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Identification and prediction of climate-weather change process for port oil piping transportation system operating area

Keywords

climate-weather change process, identification, prediction, piping operating area, extreme weather hazards

Abstract

The paper is concerned with an application of the climate-weather change process for a critical infrastructure operating area model to identification and prediction of this process for the port oil piping transportation system operating area. For the considered piping operating area, there are distinguished three different climate-weather change processes and their states. Further, there are identified the unknown parameters of those processes, i.e. the probabilities of the climate-weather change processes staying at the initial climate-weather states, the probabilities of the climate-weather change transitions between the climate-weather states and the mean values of the climate-weather change processes' conditional sojourn times at particular states. Finally, there are predicted the main characteristics of the climate-weather change processes at the distinguished operating area.

1. Introduction

The climate-weather change process for the port oil piping transportation system operating area is modelled in [1], [4]. In this paper, the identification of the piping climate-weather change process at its operating area is performed. To do this, we can apply the procedures of the climate-weather change process identification given in [3], [7]. This way, having this process identified, the prediction of the climate-weather change process characteristics is performed.

2. Climate-weather change process at port oil piping transportation system operating area identification

The climate-weather data from 3 different measurements points (initial, middle east and middle west point) after successful uniformity testing [10]-[11] are joined and analyzed together. Thus, there are considered three different climate-weather change processes:

- the climate-weather change process $C^1(t)$ for the piping under water Baltic sea operating area with data coming from initial, middle east, middle west measurement points,
- the climate-weather change process $C^2(t)$ for the piping under water Baltic sea operating area with data coming from end measurement point,
- the climate-weather change process $C^3(t)$ for the piping land Baltic seaside operating area with data coming from land measurement point.

To identify the unknown parameters of the above processes the suitable statistical data should be collected [2]. The statistical identification of the climate-weather change processes was performed according to [3], [11]: the climate-weather states were distinguished and the following unknown basic parameters of the climate-weather processes, i.e. the vectors of probabilities of the climate-weather processes staying at the initial climate-weather states, the matrices of probabilities of the climate-weather processes transitions between the climate-weather states and the matrices of the mean values of the conditional sojourn times at particular states of the climate-weather processes were evaluated.

2.1. States of climate-weather change process for piping operating area

Taking into account expert opinions on the climate-weather change processes for the piping operating area, we distinguish the following climate-weather states in particular areas [4], [6]:

<u>Climate-weather change process states for piping under water Baltic Sea operating area</u>

- the climate-weather state c_1 – the wave height from 0 up to 2 m and the wind speed from 0 m/s up to 17 m/s;
- the climate-weather state c_2 – the wave height from 2 m up to 5 m and the wind speed from 0 m/s up to 17 m/s;
- the climate-weather state c_3 – the wave height from 5 m up to 14 m and the wind speed from 0 m/s up to 17 m/s;
- the climate-weather state c_4 – the wave height from 0 up to 2 m and the wind speed from 17 m/s up to 33 m/s;
- the climate-weather state c_5 – the wave height from 2 m up to 5 m and the wind speed from 17 m/s up to 33 m/s;
- the climate-weather state c_6 – the wave height from 5 m up to 14 m and the wind speed from 17 m/s up to 33 m/s.

<u>Climate-weather change process states for piping land Baltic seaside operating area</u>

- the climate-weather state c_1 – the air temperature from -25°C up to -15°C and the soil temperature from -30°C up to -5°C;
- the climate-weather state c_2 – the air temperature from -15°C up to 5°C and the soil temperature from -30°C up to -5°C;
- the climate-weather state c_3 – the air temperature from 5°C up to 25°C and the soil temperature from -30°C up to -5°C;
- the climate-weather state c_4 – the air temperature from 25°C up to 35°C and the soil temperature from -30°C up to -5°C;
- the climate-weather state c_5 – the air temperature from -25°C up to -15°C and the soil temperature from -5°C up to 5°C;
- the climate-weather state c_6 – the air temperature from -15°C up to 5°C and the soil temperature from -5°C up to 5°C;
- the climate-weather state c_7 – the air temperature from 5°C up to 25°C and the soil temperature from -5°C up to 5°C;
- the climate-weather state c_8 – the air temperature from 25°C up to 35°C and the soil temperature from -5°C up to 5°C;
- the climate-weather state c_9 – the air temperature from -25°C up to -15°C and the soil temperature from 5°C up to 20°C;
- the climate-weather state c_{10} – the air temperature from -15°C up to 5°C and the soil temperature from 5°C up to 20°C;
- the climate-weather state c_{11} – the air temperature from 5°C up to 25°C and the soil temperature from 5°C up to 20°C;
- the climate-weather state c_{12} – the air temperature from 25°C up to 35°C and the soil temperature from 5°C up to 20°C;
- the climate-weather state c_{13} – the air temperature from -25°C up to -15°C and the soil temperature from 20°C up to 37°C;
- the climate-weather state c_{14} – the air temperature from -15°C up to 5°C and the soil temperature from 20°C up to 37°C;
- the climate-weather state c_{15} – the air temperature from 5°C up to 25°C and the soil temperature from 20°C up to 37°C;
- the climate-weather state c_{16} – the air temperature from 25°C up to 35°C and the soil temperature from 20°C up to 37°C.

