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Identification methods and procedures of climate-weather change process including extreme weather hazards of port oil piping transportation system operating at land Baltic seaside area

Keywords

climate-weather change process, semi-Markov model, modelling, identification, transportation system

Abstract

There are presented the methods of identification of the climate-weather change process. These are the methods and procedures for estimating the unknown basic parameters of the climate-weather change process semi-Markov model and identifying the distributions of the climate-weather change process conditional sojourn times at the climate-weather states. There are given the formulae estimating the probabilities of the climate-weather change process staying at the particular climate-weather states at the initial moment, the probabilities of the climate-weather change transitions between the climate-weather states and the parameters of the distributions suitable and typical for the description of the climate-weather change process conditional sojourn times at the particular climate-weather states. The proposed statistical methods applications for the unknown parameters identification of the climate-weather change process model determining the climate-weather change process parameters for the port oil piping transportation system operating at land Baltic seaside area are presented.

1. Introduction

The general model of the climate-weather change processes is proposed in [3] and [13]. The safety models of various multistate complex technical systems are considered in [5]. Consequently, the general joint models linking these system safety models with the model of their climate-weather processes, allowing us for the safety analysis of the complex technical systems at the variable climate-weather conditions, are constructed in [6]. To be able to apply these general models practically in the evaluation and prediction of the reliability and safety of real complex technical systems it is necessary to have the statistical methods concerned with determining the unknown parameters of the proposed models [1]-[2], [7]-[8], [10]-[11], [22]. Particularly, concerning the climate-weather process, the probabilities of the climate-weather change process staying at the particular climate-weather states at the initial moment, the probabilities of the climate-weather process transitions between the climate-weather states and the distributions of the conditional sojourn times of the climate-weather process at the particular climate-weather states should be identified [9], [15]-[16]. It is also necessary to use the methods of testing the hypotheses concerned with the climate-weather process conditional sojourn times at the climate-weather states [15].

2. Identification and modeling of climate-weather change process

We consider the climate-weather change process $C(t)$, $t \in < 0,+\infty >$, for the critical infrastructure operating area with w, $w \in N$, different climate-weather change states c_1, c_2, ..., c_w from the set $\{c_1, c_2, ..., c_w\}$. We assume a semi-Markov model [14]-[20], of the climate-weather change process $C(t)$ and we mark by C_{bl} its random conditional sojourn times at the climate-weather states c_b, when its next climate-weather state is c_l, $b,l = 1,2,\ldots,w$, $b \neq l$.

Let Θ be the duration time of the experiment. Furthermore, we denote by $n(0)$ the realisation of the total number of the climate-weather change process stay at the particular climate-weather states at the initial moment $t = 0$ and by $[n_b(0)]_{1\times w}$, $b = 1,2,...,w$, the vector of realisations of the numbers of staying of the climate-weather change process respectively at the climate-weather states c_1, c_2, …, c_w, at the initial moments $t = 0$ of all $n(0)$ observed realizations of the climate-weather change process. Moreover, we denote by $[n_{bl}]_{w\times w}$ the matrix of the realizations of the numbers n_{bl}, $b,l = 1,2,...,w$, $b \neq l$, of the transitions of the climate-weather change process from the climate-weather state c_b into the climate-weather state c_l at all observed realizations of the climate-weather change process. We also denote by $[n_b]_{1\times w}$, the vector of the realizations of the numbers n_b, $b = 1,2,...,w$, of departures of the climate-weather change process from the climate-weather states c_b.

Under these assumptions, the climate-weather change process may be described by the vector $[q_b(0)]_{1\text{x}w}$ of probabilities of the climate-weather change process staying at the particular climate-weather states at the initial moment $t = 0$, the matrix $[q_{bl}(t)]_{w\text{x}w}$ of the probabilities of the climate-weather change process transitions between the climate-weather states and the matrix $[C_{bl}(t)]_{w\text{x}w}$ of the distribution functions of the conditional sojourn times C_{bl} of the climate-weather change process at the climate-weather states or equivalently by the matrix $[c_{bl}(t)]_{w\text{x}w}$ of the density functions of the conditional sojourn times C_{bl}, $b,l = 1,2,\ldots,w$, $b \neq l$, of the climate-weather change process at the climate-weather states. These all parameters of the climate-weather change process are unknown and before their use to the prognosis of this process characteristics have to be estimated on the basis of statistical data coming from practice.

