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# UNIWERSAL SIMULATION METHOD FOR DETERMINING THE MANEUVERABILITY OF FERRY BASED ON THE EXAMPLE OF YSTAD PORT

**ABSTRACT**

The paper describes a universal simulation method used by the authors to determine the conditions of safe operation of sea ferries, in terms of marine traffic engineering. The assumptions, simulation experiment and results are described on the example of the m/f Mazovia manoeuvring in the Port of Ystad. Carried out and described in the article simulation study using the present method was aimed to determine the possibility of adapting the propulsion and steering systems of the ferry including:

- determination of the wind limits in the Port of Ystad in terms of Mazovia ferry operation;
- assessment of the maneuvering safety in a port area and determination of conditions of safe operation with present propulsion and steering systems;
- determination of the possibility of adapting the propulsion and steering systems to meet the requirements of the shipowner for the economically efficient and safe operation of the ferry.

**Keywords:**
Maneuverability, maneuvering safety, traffic engineering, ferry, simulation.

## 1. INTRODUCTION

The method used in the experiment is the method of real-time simulation of ship movement which, for the purposes of analysis, was implemented into navigational bridge simulator so called Full Mission Bridge Simulator produced by Kongsberg. Two models of the Mazovia ferry were built for the study:

1. Mazovia_1 – present model with parameters as close as possible to the actual ferry;
2. Mazovia_2 – rebuilt model with increased and economically optimized parameters of steering systems

Presented in the paper analysis of the manoeuvring parameters of simulation models of m/f Mazovia in present and rebuilt versions was carried out on the basis of results of two simulation experiments:

1. approach, berthing, unberthing and departure maneuvers with use of present simulation model of m/f Mazovia in Port of Ystad, to assess the fidelity level of model;
2. approach, berthing, unberthing and departure maneuvers with use of both developed models in dedicated test area.

Comparative analysis of manoeuvring parameters of both models (Mazovia_1 and Mazovia_2) was carried out to present research problem in a broader context. The main goal was to assess and next to compare chosen parameters of the propulsion and steering equipment of both models as 'universal' ie. regardless of the specific area and local conditions as it was possible, while taking into account the specifics of the Port of Ystad. For this purpose, a series of manoeuvres using both developed models in the same variants of simulation experiment were carried out in a dedicated test area. This test area was developed to ensure the possibility to perform manoeuvres typical for sea ferries, including the ferry Mazovia at the Port of Ystad [Gucma, 2005], [Gucma, 2009], [Gucma, 2012].

It was assumed that analysis of achieved results allows for assessing the influence of changes in propulsion and steering systems on manoeuvrability of the ferry in the Port of Ystad and in the same time for assessing the parameters of other typical manoeuvers in restricted area.

## 2. UNIVERSAL METHOD UTILIZED IN THE EXPERIMENT

In order to carry out the simulation experiment using the presented method dedicated test area was built. In the next stage the general assumptions were established:

- no land structures sheltering the ferry against the wind;
- no currents;
- no waves influence (minimum height of wind waves);
- depths limited to 8 meters;
- constant wind direction;
- 3 variants of wind speed for each scenario: 15, 17 and 19 m/s;
- data logging: position of waterline every 10 seconds, motion parameters, settings of steering and propulsion equipment every 2 seconds.

**The main criterion of the simulation experiment was using by the captain minimal possible settings of steering and propulsion equipment allowing for safe and effective manoeuvres according to the assumptions of scenario.**

Assumed definition of criterion enabled evaluation of minimum settings allowing for safe and effective counteracting the wind. Furthermore, it limited 'freedom' in use excessive and often unnecessary settings, which could distort the results. Where it was possible static manoeuvres were assumed.

The auxiliary criterion was to navigate in the smallest possible manoeuvring area, keeping the ferry as close to the berth as it was possible.

In presented method 4 test scenarios were defined. Each of them was located in the open area, where part of the berth (15 x 300 meters) was placed. This configuration enabled any approach and departure manoeuvre.

