Analysis of manoeuvering characteristics through sea trials and simulations

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Abstract. In recent years, Autonomous Surface Vehicles have secured the focus of major research and industrial initiatives around the world. Following this trend in the wake of fourth industrial revolution of oceans, Marine Autonomous Surface Ships (MASS) have become the center of numerous maritime-related research. Although the concepts of autonomous transportation systems were introduced decades ago, successful models and applications have only recently become a reality. [1] However, the research and development of MASS have acquired momentum over the years due to the technological advancements in maritime as well as in other academic domains. Even though there are numerous aspirations for developing autonomous ships, outcome focuses on greener shipping, optimum energy consumption and safe, as well as, efficient maneuvering. [2-5] Even though the concept of autonomous vessels seems promising, practical approach to designing an actual autonomous ship is a complex task. Hence, the postulated shift from conventional ships to autonomous ships are likely to follow a circumspect transition, rather than a steep development. [6] Although this has been discussed extensively, current progress of MASS research has been rapid due to positive advancements in technology.

As identified and recommended by recent research [7], the minimum requirement for an autonomous ship to be operational is that it should at least be as safe as a manned, conventional ship. In addition,
the safety of operation as well as personnel is identified to be the most important factor in developing MASS [8]. In order to achieve safe maneuvering in an autonomous operation, the control system is required to collect and process information. Based on the processed data, decisions on strategies are made. In a dynamic maritime environment, there are two main phases [9] [10] of motion planning. Namely, Long-term path planning (global path planning), where path or sailing route optimization is considered, and Short-term path motion planning (local path planning), where moving speed, heading and other maneuvering characteristics are considered for optimized sailing performances. Hence, prior accumulated maneuvering data is evidently important for predicting ship motion, as well as for simulating ship motion in a virtual environment. [11]

Ship simulating methods can vary depending on the approach and available data, although the fundamentals used are the same. A previous research done by Barr [12] was able to provide a comprehensive set of ways that can be utilized to predict maneuvering in calm water. Vessel motion prediction is mostly based on steady speed and constant heading, although methods adapting frequency domain approaches are more commonly utilized due to the higher computational efficiency when compared to time domain approaches. Moreover, strip theory is commonly adapted when solving hydrodynamic forces and they are summed over 2D cross sections along the ship length. [13] With the advancements in computational powers, motions in waves now can be predicted accurately. In addition, three-dimensional components of hydrodynamic forces can be simulated with improved precision. [14] However, there are limits to the exact application of vessel’s maneuverability because the ship’s performance and maneuverability deteriorate with time in sea. Therefore, maneuvering characteristics at design stage has to be tested and compared after the ship is commissioned.

The present study is threefold, structured to adhere further development of future research and a validation of a computer simulator program. First, the study is focused on identifying the benchmark results and maneuvering data for the subject ship, in order to carry out real-ship experiments in an open sea environment. Once the initial conditions are identified and discussed, second part of the paper is focused on standard real-ship experiments, which were carried out over a period of three years. Special equipment used, methodology and results are discussed. Data were accumulated and analyzed in detail to identify deviations and subsequently, to compare with initial benchmark values. Final part of the study is ongoing with a greater scope, where a specific model ship simulator is constructed to predict and analyze the standard maneuvering characteristics in open-sea environments. This particular article includes the simulation data and results of the aforementioned program for clarification and the results from both real-ship trials and simulations are compared to draw conclusions, and to validate the simulator program.

2. Training ship status

The subject vessel is registered under the South Korean flag and is categorized as a research and a training vessel. Personnel capacity of the vessel is 246 and the ship particulars are shown in Table 1.

| Ship particular parameter                     | Value       |
|----------------------------------------------|-------------|
| Length Overall (LOA)                         | ~ 117.20 m  |
| Length Between Perpendiculars (LBP)          | 104.00 m    |
| Breadth, Molded                              | 17.80 m     |
| Depth, Molded                                |             |
| Main Deck                                    | 8.15 m      |
| Upper Deck                                   | 10.80 m     |
| Designed load draft, molded                  | 5.90 m      |
| Displacement                                 | ~ 6418.00 ton |
| Deadweight                                   | 2868.00 ton |
| Gross tonnage                                | ~ 6,700 ton |
| Scantling draft                              | 6.2 m       |
Initial maneuvering trials were conducted by the ship building company after commissioning the vessel in 2005. (Training ship particulars, Korea Maritime & Ocean University) These tests included standard turning circle test and 20°/20° zig-zag test.

