Modelling climate-weather change process including extreme weather hazards for maritime ferry

Keywords
climate-weather change process, semi-Markov model, extreme weather hazard states, maritime ferry

Abstract
The climate-weather change process for the maritime ferry operating at Port Gdynia and at Baltic Sea open waters between Gdynia bay and Karlskrona bay is considered and its states are defined. Further, the semi-Markov process is defined and used to create a general probabilistic model of the climate-weather change process for the maritime ferry operating at considered areas.

1. Introduction
As shown in [20], the climate-weather change processes for the real critical infrastructures operating areas could be treat as the semi-Markov process with discrete operation states defined by the mainly climate-weather hazards which have influence on the considered critical infrastructures operating areas. In this article, we will define parameters of the climate-weather change process for the maritime ferry operating at Port Gdynia and at Baltic Sea open waters between Gdynia bay and Karlskrona bay using the bases from [20]. All analyses included in this article could be found in [5].

2. Climate-Weather Change Process for Maritime Ferry Operation Area

2.1. Description of Maritime Ferry
The maritime ferry is a passenger Ro-Ro ship operating at the Baltic Sea between Gdynia and Karlskrona ports on regular everyday line. The mentioned earlier operated area of the maritime ferry could be divided into four different areas: Gdynia Port, Baltic Sea restricted waters, Baltic Sea open waters, Karlskrona Port. The detailed maritime ferry route is illustrated in Figure 1. More information about the maritime ferry, its assets and interconnections between them could be found in [8]. In following subsections, we will analyze the climate-weather change process of the maritime ferry operating at Port Gdynia (Point 1 in Figure 1) and at Baltic Sea open waters between Gdynia bay and Karlskrona bay (Points 3-6 in Figure 1). In points 1-7 marked in the above figure were obtained the climate-weather data.
2.2. Defining parameters of climate-weather change process for Maritime Ferry operating at Gdynia Port

We distinguish \( a = 2 \) parameters which mainly describe the climate-weather states of the maritime ferry operating at Gdynia Port. These parameters are: 

\( w_1 \) – the sea level measured in centimeters and \( w_2 \) – the wind speed measured in meters per second. Next, we assume that the possible values of the parameters in this area can belong respectively to the intervals \( w_1 \in <415, 620) \) and \( w_2 \in <0, 33) \) and according to the data about ranges of hazard parameters in [9].

Moreover, the parameter \( w_1 \) values interval \( <415, 620) \) is divided into \( n_1 = 4 \) disjoint subintervals:

\(<415, 450), <450, 500), <500, 550), <550, 620)\)

and the parameter \( w_2 \) values interval \( <0, 33) \) into \( n_2 = 2 \) disjoint subintervals:

\(<0, 17.2), <17.2, 33)\).

Hence, the vector \((w_1, w_2)\) which describes the climate-weather states can take values from the set of the following \( a = 2 \) dimensional space points of the Descartes products:

\(<415, 450) \times <0, 17.2), <450, 500) \times <0, 17.2), <500, 550) \times <0, 17.2), <550, 620) \times <0, 17.2), <415, 450) \times <17.2, 33), <450, 500) \times <17.2, 33), <500, 550) \times <17.2, 33), <550, 620) \times <17.2, 33)\).

We call these products the climate-weather states of the climate-weather change process. If all of them are sensible then they are numerated from 1 up to the value \( w = n_1 \cdot n_2 = 4 \cdot 2 = 8 \) and marked by \( c_1, c_2, \ldots, c_8 \). When some of them are not possible to happen (are not sensible), then according to an expert opinion, we can omit them and their numeration can be changed.

Hence, based on the expert opinion, there are distinguished the following \( w = 8 \) climate-weather states:

- the climate-weather state \( c_1 \) – the sea level from 415 cm up to 450 cm and the wind speed from 0 m/s up to 17.2 m/s;
- the climate-weather state \( c_2 \) – the sea level from 450 cm up to 500 cm and the wind speed from 0 m/s up to 17.2 m/s;
- the climate-weather state \( c_3 \) – the sea level from 500 cm up to 550 cm and the wind speed from 0 m/s up to 17.2 m/s;
- the climate-weather state \( c_4 \) – the sea level from 550 cm up to 620 cm and the wind speed from 0 m/s up to 17.2 m/s;
- the climate-weather state \( c_5 \) – the sea level from 415 cm up to 450 cm and the wind speed from 17.2 up to 33 m/s;
- the climate-weather state \( c_6 \) – the sea level from 450 cm up to 500 cm and the wind speed from 17.2 up to 33 m/s;
- the climate-weather state \( c_7 \) – the sea level from 500 cm up to 550 cm and the wind speed from 17.2 up to 33 m/s;
- the climate-weather state \( c_8 \) – the sea level from 550 cm up to 620 cm and the wind speed from 17.2 up to 33 m/s.
Further, taking into account the agreement assumed in [9] and [20], the 1st category extreme weather hazard state of the climate-weather parameter \( w_1 \) is the interval \(<550, 620)\) and the 1st category extreme weather hazard state of the climate-weather parameter \( w_2 \) is the interval \(<17.2, 33)\).