*Scenario 1. Approach and berthing, starboard side, wind from bow direction*

To assess and compare chosen operational parameters of steering and propulsion equipment of both models following assumptions were defined in scenario 1 (see Figure 1):

- initial position: 250m southward from berth, transverse distance between starboard side and berth 25m;
- initial speed: 10kts;
- initial heading: 000deg;
- wind from the east, wind speed 15, 17 and 19 m/s.

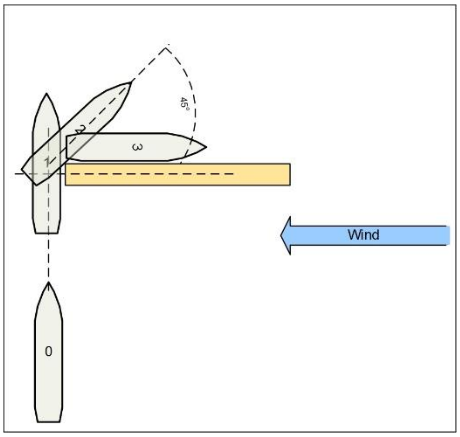


Figure 1. Manoeuvring scheme for scenario no. 1. Source: Authors.

In order to categorize accurately recorded parameters during the maneuvers, the trials were divided into 3 stages:

- Stage 1: decrease of longitudinal speed and setting the vessel perpendicular to the berth with midship at the height of berth;
- Stage 2. heading change from 000 to 045 deg. keeping minimal distance from berth;
- Stage 3. heading change from 045 to 090 deg., approach the berth with starboard side, decrease of longitudinal and transverse speed.

*Scenario 2. Approach and berthing, starboard side, wind from stern direction.*

To assess and compare chosen operational parameters of steering and propulsion equipment of both models assumptions defined in scenario 2 (see Figure 2) were the same as in scenario 1.

In order to categorize accurately recorded parameters during the maneuvers, the trials were divided into 3 stages:

- Stage 1: decrease of longitudinal speed and setting the vessel perpendicular to the berth with midship at the height of berth;
- Stage 2. heading change from 000 to 315 deg. keeping minimal distance from berth;
- Stage 3. heading change from 315 to 270 deg., approach the berth with starboard side, decrease of longitudinal and transverse speed.

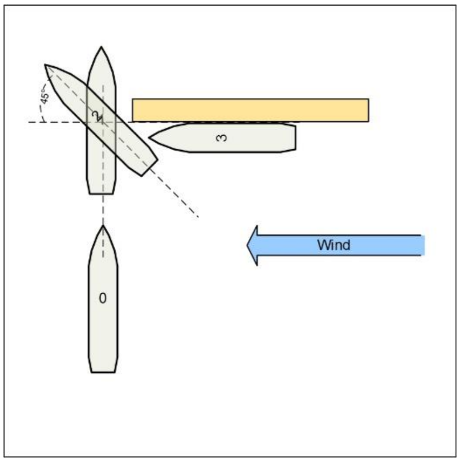


Figure 2. Manoeuvring scheme for scenario no. 2. Source: Authors.

*Scenario 3. Unberthing and departure, bow out, wind into berth direction*

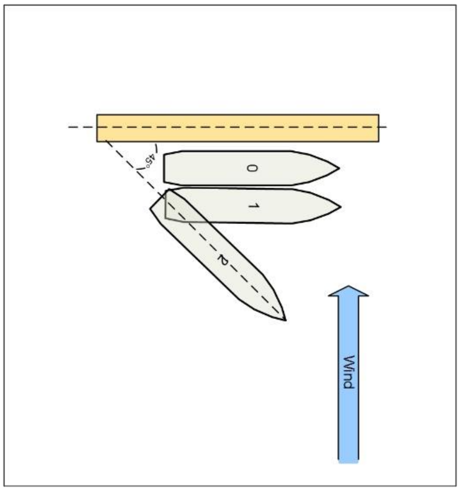


Figure 3. Maneuvering scheme for scenario no. 3. Source: Authors.