Moreover, the considered climate-weather states have following categories of the extreme weather hazard state [6]:

<u>Climate-weather change process states for piping under water Baltic Sea operating area</u>

- the 2nd category extreme weather hazard states of the climate-weather change process are c_1, c_4, c_{13}, c_{16},
- the 1st category extreme weather hazard states of the climate-weather change process are c_2, c_3, c_5, c_8, c_9, c_{12}, c_{14}, c_{15},
- the 0os category extreme weather hazard state of the climate-weather change process is c_6, c_7, c_{10}, c_{11};

<u>Climate-weather change process states for piping land Baltic seaside operating area</u>

- the 2nd category extreme weather hazard states of the climate-weather change process are c_1, c_4, c_{13}, c_{16},
- the 1st category extreme weather hazard states of the climate-weather change process are c_2, c_3, c_5, c_8, c_9, c_{12}, c_{14}, c_{15},
- the 0os category extreme weather hazard state of the climate-weather change process is c_6, c_7, c_{10}, c_{11}.

2.2. Parameters of climate-weather change process for piping operating area

<u>Climate-weather change process for piping under water Baltic Sea operating area - data coming from initial, middle east, middle west measurement points</u>

On the basis of the statistical data [2], it is possible to evaluate the following unknown basic parameters of the climate-weather change process $C^1(t)$ [6], [11]:
- the vector

$$[q_b(0)] = [0.718, 0.225, 0.004, 0, 0.035, 0.018] \quad (1)$$

of the initial probabilities $q_b(0)$, $b = 1,2,\ldots,6$, of the climate-weather change process $C^1(t)$ staying at the particular states c_b at the initial moment $t = 0$,
- the matrix

$$[q_{bl}] = \begin{bmatrix} 0 & 0.99 & 0 & 0 & 0.01 & 0 \\ 0.83 & 0 & 0 & 0 & 0.17 & 0 \\ 0 & 0.82 & 0 & 0 & 0 & 0.18 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0.02 & 0.66 & 0.08 & 0 & 0 & 0.24 \\ 0 & 0.10 & 0.70 & 0 & 0.20 & 0 \end{bmatrix}, \quad (2)$$

of the probabilities q_{bl}, $b,l = 1,2,\ldots,6$, of transitions of the climate-weather change process $C^1(t)$ from the climate-weather state c_b into the climate-weather state c_l.
- the matrix

$$[N_{bl}] = \begin{bmatrix} 0 & 255.35 & 0 & 0 & 12.87 & 0 \\ 21.51 & 0 & 0 & 0 & 3.00 & 0 \\ 0 & 3.67 & 0 & 0 & 0 & 6.00 \\ 0 & 0 & 0 & 0 & 3.00 & 0 \\ 3.00 & 10.72 & 6.00 & 0 & 0 & 10.00 \\ 0 & 6.00 & 14.57 & 0 & 7.50 & 0 \end{bmatrix} \quad (3)$$

of the mean values N_{bl}, $b,l = 1,2,\ldots,6$, of the conditional sojourn times $C^1{}_{bl}$, $b,l = 1,2,\ldots,6$, of the climate-weather change process $C^1(t)$ at the climate-weather state c_b when the next climate-weather state is c_l.

<u>Climate-weather change process for piping under water Baltic Sea operating area - data coming from end measurement point</u>

On the basis of the statistical data [2], it is possible to evaluate the following unknown basic parameters of the climate-weather change process $C^2(t)$ [4], [6]:
- the vector

$$[q_b(0)] = [0.947, 0.006, 0, 0.035, 0.012, 0] \quad (4)$$

of the initial probabilities $q_b(0)$, $b = 1,2,\ldots,6$, of the climate-weather change process $C^2(t)$ staying at the particular states c_b at the initial moment $t = 0$,
- the matrix

$$[q_{bl}] = \begin{bmatrix} 0 & 0.34 & 0 & 0.57 & 0.09 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0.59 & 0.05 & 0 & 0 & 0.36 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, \quad (5)$$

of the probabilities q_{bl}, $b,l = 1,2,\ldots,6$, of transitions of the climate-weather change process $C^2(t)$ from the climate-weather state c_b into the climate-weather state c_l.
- the matrix

$$[N_{bl}] = \begin{bmatrix} 0 & 270.27 & 0 & 230.85 & 159.00 & 0 \\ 4.33 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 5.77 & 3.00 & 0 & 0 & 4.50 & 0 \\ 0 & 0 & 0 & 6.82 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (6)$$

of the mean values N_{bl}, $b,l = 1,2,\ldots,6$, of the conditional sojourn times $C^2{}_{bl}$, $b,l = 1,2,\ldots,6$, of the climate-weather change process $C^2(t)$ at the climate-weather state c_b when the next climate-weather state is c_l.

