha) = \alpha, \quad (30)$$

and next to determine the critical domain in the form of the interval $(u_\alpha, +\infty)$ and the acceptance domain in the form of the interval $< 0, u_\alpha >$ (Figure 3);

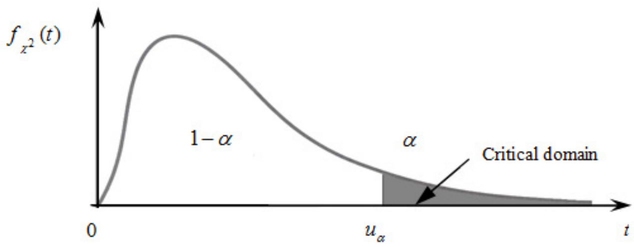

Figure 3. The graphical interpretation of the critical interval and the acceptance interval for the chi-square goodness-of-fit test

- to compare the obtained value U_{nij} of the realization of the statistics U_{nij} with the read from the Tables critical value U_α of the chi-square random variable and to decide on the previously formulated null hypothesis H_0 in the following way: if the value U_{nij} does not belong these to the critical domain, i.e. when $U_{nij} \le U_\alpha$, then we do not reject the hypothesis H_0, otherwise if the value U_{nij} belongs to the critical domain, i.e. when $U_{nij} > U_\alpha$ then we reject the hypothesis H_0.

5 CONCLUSIONS

Maritime transportation system is very important sector of critical infrastructure and European critical infrastructure. That is why it must be protected in very special way, by means of:

- monitoring and rapid detection of its functioning disturbances, that can potentially lead to crisis situations;
- planning of appropriate procedures securing system against potential crisis situations
- formulating of proper activities capable of reactioning against crisis situations in case of their appearance, and restoration of critical infrastructure systems into their previous conditions, in case of their damage.

Critical infrastructure systems' safety states model proposed in the article, and relations formulated on its basis, are intended to be the base for further evaluations, that should lead to modeling of system behaviour leading to crisis situations, and during them. The outcome should also be helpful for analysing of different factors and parameters influence on maritime transportation system safety states transitions; and supporting of activities leading to development of proper crisis management procedures.

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