To assess and compare chosen operational parameters of steering and propulsion equipment of both models following assumptions were defined in scenario 3 (see Figure 3):

- initial position: berthed, port side;
- initial speed: 0kts;
- initial heading: 090deg;
- wind from the south, wind speed 15, 17 and 19 m/s.

In order to categorize accurately recorded parameters during the maneuvers, the trials were divided into 2 stages:

- Stage 1: increase of transverse speed and departure from berth on distance of ferry breadth at least, with zero longitudinal speed;
- Stage 2. heading change from 090 to 135 deg. keeping constant distance between stern and berth.

*Scenario 4. Unberthing and departure, stern out, wind into berth direction*

To assess and compare chosen operational parameters of steering and propulsion equipment of both models assumptions defined in scenario 4 (see Figure 4) were the same as in scenario 3.

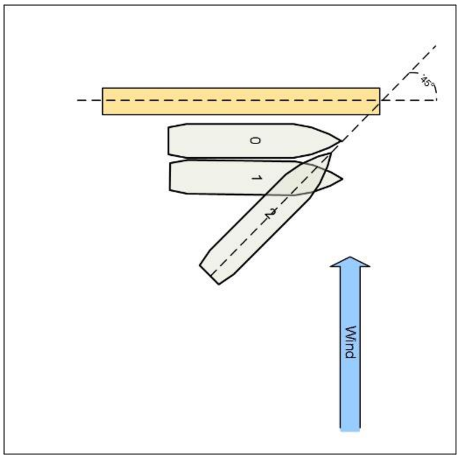


Figure 4. Maneuvering scheme for scenario no. 4. Source: Authors.

In order to categorize accurately recorded parameters during the maneuvers, the trials were divided into 2 stages:

- Stage 1: increase of transverse speed and departure from berth on distance of ferry breadth at least, with zero longitudinal speed;
- Stage 2. heading change from 090 to 045 deg. keeping constant distance between bow and berth.

## RESULTS AND ANALYSIS OF REGISTERED PARAMETERS OF VESSEL'S STEERING AND PROPULSION

Among the data recorded during the simulation for present (Mazovia_1, M_1) and rebuilt (Mazovia_2, M_2) models following parameters of steering and propulsion settings were chosen to further analysis:

- rudder angle [deg];
- THP, thrust horse-power of each screw propeller [kN];
- power of thrusters [kW] and additionally:
    - heading [deg];
    - speed [kts].

Recorded parameters were analyzed comparatively in percentage terms for both ferry models in different wind variants.

Detailed analysis included division into maneuver stages. The significant parameter was defined as ratio of minimum values of the all maximum recorded settings of steering and propulsion equipment in given stage of each series of trials and maximum possible setting. It means that minimum values that enable safe and efficient maneuvering were analyzed. Presented results shows what percentage share of maximum setting of steering and propulsion equipment have to be used to carry out safe and efficient maneuver in each stage.

The significant parameter for general analysis was defined as mean value of setting of steering and propulsion equipment recorded in all stages of maneuver presented in detailed analysis. Mathematically it is the mean value of the ratio of the minimal maximum settings recorded in given stage for each series of trials and maximum possible setting.

Presented general analysis shows what is the mean setting of steering and propulsion equipment which is necessary to carry out safe and efficient maneuver taking into account assumptions of analysis.

*Analysis of scenario 1 results.*
*Approach and berthing, starboard side, wind from bow direction.*

Detailed analysis of results achieved for trials carried out with Mazovia_1 and Mazovia_2 models is presented in table 1.

