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Application of the Multi-criteria Navigational Safety Assessment Method for the Proposed Variants of the Designed Waterway

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ABSTRACT: The article presents an exemplary application of the multi-criteria navigational safety assessment method for the proposed variants of the designed waterway in order to verify it. This method comprehensively considers the most important environmental and technical aspects related to the implementation of the planned investment. The method can be used for the purposes of navigational analysis, i.e. an engineering document that meets the requirements of the regulation of the competent, which subject to agreement with the Director of the territorially competent Maritime Office.

1 INTRODUCTION

Issues related to work on waterways are part of the group of main strategic goals in the context of the development of seaports. Actions aimed at improving access to seaports are currently a challenge that must be met by seaports serving the largest vessels. The lack of appropriate infrastructure strongly limits the possibilities of further development (Krośnicka 2016, Matczak 2017). Due to both the simultaneous increase in the operational parameters of vessels and the specialization in servicing vessels specific to a given port (Ministerstwo Transportu, Budownictwa I Gospodarki Morskiej 2013, United Nations Publications, 2019), servicing them for many ports is becoming more and more difficult. Therefore, the selection of the appropriate variant of the designed waterway is currently of interest to the maritime administration, port authorities and future port users as an investment necessary to ensure the safety of these vessels and further development of the port (Formela 2013, Formela 2015, Gucma 2001, Gucma 2015).

2 DESCRIPTION OF THE METHOD

The proposed methodology (Formela 2020) of multi-level, multi-criteria evaluation of the designed variants of waterways is based on the general methodology of solving multi-criteria decision-making problems (Żak 2005). As a result of the use of a multi-level methodology, multi-criteria assessment of variants/projects, a summary of waterway projects is obtained. This list presents the considered projects in order from the project that has the best impact (has the highest utility) on navigational safety, to the project that has the least impact on achieving the goal. Figure 1 presents a general procedure for assessing decision-making options under the proposed methodology.

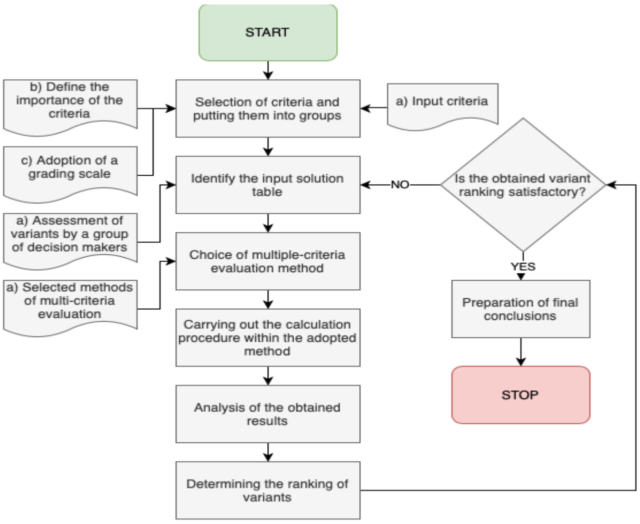

Figure 1. Scheme of procedure for the assessment of various variants of waterways in terms of multiple criteria (Formela 2020).

3 MATERIALS FOR METHOD IMPLEMENTATION

The developed method is universal and can be used for various types of waterway construction and modernization projects. The implemented projects may have a different degree of complexity. From simple works, such as widening a short section of a straight waterway, to more complex ones, such as building new ports (D'Angremond 1998, Dhillon 2011). The selection of the right criteria, their proper ordering into groups, the determination of the input table of solutions, and finally the choice of a multi-criteria method for solving the problem (comparison of variants) makes it possible to present the results of the research carried out in a relatively quick and, above all, transparent way and to make the right decision at the initial stage of work planning.

In order to comprehensively present the possibilities of the developed method, one of the many projects of building new waterways on the water reservoirs of the Republic of Poland implemented at that time was used. This allowed to compare the obtained results (selection of the development variant) with the developed method with the previously implemented project. Due to the two different geometric layouts of the breakwaters, the schemes of the waterway development variants have been divided into two groups: basic (W1, W2 and W3) and alternative (W4, W5 and W6).

3.1 *Simulator and simulation areas*

The following devices and software from TRANSAS (now Warstila) were used to perform the measurements: navigation and maneuvering simulator NaviTrainer 5000 Professional, ECDIS simulator NaviSailor 4000 as well as Model Wizard and Virtual Shipyard applications.