3. Statistical identification of climate-weather change process for port oil piping transportation system

3.1. Defining parameters and data collection of climate-weather change process for port oil piping transportation system

The unknown parameters of the climate-weather change process semi-Markov model are:

- the initial probabilities $q_b(0)$, $b = 1,2,...,36$, of the climate-weather change process staying at the particular states c_b at the moment $t = 0$,
- the probabilities q_{bl}, $b,l = 1,2,...,36$, $b \neq l$, of the climate-weather change process transitions from the climate-weather state c_b into the climate-weather state c_l,
- the distributions of the climate-weather change conditional sojourn times C_{bl}, $b,l = 1,2,...,36$, $b \neq l$, at the particular climate-weather states and their mean values $M_{bl} = E[C_{bl}]$, $b,l = 1,2,...,36$, $b \neq l$.

To identify all these parameters of the climate-weather change process the statistical data about this process is needed.

The collected by the system operators statistical data necessary to evaluating the initial transient probabilities of the climate-weather change process at the particular states are:

- the climate-weather change process observation / experiment time Θ = 8 years (2007-2015),
- the number of the climate-weather change process realizations $n(0) = 226$,
- the vector of realizations of the numbers of the climate-weather change process staying at the particular climate-weather state c_b at the initial moment $t = 0$

$$[n_b(0)] = [9, 1, 0, 0, 0, 0, 0, 89, 13, 0, 0, 0, 0, 0, 144, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0].$$

The collected statistical data necessary to evaluating the probabilities of transitions of the climate-weather state change process $C(t)$ between the climate-weather states are:

- the matrix of realizations of the numbers of climate-weather change process transitions from the state c_b into the state c_l during the experiment time

$$[n_{bl}] = \begin{bmatrix}
0 & 2 & 0 & 0 & 0 & 0 & 8 & 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
5 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
15 & 9 & 0 & 0 & 0 & 0 & 0 & 0 & 35 & 0 & 0 & 0 & 0 & 60 & 21 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 46 & 0 & 0 & 0 & 0 & 0 & 0 & 42 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 16 & 1 & 0 & 0 & 0 & 0 & 0 & 16 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 20 & 131 & 0 & 0 & 0 & 0 & 1 & 0 & 8 & 0 & 0 & 0 & 0 & 48 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 3 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

- the vector of realizations of the total numbers of the climate-weather change process transitions from the climate-weather state c_b during the experiment time

$$[n_b] = [15, 7, 0, 0, 0, 0, 5, 140, 88, 0, 0, 0, 0, 33, 208, 6, 0, 0, 0, 0, 14, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0].$$

The statistical data for the conditional sojourn times C_{bl} at the climate-weather states c_b when the next climate-weather state is c_l, $b,l = 1,2,...,36, b \neq l$, are as follows:

- the realizations C_{12}: 1, 18;
- the realizations C_{17}: 10, 13, 5, 13, 20, 39, 35, 11;
- the realizations C_{18}: 1, 8, 6, 1, 6;
- the realizations C_{21}: 1, 1, 2, 2, 3;
- the realizations C_{28}: 2, 2;
- the realizations C_{71}: 1;
- the realizations C_{78}: 2, 2, 1, 1;
- the realizations C_{81}: 159, 142, 118, 94, 70, 46, 22, 14, 17, 21, 110, 94, 70, 46, 22;
- the realizations C_{82}: 34, 25, 39, 29, 5, 17, 9, 11, 8;
- the realizations C_{89}: 2, 70, 59, 35, 11, 17, 1, 3, 3, 11, 62, 51, 27, 3, 2, 24, 24, 10, 21, 1, 3, 6, 3, 2, 12, 3, 4, 1, 6, 1, 3, 10, 6, 1, 6;
- the realizations $C_{8\,14}$: 2, 41, 33, 9, 6, 11, 108, 106, 82, 58, 34, 10, 14, 1, 47, 36, 12, 15, 21, 12, 9, 5, 17, 90, 81, 57, 33, 9, 93, 83, 59, 35, 11, 45, 34, 10, 23, 45, 35, 11, 13, 20, 1, 8, 5, 38, 34, 10, 73, 58, 34, 44, 35, 11, 19, 18, 10, 1, 11, 13;
- the realizations $C_{8\,15}$: 5, 2, 3, 19, 22, 7, 19, 53, 33, 9, 14, 19, 16, 16, 9, 22, 88, 85, 61, 37, 13;
- the realizations C_{98}: 2, 1, 2, 1, 1, 1, 3, 3, 2, 2, 1, 1, 3, 2, 1, 8, 12, 1, 1, 2, 2, 2, 2, 1, 1, 2, 3, 3, 1, 4, 1, 3, 1, 2, 1, 1, 3, 2, 1, 3, 4, 2, 2, 8, 5, 4;
- the realizations $C_{9\,15}$: 1, 1, 3, 3, 1, 5, 6, 1, 1, 1, 1, 2, 4, 2, 11, 1, 1, 3, 7, 3, 1, 3, 2, 1, 1, 1, 2, 1, 1, 4, 1, 1, 1, 12, 6, 7, 5, 1, 5, 3, 3, 4;
- the realizations $C_{14\,8}$: 3, 4, 2, 1, 1, 3, 1, 1, 5, 2, 3, 2, 1, 4, 1, 1;
- the realizations $C_{14\,9}$: 2;
- the realizations $C_{14\,15}$: 2, 1, 2, 1, 1, 3, 3, 1, 1, 1, 4, 1, 2, 1, 2, 2;
- the realizations $C_{15\,8}$: 3, 17, 24, 6, 8, 95, 92, 68, 44, 20, 1, 1, 1, 133, 116, 92, 68, 5, 1, 6;
- the realizations $C_{15\,9}$: 166, 142, 118, 94, 70, 46, 22, 5, 9, 10, 34, 19, 6, 150, 141, 117, 136, 120, 96, 72, 48, 24, 1, 19, 103, 94, 70, 46, 22, 1, 64, 43, 19, 91, 72, 48, 24, 2, 10, 5, 8, 5, 5, 5, 6, 143, 138, 114, 90, 66, 42, 18, 2, 5, 2, 43, 42, 18, 4, 26, 6, 181, 164, 140, 116, 92, 68, 44, 20, 32, 19, 7, 61, 41, 17, 39, 28, 4, 13, 10, 83, 135, 123, 100, 75, 51, 28, 3, 14, 1, 50, 28, 4, 19, 1, 23, 13, 7, 9, 1, 7, 55, 38, 14, 32, 17, 107, 96, 72, 48, 24, 45, 2, 1, 36, 16, 3, 9, 55, 43, 19, 51, 27, 3, 44, 26, 2, 60, 51, 27, 3;
- the realizations $C_{15\,14}$: 1;
- the realizations $C_{15\,16}$: 63, 59, 35, 11, 2, 52, 42, 18;
- the realizations $C_{15\,21}$: 71, 59, 35, 11, 1, 27, 11, 2, 114, 105, 81, 57, 33, 9, 39, 34, 10, 133, 132, 108, 84, 60, 36, 12, 86, 82, 58, 34, 10, 30, 10, 50, 34, 10, 30, 11, 142, 130, 106, 82, 58, 34, 10, 1, 18, 220, 203, 179;
- the realizations $C_{16\,15}$: 1, 1, 1, 5;
- the realizations $C_{16\,22}$: 2, 1;
- the realizations $C_{21\,15}$: 2, 1, 1, 1, 3, 3, 2, 2, 1, 3, 1;
- the realizations $C_{21\,22}$: 2, 1, 3;
- the realizations $C_{22\,15}$: 1;
- the realizations $C_{22\,16}$: 2, 2, 1;
- the realizations $C_{22\,21}$: 1.