Table 1. Detailed analysis: relative minimal orders for rudder, propellers and thruster, expressed as a percent of maximum value, required for safe manoeuvring in each stage of scenario no 1.

| | | WIND | | | | | |
|---|---|---|---|---|---|---|---|
| | | 15 m/s | | 17 m/s | | 19 m/s | |
| | **ORDER FOR:** | M 1 | M 2 | M 1 | M 2 | M 1 | M 2 |
| *Stage 1* | Rudder | 12% | 7% | 90% | 58% | 100% | 65% |
| | Right propeller | 35% | 28% | 42% | 36% | 67% | 32% |
| | Left propeller | 37% | 27% | 61% | 44% | 67% | 46% |
| | Bow thruster | 37% | 13% | 50% | 50% | 78% | 50% |
| *Stage 2* | Rudder | 98% | 74% | 100% | 58% | 100% | 80% |
| | Right propeller | 49% | 33% | 47% | 25% | 28% | 27% |
| | Left propeller | 70% | 59% | 91% | 27% | 98% | 32% |
| | Bow thruster | 37% | 25% | 50% | 28% | 52% | 45% |
| *Stage 3* | Rudder | 98% | 72% | 100% | 70% | 98% | 89% |
| | Right propeller | 49% | 32% | 49% | 30% | 55% | 29% |
| | Left propeller | 73% | 58% | 58% | 54% | 59% | 54% |
| | Bow thruster | 45% | 37% | 58% | 47% | 62% | 47% |

Source: Authors works.

General analysis of results achieved for trials carried out with Mazovia_1 and Mazovia_2 models is presented in table 2.

Table 2. General analysis: average minimal orders for ruder, propellers and thruster, expressed as a percent of maximum value, required for safe manoeuvring in scenario no 1.

| | WIND | | | | | |
|---|---|---|---|---|---|---|
| | 15 m/s | | 17 m/s | | 19 m/s | |
| **ORDER FOR:** | M 1 | M 2 | M 1 | M 2 | M 1 | M 2 |
| Rudder | 69% | 51% | 97% | 62% | 99% | 78% |
| Right propeller | 44% | 31% | 46% | 30% | 50% | 29% |
| Left propeller | 60% | 48% | 70% | 42% | 75% | 44% |
| Bow thruster | 40% | 25% | 53% | 42% | 64% | 47% |

Source: Authors works.

Taking into account undertaken detailed analysis, general analysis and the maximum maneuvering areas in scenario 1 it can be stated that present model (Mazovia_1) can safely perform static maneuvers up to wind of 15m/s. For wind from 15m/s to 17 m/s dynamic maneuvers should be performed, because large size of maximum maneuvering area for static maneuvers can be unacceptable. For wind over 19 m/s static maneuvers are impossible, large size of maximum maneuvering area for dynamic maneuvers can be unacceptable.

On the basis of analysis of trials carried out with rebuilt model (Mazovia_2) it can be stated that static maneuvers can be performed for wind up to 17 m/s. For wind over 17 m/s dynamic maneuvers are recommended, because large size of maximum maneuvering area for static maneuvers can be unacceptable.

*Analysis of scenario 2 results.*
*Approach and berthing, starboard side, wind from stern direction.*

Detailed analysis of results achieved for trials carried out with Mazovia_1 and Mazovia_2 models is presented in table 3.

Table 3. Detailed analysis: relative minimal orders for rudder, propellers and thruster, expressed as a percent of maximum value, required for safe manoeuvring in each stage of scenario no 2.

| | | **WIND** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **15 m/s** | | **17 m/s** | | **19 m/s** | |
| | **ORDER FOR:** | M 1 | M 2 | M 1 | M 2 | M 1 | M 2 |
| *Stage 1* | Rudder | 100% | 70% | 100% | 100% | 100% | 100% |
| | Right propeller | 68% | 44% | 67% | 37% | 66% | 43% |
| | Left propeller | 66% | 62% | 75% | 72% | 90% | 84% |
| | Bow thruster | 50% | 38% | 55% | 46% | 64% | 23% |
| *Stage 2* | Rudder | 100% | 70% | 100% | 100% | 100% | 100% |
| | Right propeller | 39% | 32% | 49% | 38% | 61% | 41% |
| | Left propeller | 76% | 60% | 98% | 76% | 98% | 92% |
| | Bow thruster | 58% | 50% | 58% | 36% | 57% | 48% |
| *Stage 3* | Rudder | 100% | 100% | 100% | 100% | 100% | 100% |
| | Right propeller | 49% | 33% | 48% | 34% | 56% | 37% |
| | Left propeller | 83% | 74% | 98% | 63% | 99% | 93% |
| | Bow thruster | 39% | 23% | 45% | 36% | 56% | 40% |