Tactical diameter, transfer at 90° change of heading, maximum advance, times to change heading 90° and 180°, and transfer loss of steady speed were recorded during the turning circle test. Moreover, initial turning time, overshoot angle and yaw checking time were recorded through the 20°/20° zig-zag test.

Test environment and the information related to external factors in turning tests are shown in Table 2.

Table 2. External factors and test environment during turning circle test.

| Parameter                  | PORT Turning | STBD Turning |
|----------------------------|--------------|--------------|
| Initial Heading (deg.)     | 201.1        | 201.5        |
| Sea Condition              | Fresh Breeze |              |
| Depth                      | 110          | 110          |
| Direction                  | 55.0         | 86.0         |
| T. Wind                    | 10.3         | 9.9          |
| M/E RPM (Initial/End)      | 176.1/108.8  | 181.7/129.6  |
| Speed (kts) (Initial/End)  | 17.6 / 6.0   | 17.5 / 6.8   |
| Ruder Angle (deg.)         | -34.1        | 32.5         |
| Advance (m)                | 329.939 (3.2LBP) | 311.941 (3.0LBP) |
| Transfer (m)               | 195.238 (1.9LBP) | 193.897 (1.9LBP) |
| Tactical Diameter (m)      | 374.561 (3.6LBP) | 407.006 (3.9LBP) |

Information of the test environment and external parameters in initial 20°/20° zig-zag test are shown in Table 3, where the initial ship-maneuvering criterion related to ship performance prior to, and during the test are tabulated.

Table 3. External factors and test environment during 20°/20° zig-zag test.

| Parameter                  | Value           |
|----------------------------|-----------------|
| Initial Heading (deg.)     | 351.1           |
| Sea Condition              | Strong Breeze   |
| Depth (m)                  | 110             |
| R. Wind                    | 334.0           |
| Velocity (kts)             | 39.7            |
| M/E R.P.M. (Initial/End)   | 177.5 / 177.4   |
| Speed (kts) (Initial/End)  | 18.8 / 14.6     |
| 1st Overshoot Angle (deg.) | 17.6            |
| 2nd Overshoot Angle (deg.) | 16.2            |

Initial results of turning circle maneuver and 20°/20° zig-zag tests are graphically represented in Figure 1. When the initial results of turning circle diameter test are considered, it was noted that the designed parameters are within the IMO accepted ranges, [15] given that, advance, transfer and tactical diameter are 3.2-3.0 LBP, 1.9-1.9 LBP, and 3.6-3.9 LBP on both port and starboard sides, respectively. Similar, 20°/20° zig-zag test results were noted to show that the first overshoot angle is less than 25 degrees and agrees with the IMO standards related to maneuvering performance characteristics. [15]
3. Sea trials and analysis

Main purpose of carrying out the sea trials was twofold: first, to compare current maneuvering characteristics with initial test results to analyze and identify possible deviations; and secondly, to acquire precise maneuvering data to use as the benchmark to validate the simulator program. Thus, special equipment were used and standard turning circle test and 20°/20° zig-zag test were carried out multiple times with different loading and weather conditions. Parameters related to the standard maneuvering tests, as well as additional parameters such as, rolling, trim, pitching and acceleration were recorded for further analysis.

3.1 Methodology of sea trials

For measuring the real-ship maneuvering performance, an Inertial Measurement Unit (IMU) consisted of a 3-axis accelerometer with a built in gyrocompass, two Global Positioning Systems (GPS) receivers and a laptop equipped with dedicated software were used. IMU was installed along the centerline of the vessel, on the deck in par with vessel’s center of gravity. Two receivers (main and secondary) were installed on either sides, parallel to the centerline. The IMU used in trials, which is a GPS aided inertial navigation system named “Spatial Fog Dual”, is showed in Figure 2. Accurate position, velocity, and acceleration of the vessel during the sea trials were measured using the spatial fog dual. Apparatus was consisted of fibre optic gyroscopes, magnetometers, accelerometers and a pressure sensor with a dual antenna Real-time Kinematic Global Navigation Satellite System (RTK GNSS) receiver.

