Kuligowska Ewa
Gdynia Maritime University, Gdynia, Poland

Identification and prediction of climate-weather change process for maritime ferry operating area

Keywords

climate-weather change process, identification, prediction, maritime ferry operating area

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 maritime ferry operating area. For the considered ferry operating area, there are distinguished four 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 maritime ferry operating area is modelled in [1], [4]. In this paper, the identification of the ferry 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], [6]-[7]. This way, having this process identified, the prediction of the climate-weather change process characteristics is performed.

2. Climate-weather change process at maritime ferry operating area identification

Climate-weather data from 4 different measurements points (1353, 1389, 1422 and 1458 point) after successful uniformity testing [10]-[11] are joined and analyzed together. Thus, there are considered four different climate-weather change processes:

- the climate-weather change process $C^1(t)$ for the maritime ferry Gdynia Port operating area with data coming from the first measurement point,
- the climate-weather change process $C^2(t)$ for the maritime ferry Restricted Waters operating area with data coming from second measurement point,
- the climate-weather change process $C^3(t)$ for the maritime ferry Open Waters operating area with data coming from 1353, 1389, 1422 and 1458 measurement points,
- the climate-weather change process $C^4(t)$ for the maritime ferry Karlskrona Port operating area with data coming from the last measurement point.

To identify the unknown parameters of the above processes the suitable statistical data coming from their real realizations 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, 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 maritime ferry operating area

Taking into account expert opinions on the climate-weather change processes for the maritime ferry operating area, we distinguish the following climate-weather states in particular areas [5]:

Climate-weather change process states for maritime ferry Gdynia port operating area

- the climate-weather state c_1 – the wind speed from 0 m up to 17 m and the wind direction from 0° up to 22.5° or from 67.5° up to 112.5° or from 337.5° up to 360°;
- the climate-weather state c_2 – the wind speed from 17 m up to 33 m and the wind direction from 0° up to 22.5° or from 67.5° up to 112.5° or from 337.5° up to 360°;
- the climate-weather state c_3 – the wind speed from 0 m up to 17 m and the wind direction from 22.5° up to 67.5° or from 112.5° up to 247.5°;
- the climate-weather state c_4 – the wind speed from 17 m up to 33 m and the wind direction from 22.5° up to 67.5° or from 112.5° up to 247.5°;
- the climate-weather state c_5 – the wind speed from 0 m up to 17 m and the wind direction from 247.5° up to 337.5°;
- the climate-weather state c_6 – the wind speed from 17 m up to 33 m and the wind direction from 247.5° up to 337.5°;

Climate-weather change process states for maritime ferry restricted waters operating area

- the climate-weather state c_1 – the wave height from 0 m 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 m up to 2 m and the wind speed from 17 m/s 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 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 to 33 m/s;

Climate-weather change process states for maritime ferry Baltic Sea open waters operating area

- the climate-weather state c_1 – the wave height from 0 m 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 m up to 2 m and the wind speed from 17 m/s 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 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 to 33 m/s;

Climate-weather change process states for maritime ferry Karlskrona port operating area

- the climate-weather state c_1 – the wind speed from 0 m up to 17 m and the wind direction from 0° up to 67.5° or from 292.5° up to 360°;
- the climate-weather state c_2 – the wind speed from 17 m up to 33 m and the wind direction from 0° up to 67.5° or from 292.5° up to 360°;
- the climate-weather state c_3 – the wind speed from 0 m up to 17 m and the wind direction from 67.5° up to 157.5°;
- the climate-weather state c_4 – the wind speed from 17 m up to 33 m and the wind direction from 67.5° up to 157.5°;
- the climate-weather state c_5 – the wind speed from 0 m up to 17 m and the wind direction from 157.5° up to 292.5°;
- the climate-weather state c_6 – the wind speed from 17 m up to 33 m and the wind direction from 157.5° up to 292.5°.