3.2. Evaluating basic parameters of climate-weather change process for port oil piping transportation system

On the basis of the statistical data from Section 3.1, it is possible to evaluate the following unknown basic parameters of the climate-weather change process:

- the vector

$$[q_b(0)] = [0.04, 0, 0, 0, 0, 0, 0, 0.35, 0.05, 0, 0, 0, 0, 0, 0.56, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],$$

of the initial probabilities $q_b(0)$, $b,l = 1,2,...,36$, of the climate-weather change process staying at the particular states c_b at the $t = 0$,

- the matrix

$$[q_{bl}] =$$

$$\begin{bmatrix}
0 & 0.13 & 0 & 0 & 0 & 0 & 0.53 & 0.34 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0.71 & 0 & 0 & 0 & 0 & 0 & 0 & 0.29 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0.20 & 0 & 0 & 0 & 0 & 0 & 0 & 0.80 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0.11 & 0.06 & 0 & 0 & 0 & 0 & 0 & 0 & 0.25 & 0 & 0 & 0 & 0 & 0.43 & 0.15 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.52 & 0 & 0 & 0 & 0 & 0 & 0 & 0.48 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.48 & 0.04 & 0 & 0 & 0 & 0 & 0 & 0.48 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.10 & 0.63 & 0 & 0 & 0 & 0 & 0 & 0 & 0.04 & 0 & 0 & 0 & 0 & 0.23 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.67 & 0 & 0 & 0 & 0 & 0 & 0 & 0.33 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0.21 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.20 & 0.60 & 0 & 0 & 0 & 0 & 0.20 & 0 & 0 & \cdots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix},$$

of the probabilities q_{bl}, $b,l = 1,2,...,36$, of transitions of the climate-weather change process from the climate-weather state c_b into the climate-weather state c_l.

3.3. Evaluating parameters of distributions of climate-weather change process for port oil piping transportation system

On the basis of the statistical data partly presented in Section 3.1 using the procedure and the formulae given in [13], it is possible to determine the empirical parameters of the conditional sojourn times of the climate-weather change process at the particular climate-weather states. To illustrate the application of this procedure and these formulae, we perform it for the conditional sojourn time C_{98}, and the results are:

- the realization $\bar{C}_{98}$ of the mean value of the conditional sojourn time C_{98} of the climate-weather change process at the climate-weather state c_9 when the next transition is to the climate-weather state c_8

$$\bar{C}_{98} = \frac{1}{46}\sum_{k=1}^{46} C_{98}^k = \frac{114}{46} \cong 2.48,$$

- the number $\bar{r}_{98}$ of the disjoint intervals $I_j =< a_{98}^j, b_{98}^j)$, $j = 1,2,...,\bar{r}_{98}$, that include the realizations C_{98}^k, $k = 1,2,...,46$, of the conditional sojourn times C_{98} at the climate-weather state c_9 when the next transition is to the climate-weather state c_8

$$\bar{r}_{98} \cong \sqrt{46} \cong 7,$$

- the length d_{98} of the intervals $I_j =< a_{98}^j, b_{98}^j)$, $j = 1,2,...,7$, that after considering

$$\bar{R}_{98} = \max_{1 \le k \le 46} C_{98}^k - \min_{1 \le k \le 46} C_{98}^k = 12 - 1 = 11$$

is

$$d_{98} = \frac{\bar{R}_{98}}{\bar{r}_{98} - 1} = \frac{11}{6} \cong 1.83,$$

- the ends a_{98}^j, b_{98}^j, of the intervals $I_j =< a_{98}^j, b_{98}^j)$, $j = 1,2,...,7$, that after considering