Integration of the GPS receivers, IMU and dedicated software used in real-ship experiments, and the graphical user interface (GUI) of the software are shown Figure 3.
Once the equipment were installed, the ship was maneuvered following the standard turning circle and 20°/20° zig-zag test procedures and data were recorded. Same experiment was carried out over a period of three years; from 2017 to 2019. Each test was carried twice a year to ensure accuracy. This data was then tabulated and represented graphically to identify the changes in maneuvering characteristics of the training ship.

3.2 Comparison of initial and ongoing sea trials data

Importance of using specific equipment for the trials is reemphasized, and data was collected from the turning circle test and 20°/20° zig-zag test over the course of three years, from 2017 to 2019.

Time and location of ship trials are included for precision and transparency. Information such as advance, transfer and turning circle diameter (TCD) related to turning test, and overshoot angles related to 20°/20° zig-zag test are tabulated. For further clarification, initial test data is included in study.

It should be noted that the data recorded using the Navigational Decision Support System (NDSS), together with IMU and other apparatuses, provide an un-calibrated result. In order to identify parameters such as TCD and advance, equipment were calibrated accordingly, and was an important part of the study. Difference between pre and post-calibrated results are shown in Figure 4 for clarification.

![Figure 3. Integration of GPS receivers and IMU (Left) and GUI (Right).](image)

![Figure 4. Graphical representation of pre and post-calibrated data of two starboard-side turning circle tests with different heading angles, 90° and 270°.](image)

Each real-ship test included a turning circle test and a 20°/20° zig-zag test and all parameters were recorded accordingly. Moreover, environmental conditions such as wind, current, tide direction and wave height etc. were measured to evaluate external factors during the tests.
Collected data is summarized in Table 4. 17-1, 17-2, 18-1 and 18-2 denote the first and second tests done in each year in 2017 and 2018, respectively. 19-1A, 19-1B, 19-2A, 19-2B denote the first and second tests done in 2019 with two different heading angles, A and B (90° and 270°, respectively), in order to expand the data range for accuracy, starting from 2019. (20°/20° zig-zag and starboard turning test) Advance, transfer and tactical diameter are tabulated with respect to LBP, which is 104 (m).