<u>Climate-weather change process for piping land Baltic seaside operating area - data coming from land measurement point</u>

On the basis of the statistical data [2], it is possible to evaluate the following unknown basic parameters of the climate-weather change process $C^3(t)$ [4], [6]:
- the vector

$$[q_b(0)] = [0.012, 0.118, 0, 0, 0, 0.784, 0.035, 0, 0, 0, 0.051, 0, 0, 0, 0, 0] \quad (7)$$

of the initial probabilities $q_b(0)$, $b = 1,2,\ldots,16$, of the climate-weather change process $C^3(t)$ staying at the particular states c_b at the initial moment $t = 0$,
- the matrix $[q_{bl}]$ of the probabilities q_{bl}, $b, l = 1,2,\ldots,16$, of transitions of the climate-weather change process $C^3(t)$ from the climate-weather state c_b into the climate-weather state c_l and the matrix $[N_{bl}]$ of the mean values N_{bl}, $b,l = 1,2,\ldots,16$, of the conditional sojourn times $C^3{}_{bl}$, $b,l = 1,2,\ldots,16$, of the climate-weather change process $C^3(t)$ at the climate-weather state c_b when the next climate-weather state is c_l:

$$[q_{bl}]_{16x16} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0.10 & 0 & 0 & 0 & 0 & 0.90 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0.18 & 0 & 0 & 0 & 0 & 0.22 & 0 & 0 & 0.47 & 0.13 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.72 & 0 & 0 & 0 & 0 & 0.28 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.55 & 0.02 & 0 & 0 & 0 & 0.43 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.20 & 0.69 & 0 & 0 & 0.11 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, \quad (8)$$

$$[N_{bl}]_{16x16} = \begin{bmatrix} 0 & 3.57 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 19.57 & 0 & 0 & 0 & 0 & 18.94 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 64.12 & 0 & 0 & 0 & 0 & 57.87 & 0 & 0 & 119.70 & 44.78 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 6.50 & 0 & 0 & 0 & 0 & 2.00 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 2.33 & 4.00 & 0 & 0 & 0 & 1.86 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 3.81 & 12.63 & 0 & 0 & 3.11 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}. \quad (9)$$

3. Climate-weather change process for port oil piping transportation system operating area prediction characteristics

The climate-weather change processes for the piping operating area are defined in [4], [6] and [10]-[11]. Considering these results and assuming that we have identified the unknown parameters of the climate-weather change processes for the piping operating area, we can predict basic characteristics of those processes.

3.1. Transient probabilities of climate-weather change process for piping operating area

Climate-weather change process for piping under water Baltic Sea operating area - data coming from initial, middle east, middle west measurement points

The limit values of the climate-weather change process $C^1(t)$ for the considered measurement points of the piping under water Baltic sea operating area transient probabilities $q_b(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, are given in the vector [6], [11]:

$$[q_b] \cong [0.901, 0.087, 0.001, 0, 0.008, 0.003]; \quad (10)$$

Climate-weather change process for piping under water Baltic Sea operating area - data coming from end measurement point

The limit values of the climate-weather change process $C^2(t)$ for the considered measurement point of the piping operating under water Baltic sea area transient probabilities $q_b(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, are given in the vector [4], [6]:

$$[q_b] \cong [0.959, 0.007, 0, 0.021, 0.013, 0]; \quad (11)$$

Climate-weather change process for piping land Baltic seaside operating area - data coming from land measurement point

The limit values of the climate-weather change process $C^3(t)$ for the considered measurement point of the piping land Baltic seaside operating area transient probabilities $q_b(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,16$, are given in the vector [4], [6]:

$$[q_b] \cong [0.001, 0.038, 0, 0, 0, 0.868, 0.031, 0, 0, 0.011, 0.051, 0, 0, 0, 0, 0]. \quad (12)$$

3.2. Total sojourn times of climate-weather change process for piping operating area

Climate-weather change process for piping under water Baltic Sea operating area - data coming from initial, middle east, middle west measurement points