$$\min_{1 \le k \le 46} C_{98}^k - \frac{d_{98}}{2} = 1 - \frac{1.83}{2} \cong 0.09,$$

are

$$a_{98}^1 = \max\{0.09, 0\} = 0,$$
$$b_{98}^1 = a_{98}^1 + 1.83 = 0.09 + 1.83 = 1.92,$$
$$a_{98}^2 = b_{98}^1 = 1.92,$$
$$b_{98}^2 = a_{98}^1 + 2 \cdot 1.83 = 0.09 + 3.66 = 3.75,$$
$$a_{98}^3 = b_{98}^2 = 3.75,$$
$$b_{98}^3 = a_{98}^1 + 3 \cdot 1.83 = 0.09 + 45.49 = 5.58,$$
$$a_{98}^4 = b_{98}^3 = 5.58,$$
$$b_{98}^4 = a_{98}^1 + 4 \cdot 1.83 = 0.09 + 7.32 = 7.41,$$
$$a_{98}^5 = b_{98}^4 = 7.41,$$
$$b_{98}^5 = a_{98}^1 + 5 \cdot 1.83 = 0.09 + 9.15 = 9.24,$$
$$a_{98}^6 = b_{98}^5 = 9.24,$$
$$b_{98}^6 = a_{98}^1 + 6 \cdot 1.83 = 0.09 + 10.98 = 11.07,$$
$$a_{98}^7 = b_{98}^6 = 11.07,$$
$$b_{98}^7 = a_{98}^1 + 7 \cdot 1.83 = 0.09 + 12.81 = 12.90,$$

- the numbers n_{98}^j of the realizations C_{98}^k in particular intervals $I_j =< a_{98}^j, b_{98}^j)$, $j = 1,2,...,7$,

$$n_{98}^1 = 17,\ n_{98}^2 = 22,\ n_{98}^3 = 4,\ n_{98}^4 = 0,\ n_{98}^5 = 2,$$
$$n_{98}^6 = 0,\ n_{98}^7 = 1.$$

3.4. Identification of distribution functions of climate-weather change process for port oil piping transportation system

Using the procedure given in [4], [16] and the statistical data from Section 3.1 and the results from Section 3.3, we may verify the hypotheses on the distributions of the climate-weather change process conditional sojourn times C_{bl}, $b,l = 1,2,...,36, b \neq l$, at the particular states. To do this, we need a sufficient number of realizations of these variables [2], [8], [21], [23]-[24], namely, the sets of their realizations should contain at least 30 realizations coming from the experiment. This condition is not satisfied for the statistical data we have in disposal and that are presented in Section 3.1. However, to make the procedure familiar to the reader, we perform it for the conditional sojourn time C_{98} having sufficiently numerous set of realizations and preliminarily analyzed in Section 3.3.

The realization $\bar{c}_{98}(t)$ of the histogram of the climate-weather change process conditional sojourn time C_{98}, is presented in *Table 1* and illustrated in *Figure 1*

Table 1. The realization of the histogram of the climate-weather change process conditional sojourn time C_{98}

Histogram of the conditional sojourn time C_{98}							
$I_j = \langle a_{98}^j, b_{98}^j)$	0.09 – 1.92	1.92 – 3.75	3.75 – 5.58	5.58 – 7.41	7.41 – 9.24	9.24 – 11.07	11.07 – 12.90
n_{98}^j	17	22	4	0	2	0	1
$\bar{h}_{98}(t) = n_{98}^j / n_{98}$	17/46	22/46	4/46	0/46	2/46	0/46	1/46