Using the Transas Model Wizard application (Transas 2015), six dedicated simulation areas were prepared, based on the following source data: paper navigational charts, ENC maps, navigation aids and publications and materials provided by the investor. The process of building the measuring basin in the software used was divided into the following stages:

1. Selection and import of partial data;
2. Implementation of data into the simulation environment;
3. Data processing;
4. Compilation of layers;
5. Importing the obtained output file to the simulator environment.

On the designed areas, it was possible to simulate various hydro meteorological conditions, such as: wind speed and direction, as well as the type and parameters of waves. Depending on the research scenario, various values of weather factors were defined. The selection of the model used in the research was based on the guidelines of the Research Team and the Investor. The above assumptions were compared with the parameters of all models of units from the simulator data base.

3.2 *Hydro meteorological conditions*

Hydro meteorological conditions in the area, including wave and wind parameters, which are the main environmental factor affecting the course of port maneuvers, were designed in accordance with the following assumptions:

1. Only the occurrence of a wind wave was considered in each of the analyzed cases;
2. The wind force was analyzed for representative wind speeds, determined on the basis of predefined values from the navigation and maneuvering simulator (Transas 2015) in the range of 2, 4 and 6 on the Beaufort scale (1.6, 5.5 and 10.8 m/s);
3. Parameters of waves in the foreground of the planned development were simulated in accordance with the other studies (Szmytkiewicz 2017);
4. The wave-cut function built into the software (Transas 2015) was used to take into account wave distributions in the simulation environment and to set different wave heights in the measurement basin. This tool allows you to extinguish the wave by changing its height in a percentage in a given area.

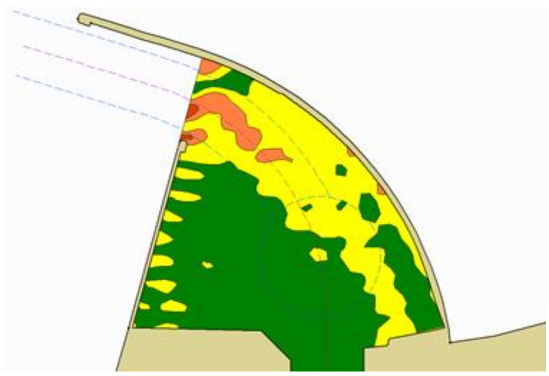

Figure 2. Wave distribution applied to the simulation basin by using wave-cut function

3.3 *Development and selection of navigation safety criteria*

The procedure of simulation tests used in the design and selection of sea waterways is carried out in the following order (Bąk 2021):

– formulating the research problem, including the purpose of designing, the simulation methods used and the type of simulators;
– construction of ship traffic models on the simulator and their verification;
– designing the experimental setup and conducting the experiment;
– development and statistical analysis of research results.

In accordance with the design assumptions of the research, measurement sessions were carried out in accelerated time. In order to normalize the measurements, the maneuvers of the ships were carried out based on the operation of the automatic control system, taking into account sailing along a given route. The positions of waypoints (WP), as well as turning radius TR (Turning radius), were adjusted in each configuration in such a way that the determined route of the vessel reflected the diametrical of the designed fairway as accurately as possible. The values of the allowable deviation error were adopted so that they reached the same values for both sides of the track.

Wind and waves are among the main environmental factors affecting navigational safety. The influence of the wind on the hull of the vessel is not directly related to the variant of the waterway. The geometric layout of the breakwaters shapes the distribution of the wave field inside the port, which affects the reactions and maneuverability of the vessel. The arrangement of the breakwaters does not have a significant effect on the damping of the wind force and the reduction of its effect on the windage area of the vessel.

Safe navigation requires full recognition of the current navigational and maneuvering situation of the ship, as an important factor affecting safety is the correct execution of maneuvers on the approach fairway (Ślączka 2017, Śmierzchalski 1998).

In order to determine the trajectory of the designed domain of the vessel as precisely as possible, the positions of the simulation model were projected onto the plane. The geographic coordinates exported from the test stand were transformed into flat ones using the UTM (Universal Transverse Mercator) system (Specht 2013).