Moreover, the considered climate-weather states have following categories of the extreme weather hazard state [4]-[5]:

Climate-weather change process states for maritime ferry Gdynia port operating area

- the 2nd category extreme weather hazard states of the climate-weather change process are c_2, c_6,
- the 1st category extreme weather hazard states of the climate-weather change process are c_1, c_4, c_5,
- the 0os category extreme weather hazard state of the climate-weather change process is c_3;

Climate-weather change process states for maritime ferry restricted waters operating area

- the 2nd category extreme weather hazard state of the climate-weather change process is c_6,
- the 1st category extreme weather hazard states of the climate-weather change process are c_3, c_4, c_5,
- the 0os category extreme weather hazard states of the climate-weather change process are c_1, c_2;

Climate-weather change process states for maritime ferry Baltic Sea open waters operating area

- the 2nd category extreme weather hazard state of the climate-weather change process is c_6,
- the 1st category extreme weather hazard states of the climate-weather change process are c_3, c_4, c_5,
- the 0os category extreme weather hazard states of the climate-weather change process are c_1, c_2;

Climate-weather change process states for maritime ferry Karlskrona port operating area

- the 2nd category extreme weather hazard state of the climate-weather change process is c_4,
- the 1st category extreme weather hazard states of the climate-weather change process are c_2, c_3, c_6,
- the 0os category extreme weather hazard states of the climate-weather change process are c_1, c_5.

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

Climate-weather change process for maritime ferry Gdynia port operating area - data coming from first measurement point

On the basis of the statistical data [2], it is possible to evaluate the following unknown basic parameters of the climate-weather change process $C^1(t)$ [5], [10]-[11]:
- the vector

$$[q_b(0)] = [0.447, 0.029, 0.424, 0.018, 0.082, 0], \quad (1)$$

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

$$[q_{bl}] = \begin{bmatrix} 0 & 0.05 & 0.89 & 0.01 & 0.05 & 0 \\ 0.93 & 0 & 0 & 0.07 & 0 & 0 \\ 0.84 & 0 & 0 & 0.04 & 0.12 & 0 \\ 0.22 & 0.45 & 0.33 & 0 & 0 & 0 \\ 0.33 & 0 & 0.67 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, \quad (2)$$

of the probabilities q_{bl}, $b,l = 1,2,\dots,6$, 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

$$[N_{bl}] = \begin{bmatrix} 0 & 5.33 & 24.36 & 12.00 & 12.00 & 0 \\ 8.08 & 0 & 0 & 15.00 & 0 & 0 \\ 23.59 & 0 & 0 & 16.71 & 33.90 & 0 \\ 12.00 & 12.00 & 5.00 & 0 & 0 & 0 \\ 16.00 & 0 & 52.50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, \quad (3)$$

of the mean values N_{bl}, $b,l = 1,2,\dots,6$, of the conditional sojourn times C^1_{bl}, $b,l = 1,2,\dots,6$, 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.

Climate-weather change process for maritime ferry restricted waters operating area - data coming from second measurement point

On the basis of the statistical data [2], it is possible to evaluate the following unknown basic parameters of the climate-weather change process $C^2(t)$ [5]:
- the vector

$$[q_b(0)] = [0.670, 0.271, 0.006, 0, 0.024, 0.029], \quad (4)$$

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

$$[q_{bl}] = \begin{bmatrix} 0 & 0.99 & 0 & 0 & 0.01 & 0 \\ 0.84 & 0 & 0.02 & 0 & 0.14 & 0 \\ 0 & 0.80 & 0 & 0 & 0 & 0.20 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.36 & 0 & 0 & 0 & 0.64 \\ 0 & 0 & 0.93 & 0 & 0.07 & 0 \end{bmatrix}, \quad (5)$$

of the probabilities q_{bl}, $b,l = 1,2,\dots,6$, 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

$$[N_{bl}] = \begin{bmatrix} 0 & 102.22 & 0 & 0 & 13.50 & 0 \\ 17.85 & 0 & 24.00 & 0 & 15.64 & 0 \\ 0 & 6.38 & 0 & 0 & 0 & 6.00 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3.60 & 0 & 0 & 0 & 5.67 \\ 0 & 0 & 10.85 & 0 & 6.00 & 0 \end{bmatrix}, \quad (6)$$

of the mean values N_{bl}, $b,l = 1,2,\dots,6$, of the conditional sojourn times C^2_{bl}, $b,l = 1,2,\dots,6$, 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.