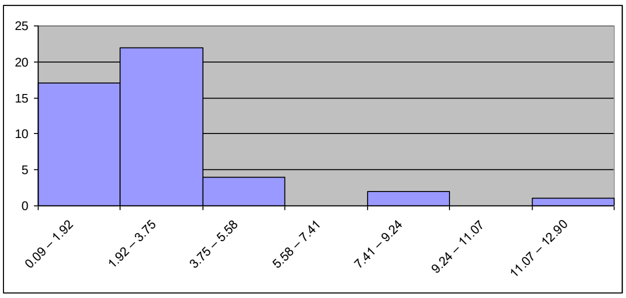

Figure 1. The graph of the histogram of the climate-weather change process conditional sojourn time C_{98}

After analyzing and comparing the realization $\bar{c}_{98}(t)$ of the histogram with the graphs of the density functions $c_{bl}(t)$ of the previously distinguished in [3] distributions, we formulate the null hypothesis H_0 in the following form:

H_0: The climate-weather change process conditional sojourn time C_{98} at the climate-weather state c_9 when the next transition is to the climate-weather state c_8, has the chimney distribution with the density function defined by (4.7) in [3] of the form

$$c_{98}(t) = \begin{cases} 0, & t < x_{98} \\ \dfrac{A_{98}}{z_{98}^1 - x_{98}}, & x_{98} \le t \le z_{98}^1 \\ \dfrac{K_{98}}{z_{98}^2 - z_{98}^1}, & z_{98}^1 \le t \le z_{98}^2 \\ \dfrac{D_{98}}{y_{98} - z_{98}^2}, & z_{98}^2 \le t \le y_{98} \\ 0, & t > y_{98}. \end{cases} \qquad (8)$$

We join the intervals defined in the realization of the histogram $\bar{h}_{98}(t)$ that have the numbers n_{98}^j, of realizations less than 4 into new intervals and we perform the following steps:

- we fix the new number of intervals $\bar{\bar{r}}_{98} = 3$,
- we determine the new intervals and we fix the numbers of realizations in the new intervals

Table 2. The numbers of the conditional sojourn time C_{98} realizations in the intervals $\bar{I}_j$

$\bar{I}_j = \langle \bar{a}_{98}^j, \bar{b}_{98}^j)$	0.09 – 1.92	1.92 – 3.75	3.75 – 12.90
$\bar{n}_{98}^j$	17	22	7

We estimate the unknown parameters of the density function of the hypothetical chimney distribution using formulae (2.15) - (2.32) in [4] we obtain the following results

$$x_{98} = \bar{a}_{98}^1 = 0.09, \quad y_{98} = x_{98} + \bar{r}_{98} \cdot d_{98} = 12.90,$$

$i = 2$ is the number of the interval including the largest number of realizations i.e. such as that

$$\bar{n}_{98}^2 = \max_{1 \le j \le \bar{r}_{98}} \{\bar{n}_{98}^j\} = 22,$$

$$\bar{n}_{98}^1 = 17 \neq 0, \quad \frac{\bar{n}_{98}^2}{\bar{n}_{98}^1} = \frac{22}{17} < 3 \quad \text{and} \quad \frac{\bar{n}_{98}^2}{\bar{n}_{98}^3} = \frac{22}{7} \ge 3,$$

so

$$z_{98}^1 = x_{98} + (i-2)d_{98} = 0.09,$$

$$z_{98}^2 = x_{98} + i d_{98} = 3.75, \quad A_{98} = \frac{0}{n_{98}} = 0,$$

$$K_{89} = \frac{\bar{n}_{98}^{i-1} + \bar{n}_{98}^{i}}{n_{98}} = 0.85, \quad D_{98} = \frac{\bar{n}_{98}^{i+1}}{n_{98}} = 0.15.$$

- we calculate the hypothetical probabilities that the variable C_{98} takes values from the new intervals

$$p_1 = P(C_{98} \in \bar{I}_1) = P(0.09 \le C_{98} < 1.92)$$
$$= C_{98}(1.92) - C_{98}(0.09) = 0.43 - 0 = 0.43,$$
$$p_2 = P(C_{98} \in \bar{I}_2) = P(1.92 \le C_{98} < 3.75)$$
$$= C_{98}(3.75) - C_{98}(1.92) = 0.86 - 0.43 = 0.43,$$
$$p_3 = P(C_{98} \in \bar{I}_3) = P(3.75 \le C_{98} < 12.90)$$
$$= C_{98}(12.90) - C_{98}(3.75) = 1 - 0.86 = 0.14,$$