Consequently, the 2nd category extreme weather hazard state of the climate-weather change process is \( c_8 \), the 1st category extreme weather hazard states of the climate-weather change process are \( c_4, c_5, c_6, c_7 \) and the 0th category extreme weather hazard states of the climate-weather change process are \( c_1, c_2, c_3 \).

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

- the initial probabilities \( q_{bl}(0), b = 1, 2, \ldots, 8 \), of the climate-weather change process staying at the particular state \( c_b \) at the moment \( t = 0 \),
- the probabilities \( q_{bt}, b, l = 1, 2, \ldots, 8, b \neq l \), 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 process conditional sojourn times \( C_{bl}, b, l = 1, 2, \ldots, 8, b \neq l \), at the particular climate-weather change states and their mean values \( M_{bl} = \mathbb{E}[C_{bl}], b, l = 1, 2, \ldots, 8, b \neq l \).

The identification of all these parameters of the climate-weather change process could be found in [17].

### 2.3. Defining parameters of climate-weather change process of Maritime Ferry operating at Baltic Sea open waters

We distinguish \( a = 2 \) parameters which mainly describe the climate-weather states of the maritime ferry operating at Baltic Sea open waters. These parameters are: \( w_1 \) – the wave height measured in meters and \( w_2 \) – the wind speed measured in meters per second. Next, we assume that the possible values of the parameters in this area can belong respectively to the intervals \( w_1 \in <0, 14) \) and \( w_2 \in <0, 33) \) according to the data about ranges of hazard parameters in [9].

Moreover, the parameter \( w_1 \) values interval \(<0, 14) \) is divided into \( n_1 = 3 \) disjoint subintervals:

\(<0, 2), <2, 5.5), <5.5, 14)\)

and the parameter \( w_2 \) values interval \(<0, 33) \) into \( n_2 = 2 \) disjoint subintervals:

\(<0, 17.2), <17.2, 33)\).

Hence, the vector \((w_1, w_2)\) which describes the climate-weather states can take values from the set of the following \( a = 2 \) dimensional space points of the Descartes products:

\(<0, 2) \times <0, 17.2), <2, 5.5) \times <0, 17.2), <5.5, 14) \times <0, 17.2), <0, 2) \times <17.2, 33), <2, 5.5) \times <17.2, 33), <5.5, 14) \times <17.2, 33)\).

We call these products the climate-weather states of the climate-weather change process. If all of them are sensible then they are numerated from 1 up to the value \( n_1 \cdot n_2 = 3 \cdot 2 = 6 \) and marked by \( c_1, c_2, \ldots, c_6 \). When some of them are not possible to happen (are not sensible), then according to an expert opinion, we can omit them and their numeration can be changed.

Hence, based on the expert opinion, there are distinguished the following \( w = 6 \) climate-weather states:

- 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 17.2 m/s;
- the climate-weather state \( c_2 \) – the wave height from 2 m up to 5.5 m and the wind speed from 0 m/s up to 17.2 m/s;
- the climate-weather state \( c_3 \) – the wave height from 5.5 m up to 14 m and the wind speed from 0 m/s up to 17.2 m/s;
- the climate-weather state \( c_4 \) – the wave height from 0 m up to 2 m and the wind speed from 17.2 m/s to 33 m/s;
- the climate-weather state \( c_5 \) – the wave height from 2 m up to 5.5 m and the wind speed from 17.2 m/s to 33 m/s;
- the climate-weather state \( c_6 \) – the wave height from 5.5 m up to 14 m and the wind speed from 17.2 m/s to 33 m/s;

Further, taking into account the agreement assumed in [9] and [20], the 1st category extreme weather hazard state of the climate-weather parameter \( w_1 \) is the interval \(<5.5, 14) \) and the 1st category extreme weather hazard state of the climate-weather parameter \( w_2 \) is the interval \(<17.2, 33) \).

Consequently, 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 \( c_3, c_4, c_5 \) and the 0th category extreme weather hazard states of the climate-weather change process are \( c_1, c_2 \).

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

- the initial probabilities \( q_{bl}(0), b = 1, 2, \ldots, 6 \), of the climate-weather change process staying at the particular state \( c_b \) at the moment \( t = 0 \),
- the probabilities \( q_{bt}, b, l = 1, 2, \ldots, 6, b \neq l \), 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 process conditional sojourn times $C_{bl}$, $b, l = 1, 2, ..., 6$, $b \neq l$, at the particular climate-weather change states and their mean values $M_{bl} = E[C_{bl}]$, $b, l = 1, 2, ..., 6$, $b \neq l$.

The identification of all these parameters of the climate-weather change process could be found in [16].

3. Conclusions

The probabilistic models of the climate-weather change processes of the maritime ferry operating at Gdynia port area and at Baltic Sea open waters are the basis for the considerations in articles [16]-[17]. In these articles are shown statistical methods of identification and are identified the unknown parameters of the climate-weather change processes for the maritime ferry operating at Gdynia port area and at Baltic Sea open waters.

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