The expected values of the total sojourn times $\hat{C}_b^1$, $b = 1,2,\ldots,6$, of the climate-weather change process $C^1(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, during the fixed operation time $C^1 = 1$ month (February) = 29 days, are given in the vector (its coordinates are measured in days) [6], [11]:

$$[\hat{N}_b^1] = [E[\hat{C}_b^1]] \cong [26.13, 2.52, 0.03, 0, 0.23, 0.09]; \quad (13)$$

Climate-weather change process for piping under water Baltic Sea operating area - data coming from end measurement point

The expected values of the total sojourn times $\hat{C}_b^2$, $b = 1,2,\ldots,6$, of the climate-weather change process $C^2(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, during the fixed operation time $C^2 = 1$ month (February) = 29 days, are given in the vector (its coordinates are measured in days) [4], [6]:

$$[\hat{N}_b^2] = [E[\hat{C}_b^2]] \cong [27.81, 0.20, 0, 0.61, 0.38, 0]; \quad (14)$$

Climate-weather change process for land piping Baltic seaside operating area - data coming from land measurement point

The expected values of the total sojourn times $\hat{C}_b^3$, $b = 1,2,\ldots,16$, of the climate-weather change process $C^3(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,16$, during the fixed operation time $C^3 = 1$ month (February) = 29 days, are given in the vector (its coordinates are measured in days) [4], [6]:

$$[\hat{N}_b^3] = [E[\hat{C}_b^3]] \cong [0.03, 1.1, 0, 0, 0, 25.14, 0.9, 0, 0, 0.32, 1.51, 0, 0, 0, 0, 0]. \quad (15)$$

4. Conclusions

The probabilistic model of the climate-weather change process for a critical infrastructure operating area presented in [4], [6] was applied to identify and predict the climate-weather change process at piping port operating area. The obtained results justify practical sensibility and very high importance of considering the climate-weather change process at critical infrastructure different operating areas. Especially, this considering is important in the investigation of the climate weather change process influence on the critical infrastructure safety as it could be different at various operating areas [9].

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References

[1] EU-CIRCLE Report D2.1-GMU3. (2016). *Modelling Climate-Weather Change Process Including Extreme Weather Hazards.*

[2] EU-CIRCLE Report D2.2-GMU5. (2016). *Climate Change Related Data Collection for the Port Oil Piping Transportation and the Maritime Ferry Operating at the Baltic Sea Area.*

[3] EU-CIRCLE Report D2.3-GMU2. (2016). *Identification Methods and Procedures of Climate-Weather Change Process Including Extreme Weather Hazards.*

[4] EU-CIRCLE Report D3.3-GMU3-C-WCP. (2016). *Critical Infrastructure Operating Area Climate-Weather Change Process (C-WCP) Including Extreme Weather Hazards (EWH) C-WCP Model*.

[5] EU-CIRCLE Report D6.4-GMU1. (2017). *Critical Infrastructure Operation Process General Model (CIOPGM) Application to Port Piping Transportation System Operation Process Related to Operating Environment Threats (OET) and Extreme Weather Hazards (EWH)*.

[6] Kołowrocki, K., Soszyńska-Budny, J. & Torbicki, M. (2017). Critical infrastructure operating area climate-weather change process including extreme weather hazards, *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association* 8, 2, 15-24.

[7] Kołowrocki, K. & Soszyńska-Budny, J. (2017). Identification methods and procedures of climate-weather change process including extreme weather hazards, *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association* 8, 2, 85-95.

[8] Kołowrocki, K. & Soszyńska-Budny, J. (2017). Integrated impact model on critical infrastructure safety related to climate-weather change process including extreme weather hazards, *Summer Safety & Reliability Seminars. Journal of Polish Safety and Reliability Association* 8, 4, 21-32.

[9] Kołowrocki, K. Soszyńska-Budny, J. & Torbicki, M. Critical infrastructure integrated safety model related to climate-weather change process application to port oil piping transportation system operating at land Baltic seaside area. *27th ESREL Conference Proceedings*, European Safety and Reliability Conference 2017, Portoroz, Slovenia, 2017, *to appear*.

[10] Kuligowska, E. & Torbicki, M. Climate-weather change process realizations uniformity testing for port oil piping transportation system operating area. *17th ASMDA Conference Proceedings*, Applied Stochastic Models and Data Analysis 2017, London, United Kingdom, 2017, *to appear*.

[11] Kuligowska, E. & Torbicki, M. Identification and prediction of climate-weather change processes for port oil piping transportation system and maritime ferry operation areas after their realisations successful uniformity testing. *17th ASMDA Conference Proceedings*, Applied Stochastic Models and Data Analysis 2017, London, United Kingdom, 2017, *to appear*.