- we calculate the realization of the χ^2 (chi-square)-Pearson's statistics

$$u_{98} = \sum_{j=1}^{3} \frac{(\bar{n}_{98}^j - n_{98} \cdot p_j)^2}{n_{98} \cdot p_j} = \frac{(17 - 46 \cdot 0.43)^2}{46 \cdot 0.43}$$
$$+ \frac{(22 - 46 \cdot 0.43)^2}{46 \cdot 0.43} + \frac{(7 - 46 \cdot 0.14)^2}{46 \cdot 0.14}$$
$$\cong 0.3907 + 0.2492 + 0.0487 = 0.6886 \cong 0.69,$$

- we assume the significance level $\alpha = 0.05$,
- we fix the number of degrees of freedom

$$\bar{\bar{r}}_{98} - l - 1 = 3 - 0 - 1 = 2,$$

- we read from the tables of the χ^2 – Pearson's distribution the value u_α for the fixed values of the significance level $\alpha = 0.05$ and the number of degrees of freedom $\bar{\bar{r}}_{98} - l - 1 = 2$, such that, according to (2.48), the following equality holds

$$P(U_{98} > u_\alpha) = \alpha = 0.05$$

that amounts $u_\alpha = 5.99$ and we determine the critical domain in the form of the interval $(5.99, +\infty)$ and the acceptance domain in the form of the interval $< 0, 5.99 >$.
- we compare the obtained value $u_{98} = 0.69$ of the realization of the statistics U_{98} with the read from the tables critical value $u_\alpha = 5.99$ of the chi-square random variable and since the value $u_{98} = 0.69$ does not belong to the critical domain, i.e.

$$u_{98} = 0.69 \le u_\alpha = 5.99,$$

then we do not reject the hypothesis H_0, that the sojourn time C_{98} has the chimney distribution with the density function given by (8).

For the remaining cases, when the realizations of conditional sojourn times C_{bl}, $b,l = 1,2,...,36$, $b \ne l$, at the particular climate-weather states are more than 30, proceeding afterwards in an analogous way as in the case of the conditional sojourn time C_{98}, we can get the following results:

- the climate-weather change process conditional sojourn time C_{89} has the exponential distribution with the density function defined by (4.5) in [3] of the form

$$c_{89}(t) = \begin{cases} 0, & t < x_{89} \\ \alpha_{89} \exp[-\alpha_{89}(t - x_{89})], & t \ge x_{89}, \end{cases}$$

with the parameters

$$x_{89} = a_{89}^1 = 0,$$
$$\alpha_{89} = \frac{1}{\bar{C}_{89} - x_{89}} = \frac{1}{14.40 - 0} \cong 0.0694.$$

- the climate-weather change process conditional sojourn time $C_{8\,14}$ has the exponential distribution with the density function defined by (4.5) in [3] of the form

$$c_{8\,14}(t) = \begin{cases} 0, & t < x_{8\,14} \\ \alpha_{8\,14} \exp[-\alpha_{8\,14}(t - x_{8\,14})], & t \ge x_{8\,14}, \end{cases}$$

with the parameters

$$x_{8\,14} = a_{8\,14}^1 = 0,$$
$$\alpha_{8\,14} = \frac{1}{\bar{C}_{8\,14} - x_{8\,14}} = \frac{1}{31.65 - 0} \cong 0.0316.$$