Climate-weather change process for maritime ferry Baltic Sea open waters operating area - data coming from 1353, 1389, 1422 and 1458 measurement points

On the basis of the statistical data [2], it is possible to evaluate the following unknown basic parameters of the climate-weather change process $C^3(t)$ [5]:

- the vector

$$[q_b(0)] = [0.595, 0.349, 0, 0, 0.04, 0.016], \qquad (7)$$

of the initial probabilities $q_b(0)$, $b = 1,2,\ldots,6$, of the climate-weather change process $C^3(t)$ staying at the particular states c_b at the initial moment $t = 0$,
- the matrix

$$[q_{bl}] = \begin{bmatrix} 0 & 0.99 & 0 & 0 & 0.01 & 0 \\ 0.78 & 0 & 0 & 0 & 0.22 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0.73 & 0.02 & 0 & 0 & 0.25 \\ 0 & 0.31 & 0 & 0 & 0.69 & 0 \end{bmatrix}, \qquad (8)$$

of the probabilities q_{bl}, $b,l = 1,2,\ldots,6$, 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.
- the matrix

$$[N_{bl}] = \begin{bmatrix} 0 & 151.53 & 0 & 6 & 5.4 & 0 \\ 30.56 & 0 & 0 & 0 & 16.02 & 0 \\ 0 & 3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 \\ 0 & 9.01 & 6 & 0 & 0 & 8.44 \\ 0 & 16 & 0 & 0 & 16.05 & 0 \end{bmatrix}, \qquad (9)$$

of the mean values N_{bl}, $b,l = 1,2,\ldots,6$, of the conditional sojourn times C^3_{bl}, $b,l = 1,2,\ldots,6$, 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.

<u>Climate-weather change process for maritime ferry Karlskrona port operating area - data coming from last 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 $C^4(t)$ [5]:
- the vector

$$[q_b(0)] = [0.324, 0.018, 0.447, 0.029, 0.182, 0] \qquad (10)$$

of the initial probabilities $q_b(0)$, $b = 1,2,\ldots,6$, of the climate-weather change process $C^4(t)$ staying at the particular states c_b at the initial moment $t = 0$,
- the matrix

$$[q_{bl}] = \begin{bmatrix} 0 & 0.14 & 0.54 & 0.01 & 0.31 & 0 \\ 0.09 & 0 & 0.27 & 0.64 & 0 & 0 \\ 0.70 & 0.01 & 0 & 0.10 & 0.19 & 0 \\ 0 & 0.05 & 0.95 & 0 & 0 & 0 \\ 0.43 & 0 & 0.57 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, \qquad (11)$$

of the probabilities q_{bl}, $b,l = 1,2,\ldots,6$, of transitions of the climate-weather change process $C^4(t)$ from the climate-weather state c_b into the climate-weather state c_l.
- the matrix

$$[N_{bl}] = \begin{bmatrix} 0 & 40.93 & 25.00 & 6.00 & 38.76 & 0 \\ 3.00 & 0 & 5.00 & 9.86 & 0 & 0 \\ 22.68 & 21.00 & 0 & 10.50 & 28.96 & 0 \\ 0 & 3.00 & 11.37 & 0 & 0 & 0 \\ 56.05 & 0 & 24.83 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, \qquad (12)$$

of the mean values N_{bl}, $b,l = 1,2,\ldots,6$, of the conditional sojourn times C^4_{bl}, $b,l = 1,2,\ldots,6$, of the climate-weather change process $C^4(t)$ at the climate-weather state c_b when the next climate-weather state is c_l.