Source: Authors works.

General analysis of results achieved for trials carried out with Mazovia_1 and Mazovia_2 models is presented in table 4.

Table 4. General analysis: average minimal orders for ruder, propellers and thruster, expressed as a percent of maximum value, required for safe manoeuvring in scenario no 2.

| | **WIND** | | | | | |
|---|---|---|---|---|---|---|
| | **15 m/s** | | **17 m/s** | | **19 m/s** | |
| **ORDER FOR:** | M 1 | M 2 | M 1 | M 2 | M 1 | M 2 |
| Rudder | 100% | 80% | 100% | 100% | 100% | 100% |
| Right propeller | 52% | 36% | 55% | 36% | 61% | 40% |
| Left propeller | 75% | 65% | 90% | 70% | 96% | 90% |
| Bow thruster | 49% | 37% | 53% | 39% | 59% | 37% |

Source: Authors works.

Taking into account undertaken detailed analysis, general analysis and the maximum maneuvering areas in scenario 2 it can be stated (as for scenario 1) that present model (Mazovia_1) can safely perform static maneuvers up to wind of 15m/s. For wind from 15m/s to 17 m/s dynamic maneuvers should be performed, because large size of maximum maneuvering area for static maneuvers can be unacceptable. For wind over 19 m/s static maneuvers are impossible, large size of maximum maneuvering area for dynamic maneuvers can be unacceptable.

On the basis of analysis of trials carried out with rebuilt model (Mazovia_2) it can be stated that static maneuvers can be performed for wind up to 17 m/s. For wind over 17 m/s dynamic maneuvers are recommended, because large size of maximum maneuvering area for static maneuvers can be unacceptable.

For both models (Mazovia_1 for wind 17m/s and 19 m/s, Mazovia_2 for wind 19m/s) during the turn the thruster setting keeping the bow close to the berth should be decreased because the moment caused by propulsion and rudder was insufficient.

*Analysis of scenario 3 results.*
*Unberthing and departure, bow out, wind into berth direction.*

Detailed analysis of results achieved for trials carried out with Mazovia_1 and Mazovia_2 models is presented in table 5.

Table 5. Detailed analysis: relative minimal orders for rudder, propellers and thruster, expressed as a percent of maximum value, required for safe manoeuvring in each stage of scenario no 3. >100% - required settings exceed maximum possible settings, manoeuvre impossible.

| | | WIND | | | | | |
|---|---|---|---|---|---|---|---|
| | | **15 m/s** | | **17 m/s** | | **19 m/s** | |
| | **ORDER FOR:** | M 1 | M 2 | M 1 | M 2 | M 1 | M 2 |
| *Stage 1* | Rudder | 100% | 100% | >100% | 100% | >100% | 100% |
| | Right propeller | 54% | 42% | >100% | 55% | >100% | 56% |
| | Left propeller | 96% | 61% | >100% | 88% | >100% | 93% |
| | Bow thruster | 66% | 50% | >100% | 50% | >100% | 50% |
| *Stage 2* | Rudder | 100% | 100% | >100% | 65% | >100% | 100% |
| | Right propeller | 94% | 89% | >100% | 35% | >100% | 44% |
| | Left propeller | 66% | 45% | >100% | 38% | >100% | 38% |
| | Bow thruster | 73% | 50% | >100% | 78% | >100% | 92% |

Source: Authors works.