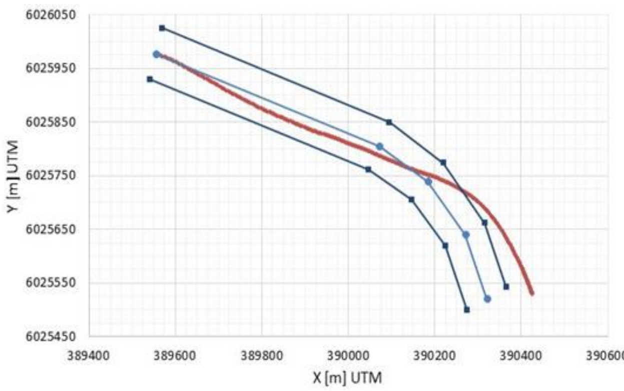

Figure 3. The printout of the vessel positions in a simulation test with diametric and fairway limits

The transformation of coordinates from geographic to flat (UTM) allowed for the creation of two-dimensional charts of the vessel's past positions (Figure 3),. Linking the X and Y points of the center of the model with the construction points of the domain as well as the boundaries and diametrical of the approach track allowed for the depiction of all completed trajectories.

Based on the determined coordinates of the characteristic points of the hull in the stern and fore parts of the vessel, further calculations can be performed to determine the width of the ship's traffic lane in a single passage. The basic problem in the selection of criteria is the correct selection of dependent variables, especially when it comes to variables related to the parameters of the waterway in the ship control function. This is due to the fact that the navigator's control of the ship is strictly dependent on many factors, including the maneuvering itself and the water area on which the control takes place. Due to the difficulty of including a qualitative feature such as the above variables in the model, it was decided to use the model of autonomous ship steering, where the quantitative values were recorded - maximum rudder movements and the total number of changes in the rudder angle as a function of time.

4 SYNTHESIS OF CLIMATIC DATA RESULTS AND NAVIGATION CRITERIA

For reporting purposes, sheets were prepared in which simulation results were compiled - the adopted criteria in relation to wind parameters. In accordance with the adopted research objective, criteria were registered for each of the measurements, depending on the test recorded at the time. In order to illustrate the impact of the wind parameter on the selected criterion, the recorded values were grouped using data bars and a gradual color scale. Color bars and scales were used as conditional formats that create visual effects in data. Conditional formats make it easy to compare values across a range of cells at the same time. Color scales make it easier to understand the distribution and variation of data. The cells are shaded using color gradations corresponding to the minimum and maximum value thresholds, as shown in Table 1-2.

Table 1. Criteria color scale for quantitative criteria

1	Minimum value
2	
3	
4	
5	Intermediate values
6	
7	
8	
9	
10	Maximum value

Table 2. Criteria color scale for qualitative criteria

10	Minimum value
9	
8	
7	
6	Intermediate values
5	
4	
3	
2	
1	Maximum value

Analyzing the summary of simulation results, a summary sheet was prepared to hierarchize all variants of the waterway for the selected wind direction and force, assigning them the position obtained in the ranking - from 1 to 6, where the first place means the best variant, the sixth place - the worst, in relation to the adopted criteria for assessing navigational safety.

For each variant, the sum of the places obtained in the ranking was counted, reaching total ranking points. The variant that obtained the lowest sum of ranking points is the variant of the best among the given criteria for the adopted criteria in given wind conditions.

With detailed wind data, i.e. wind strength, direction and frequency in a given area, it is possible to prioritize the variant as a function of wind frequency. This is important because it allows you to include or exclude the best ratings in the ranking and worst, for conditions that occur most often and least often.

5 CONCLUSIONS

The assessment of navigational safety for various variants of the planned waterway, allowing the decision makers to decide which variant will be ultimately selected for implementation, requires the analysis and evaluation of many criteria. The correctness of the selected waterway variant is influenced by both the accuracy of the selected criteria and their proper gradation. Processing a large amount of information is a complex process carrying the risk of making a mistake related to not considering all the relevant information needed to make the right decision.

Therefore, the selection of a waterway construction variant at the initial design stage is a difficult and complex process. The multidimensional nature of the process creates uncertainty and thus ambiguity of the results. Complicated processes should therefore be assessed by experts, as such action allows to obtain a wide spectrum of various types of experience and solutions. This contributes to a better assessment and improvement of the selection process of the tested variants and thus their appropriate selection. In addition, the expert assessment allows to determine the values of the evaluations of the required criteria in the study using the multi-criteria method of hierarchical analysis of decision-making problems.

Automating the evaluation processes of the selection of given waterways, in the function of assessing navigational safety for selected criteria, serves to reduce the possibility of making mistakes.

A detailed analysis of the conditions of the waterway variants using the above-mentioned method, allowed to obtain results in the selection of the best of the proposed waterway construction variants. The use of the method allows to reduce possible costs (that is, taking into account the economic aspect) and to improve the functioning of both the investor, the client and the potential user of the waterway.

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