3. Climate-weather change process for maritime ferry operating area prediction characteristics

The climate-weather change processes for the maritime ferry operating area are defined in [5], [10]-[11]. Considering these results and assuming that we have identified the unknown parameters of the climate-weather change processes for the maritime ferry operating area, we can predict basic characteristics of those processes.

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

<u>Climate-weather change process for maritime ferry Gdynia port operating area - data coming from first measurement point</u>

The limit values of the climate-weather change process $C^1(t)$ for the considered measurement points of the maritime ferry operation area transient probabilities $q_b(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, are given in the vector [5], [11]:

$$[q_b]_{1x6} \cong [0.404, 0.011, 0.451, 0.01, 0.124, 0]; \quad (13)$$

Climate-weather change process for maritime ferry restricted waters operating area - data coming from second measurement point

The limit values of the climate-weather change process $C^2(t)$ for the considered measurement point of the maritime ferry operation area transient probabilities $q_b(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, are given in the vector [5]:

$$[q_b]_{1x6} \cong [0.805, 0.167, 0.008, 0, 0.007, 0.013]; \quad (14)$$

Climate-weather change process for maritime ferry Baltic Sea open waters operating area - data coming from 1353, 1389, 1422 and 1458 measurement points

The limit values of the climate-weather change process $C^3(t)$ for the considered measurement point of the maritime ferry operation area transient probabilities $q_b(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, are given in the vector [5]:

$$[q_b]_{1x16} \cong [0.792, 0.185, 0, 0, 0.016, 0.007]. \quad (15)$$

Climate-weather change process for maritime ferry Karlskrona port operating area - data coming from last measurement point

The limit values of the climate-weather change process $C^4(t)$ for the considered measurement point of the maritime ferry operation area transient probabilities $q_b(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, are given in the vector [5]:

$$[q_b]_{1x16} \cong [0.394, 0.016, 0.311, 0.030, 0.249, 0]. \quad (16)$$

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

Climate-weather change process for maritime ferry Gdynia port operating area - data coming from first measurement point

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) [5], [11]:

$$[\hat{N}_b^1] = [E[\hat{C}_b^1]] \cong [11.71, 0.32, 13.08, 0.29, 3.60, 0]; \quad (17)$$

Climate-weather change process for maritime ferry restricted waters operating area - data coming from second 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) [5]:

$$[\hat{N}_b^2] = [E[\hat{C}_b^2]] \cong [23.35, 4.84, 0.23, 0, 0.20, 0.38]; \quad (18)$$

Climate-weather change process for maritime ferry Baltic Sea open waters operating area - data coming from 1353, 1389, 1422 and 1458 measurement points

The expected values of the total sojourn times $\hat{C}_b^3$, $b = 1,2,\ldots,6$, of the climate-weather change process $C^3(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, during the fixed operation time $C^3 = 1$ month (February) = 29 days, are given in the vector (its coordinates are measured in days) [5]:

$$[\hat{N}_b^3] = [E[\hat{C}_b^3]] \cong [22.968, 5.365, 0, 0, 0.464, 0.203]. \quad (19)$$

Climate-weather change process for maritime ferry Karlskrona port operating area - data coming from last measurement point

The expected values of the total sojourn times $\hat{C}_b^4$, $b = 1,2,\ldots,6$, of the climate-weather change process $C^4(t)$ at the particular climate-weather states c_b, $b = 1,2,\ldots,6$, during the fixed operation time $C^4 = 1$ month (February) = 29 days, are given in the vector (its coordinates are measured in days) [5]:

$$[\hat{N}_b^4] = [E[\hat{C}_b^4]] \cong [11.43, 0.46, 9.02, 0.87, 7.22, 0]. \quad (20)$$

4. Conclusions

The probabilistic model of the climate-weather change process for a critical infrastructure operating area presented in [6] was applied to construct the climate-weather change process at maritime ferry 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 [8]-[9].

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