General analysis of results achieved for trials carried out with Mazovia_1 and Mazovia_2 models is presented in table 6.

Table 6. General analysis: average minimal orders for ruder, propellers and thruster, expressed as a percent of maximum value, required for safe manoeuvring in scenario no 3.

| | **WIND** | | | | | |
|---|---|---|---|---|---|---|
| | **15 m/s** | | **17 m/s** | | **19 m/s** | |
| **ORDER FOR:** | M 1 | M 2 | M 1 | M 2 | M 1 | M 2 |
| Rudder | 100% | 100% | >100% | 83% | >100% | 100% |
| Right propeller | 74% | 66% | >100% | 45% | >100% | 50% |
| Left propeller | 81% | 53% | >100% | 63% | >100% | 66% |
| Bow thruster | 70% | 50% | >100% | 64% | >100% | 71% |

Source: Authors works.

Taking into account undertaken detailed analysis, general analysis and the maximum maneuvering areas in scenario 3 it can be stated that present model (Mazovia_1) can safely perform static maneuvers up to wind of 15m/s. For wind 17m/s and 19 m/s neither static nor dynamic maneuvers are possible.

On the basis of analysis of trials carried out with rebuilt model (Mazovia_2) it can be stated that static maneuvers can be performed safely for wind up to 17 m/s. For wind exceeding 17 m/s dynamic maneuvers are recommended, they should increase transverse speed of the stern and thus increase rate of turn. The first stage is possible with static maneuvers.

*Analysis of scenario 4 results.*
*Unberthing and departure, stern out, wind into berth direction*

Detailed analysis of results achieved for trials carried out with Mazovia_1 and Mazovia_2 models is presented in table 7.

Table 7. Detailed analysis: relative minimal orders for rudder, propellers and thruster, expressed as a percent of maximum value, required for safe manoeuvring in each stage of scenario no 4. >100% - required settings exceed maximum possible settings, manoeuvre impossible.

| | | **WIND** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **15 m/s** | | **17 m/s** | | **19 m/s** | |
| | **ORDER FOR:** | M 1 | M 2 | M 1 | M 2 | M 1 | M 2 |
| *Stage 1* | Rudder | 100% | 100% | >100% | 100% | >100% | 100% |
| | Right propeller | 66% | 56% | >100% | 50% | >100% | 60% |
| | Left propeller | 96% | 90% | >100% | 89% | >100% | 91% |
| | Bow thruster | 77% | 50% | >100% | 50% | >100% | 50% |
| *Stage 2* | Rudder | 100% | 100% | >100% | 100% | >100% | 100% |
| | Right propeller | 97% | 64% | >100% | 75% | >100% | 74% |
| | Left propeller | 96% | 90% | >100% | 95% | >100% | 95% |
| | Bow thruster | 60% | 50% | >100% | 66% | >100% | 100% |

Source: Authors work.

General analysis of results achieved for trials carried out with Mazovia_1 and Mazovia_2 models is presented in table 8.

Table 8. General analysis: average minimal orders for ruder, propellers and thruster, expressed as a percent of maximum value, required for safe manoeuvring in scenario no 4.

| | **WIND** | | | | | |
|---|---|---|---|---|---|---|
| | **15 m/s** | | **17 m/s** | | **19 m/s** | |
| **ORDER FOR:** | M 1 | M 2 | M 1 | M 2 | M 1 | M 2 |
| Rudder | 100% | 100% | >100% | 100% | >100% | 100% |
| Right propeller | 82% | 60% | >100% | 63% | >100% | 67% |
| Left propeller | 96% | 90% | >100% | 92% | >100% | 93% |
| Bow thruster | 69% | 50% | >100% | 58% | >100% | 75% |

Source: Authors work.