- the climate-weather change process conditional sojourn time $C_{9\,15}$ has the exponential distribution with the density function defined by (4.5) in [3] of the form

$$c_{9\,15}(t) = \begin{cases} 0, & t < x_{9\,15} \\ \alpha_{9\,15} \exp[-\alpha_{9\,15}(t - x_{9\,15})], & t \ge x_{9\,15}, \end{cases}$$

with the parameters

$$x_{9\,15} = a_{9\,15}^1 = 0,$$
$$\alpha_{9\,15} = \frac{1}{\bar{C}_{9\,15} - x_{9\,15}} = \frac{1}{2.95 - 0} \cong 0.3390.$$

- the climate-weather change process conditional sojourn time $C_{15\,9}$ has the exponential distribution with the density function defined by (4.5) in [3] of the form

$$c_{15\,9}(t)=\begin{cases}0, & t<x_{15\,9}\\ \alpha_{15\,9}\exp[-\alpha_{15\,9}(t-x_{15\,9})], & t\ge x_{15\,9},\end{cases}$$

with the parameters

$$x_{15\,9}=a^1_{15\,9}=0,$$

$$\alpha_{15\,9}=\frac{1}{\bar{C}_{15\,9}-x_{15\,9}}=\frac{1}{46.29-0}\cong 0.0216.$$

- the climate-weather change process conditional sojourn time $C_{15\,21}$ has the exponential distribution with the density function defined by (4.5) in [3] of the form

$$c_{15\,21}(t)=\begin{cases}0, & t<x_{15\,21}\\ \alpha_{15\,21}\exp[-\alpha_{15\,21}(t-x_{15\,21})], & t\ge x_{15\,21},\end{cases}$$

with the parameters

$$x_{15\,21}=a^1_{15\,21}=0,$$

$$\alpha_{15\,21}=\frac{1}{\bar{C}_{15\,21}-x_{15\,21}}=\frac{1}{60.25-0}\cong 0.0166.$$

For the distributions identified in this section, by application either the general formulae for the mean value given by (2.12) or the particular formulae (2.13)-(2.19) in [16], the mean values $M_{bl}=E[\theta_{bl}]$, b,l = 1,2,...,36, $b\neq l$, of the port oil piping transportation climate-weather change process conditional sojourn times at the particular climate-weather states can be determined and they amount:

$M_{89}\cong 14.41$, $M_{8\,14}\cong 31.65$, $M_{98}\cong 2.88$.
$M_{9\,15}\cong 2.95$, $M_{15\,9}\cong 46.30$, $M_{15\,21}\cong 60.24$.

Because of the lack of sufficient numbers of realizations of the climate-weather change process conditional sojourn times at the climate-weather states, it is not possible to identify statistically their distributions. In those cases of not identified distributions it is possible to find the approximate empirical values of the mean values $M_{bl}=E[C_{bl}]$ of the conditional sojourn times at the particular climate-weather states that are as follows:

$M_{12}=9.50$, $M_{17}=18.25$, $M_{18}=4.40$, $M_{21}=1.80$,
$M_{28}=2.00$, $M_{71}=1.00$, $M_{78}=1.50$, $M_{81}\cong 69.67$,
$M_{82}\cong 19.67$, $M_{8\,15}\cong 26.29$, $M_{14\,8}\cong 2.19$,
$M_{14\,9}=2.00$, $M_{14\,15}=1.75$, $M_{15\,8}=40.05$,
$M_{15\,14}=1.00$, $M_{15\,16}=35.25$, $M_{16\,15}=2.00$,
$M_{16\,22}=1.50$, $M_{21\,15}=1.82$, $M_{21\,22}=2.00$,
$M_{22\,15}=1.00$, $M_{22\,16}\cong 1.67$, $M_{22\,21}=1.00$.

As there are no realizations for the rest conditional sojourn times at the climate-weather states of the port oil piping transportation climate-weather change process, it is impossible to estimate their empirical conditional mean values.

4. Conclusions

The proposed statistical methods of identification of the unknown parameters of the climate-weather change processes allow us for the identification of the models discussed in [6] and next their practical applications in evaluation, prediction and optimization of reliability, availability and safety of real complex critical infrastructures.

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