Taking into account undertaken detailed analysis, general analysis and the maximum maneuverings areas in scenario 4 it can be stated (as for scenario 3) that present model (Mazovia_1) can safely perform static manoeuvres up to wind of 15m/s. For wind 17m/s and 19 m/s neither static nor dynamic manoeuvres are possible.

On the basis of analysis of trials carried out with rebuilt model (Mazovia_2) it can be stated that static manoeuvres can be performed safely for wind up to 17 m/s. For wind exceeding 17 m/s dynamic manoeuvres are recommended, they should increase transverse speed of the bow and thus increase rate of turn. The first stage is possible with static manoeuvres.

## CONCLUSIONS

Presented method used in simulation experiment enabled, on the basis of real data and expert opinion, verification of present model of m/f Mazovia (Mazovia_1). In the next stage the method allows for analysis of manoeuvrability of rebuilt model of the ferry (Mazovia_2). Safe and efficient range of ferry modernisation determined on the basis of simulations includes:

- 50% increase of rudder force;
- 50% increase of bowthrusters power.

The main conclusions concerning present model (Mazovia_1) are:

- upwind approaches and departures are carried out easily to the wind speed 15m/s, what is confirmed by real observations;

- for wind speed 15-17m/s dynamic manoeuvres should be used;
- dynamic manoeuvres are not preferred by captains of Mazovia due to maintaining margin of safety and company instructions;
- model cannot be safely manoeuvred for wind exceeding 17m/s from side;
- preference of static manoeuvres rather than dynamic decreases the range of permissible winds;
- berthing tactics used by captains in Ystad consist in not entering the basin is conservative and can be changed through the trainings in simulators.

Main conclusions concerning rebuilt model (Mazovia_2) are:

- model is able to manoeuvre statically for wind speed up to 17m/s;
- model is able to manoeuvre dynamically for wind speed up to 19m/s;
- manoeuvres for wind exceeding 19 m/s are dangerous.

Taking into account hydro-meteorological conditions [Tarnowska 2011], [Bergström and Söderberg 2009], [Hasager et al., 2011] and expert knowledge of captains of ferries manoeuvring in ports of South-West Baltic Sea [Determination, 2008], [Determination, 2010] critical values of wind speed that enables safe manoeuvres were evaluated. Table 9 shows achieved results for chosen ferries navigating in studied area.

Table 9. Critical values of wind speed for selected ferries.

| Ferry name | Average critical wind speed [m/s] |
|---|---|
| *Mikołaj Kopernik* | 15 |
| *Gryf* | 15 |
| *Dueodde* | 15 |
| *Hammerodde* | 16 |
| ***Mazovia*** (real) *Mazovia_1* (model) | **15 - 17** |
| *Galileusz* | 15 - 17 |
| *Pomerania* | 17 |
| *Wolin* | 16-18 |
| ***Mazovia_2*** (model) | **17 - 19** |
| *J. Śniadecki* | 19 |
| *Poovl Anker* | 22 |
| *Skania* | 21 - 24 |
| *Wawel* | 25 |
| *Polonia* | 27 |

Source: Authors work.

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**STRESZCZENIE**

W artykule opisano uniwersalną metodę symulacji używaną przez autorów dla określania bezpiecznych warunków operowania przez promy morskie w kontekście zasad inżynierii morskiej. Założenia, eksperyment symulacji i wyniki są opisane na przykładzie m/f Mazowsza manewrującego w Porcie Ystad.

Badania symulacyjne oparte o powyższą metodę i opisane w artykule zakładały określenie możliwości dostosowania systemów napędowych i sterowania promów włącznie z

- określeniem ograniczeń wiatru w porcie Ystad w kontekście możliwości manewrowych promu Mazovia;
- oszacowanie bezpieczeństwa manewrów w porcie oraz określenia warunków bezpieczeństwa operacji przy obecnych systemach napędowych i sterowych;
- określenie możliwości dostosowania układów napędowych i sterowych dla spełnienia oczekiwań armatora odnośnie ekonomiki i bezpieczeństwa operacji promowych.