**Table 4.** Comparison of initial test in 2005 and test trails data from 2017 to 2019.

| Date            | Initial | 17-1 | 17-2 | 18-1 | 18-2 | 19-1A | 19-1B | 19-2A | 19-2B |
|-----------------|---------|------|------|------|------|-------|-------|-------|-------|
| Date            | 2005. 11.18 | 2017.09.08 | 2017.10.28 | 2018.10.12 | 2019.04.08 | 2019.04.08 | 2019.04.22 | 2019.04.22 |
| Sea Area        | Busan | Busan | South China Sea | Vietnam | Jeju | Ulsan | Ulsan | East sea | East sea |
| Environment     |        |       |       |       |       |       |       |       |       |
| Condition       | Wind (m/s) | Current (kts) | Tide Direction (rel. deg.) | wave height (m) |        |       |       |       |       |
|                 | 10.3 | 2.3 | 5.3 | 1.9 | 6 | 9.1 | 9.1 | 12.4 | 12.4 |
|                 | 1.3 | 0.4 | 0.2 | 0.7 | 1 | 1 | 0.9 | 0.9 |       |
|                 | 100 | 220 | 345 | 305 | 90 | 270 | 90 | 270 |       |
|                 | 0.3 | 0.3 | 0.2 | 0.6 | 0.3-0.5 | 0.3-0.6 | 0.3-0.7 | 0.3-0.8 |
| Loading         | Disp. (ton) | -1.137 | -1.49 | -0.98 | -0.54 | -0.03 | -0.82 | -0.82 | -0.92 |
| Condition       | Trim (m) | -2.14 | -1.77 | -1.25 | 0.48 | -1.16 | -1.16 | -1.22 | -1.22 |
|                 | LCG (m) | - | | | | | | |
| Turning (P)     | Init. SPD (kts) | 17.6 | 11.7 | 11.2 | 11.5 | 10.3 | 10.6 | 10.2 |       |
|                 | Rudder (deg.) | -34.1 | -35.7 | 33.7 | -35.1 | -34.3 | -34.4 | -34.3 |       |
|                 | Advance (m(LBP)) | 3.2 | 2.68 | 3.44 | 3.16 | 2.75 | 3.25 | 2.82 |       |
|                 | Transfer (m(LBP)) | 1.9 | 1.68 | 1.38 | 1.62 | 1.73 | 2.26 | 1.56 |       |
|                 | Tac. Dia. (m(LBP)) | 3.6 | 3.37 | 3.36 | 3.24 | 2.1 | 3.51 | 3.26 |       |
|                 | Drift Angle (deg.) | - | 2.5 | -2.4 | -1.6 | 0.1 | 5.1 | -1.7 |       |
| Turning (S)     | Init. SPD (kts) | 17.5 | 10.2 | 11.2 | 10.9 | 10.1 | 10.4 | 10.4 | 10.2 |
|                 | Rudder (deg.) | 32.5 | 35.3 | 30.7 | 34.2 | 34.6 | 34.7 | 34.7 | 34.7 |
|                 | Advance (m(LBP)) | 3 | 2.99 | 3.33 | 2.78 | 3.01 | 3.25 | 3.17 | 3.05 |
|                 | Transfer (m(LBP)) | 1.9 | 1.57 | 1.79 | 1.97 | 1.56 | 1.71 | 2.56 | 1.41 |
|                 | Tac. Dia. (m(LBP)) | 3.9 | 3.3 | 3.94 | 3.65 | 3.43 | 3.38 | 3.52 | 3.47 |
|                 | Drift Angle (deg.) | - | 12.3 | -1.2 | -0.5 | -0.2 | 5.2 | -4.5 | 3.2 |
| Zig-Zag 20      | Init. SPD (kts) | 18.8 | 12.5 | 11.2 | 12.7 | 10 | 10.3 | 10.1 | 9.8 |
|                 | 1st OA | (177.5 rpm) | (120 rpm) | (120 rpm) | rpm | rpm | rpm | rpm | rpm |
|                 | Drift Angle (deg.) | - | 5.3 | 8.4 | 10.8 | 10.6 | 6 | 6.7 |       |
Calibrated turning circle data (port and starboard) over the time span from 2017 to 2019 are graphically represented in Figure 5. Changes and differences in parameters in each turning circle test are evaluated through the analysis and the primary benchmark for simulations were set using the aforementioned data. Results of real-ship turning circle tests are summarized in following representation.

Similarly, 20°/20° zig-zag tests were carried out twice a year, over the time span of three years. (Data is tabulated in Table 4) In this particular paper, only the graphical representation of the last two zig-zag tests, which were carried out in 2019 are included. First test was carried out (19-1A) with a relative angle of 90 degrees, and the second 20°/20° zig-zag test (19-1B) with a relative angle of 270 degrees. Figure 6 represents the said results; however, the complete data analysis is included in the study.

Similarly, data was collected for all 20°/20° zig-zag tests, which were carried out from 2017 to 2019. Analysis was primarily focused on turning circle data and it was noted that, with the increment of initial speed, advance increases and consequently, advance decreases with the increment of rudder angle. Moreover, increment of turning circle diameter was noted with the increasing values of displacement. However, the need of having a controlled environment for simulations more than the real-ship tests were clarified since external parameters evidently cause an unpredictable variation in maneuvering results. Thus, the importance of accumulating real-ship test results in MASS and decision-making system design was established.

4. Simulations

Two vital parts were focused under the simulations. First, the mathematical model used in simulation is discussed, and second, the process of constructing the simulation program for the subject vessel, using a model approach to predict maneuvering characteristics and validating it with real-ship data were carried out.
Mathematical modeling of seakeeping and simulations have proven to be vital in utilizing automatic control in marine vessels for several years. However, there is a limited number of robust and versatile applications available due to the complexity of the models. A model was proposed by Son and Nomoto, combining test data obtained for lateral motion through planar motion mechanism (PMM), integrating different values of static heel with roll motion tests. Moreover, multiple models were proposed using experimental data in a unique 4 degree of freedom roll planar motion mechanism (RPMM). In this study, however, a standard mathematical model is followed to approach a simpler model to simulate maneuvering procedures of the subject vessel.

4.1 Mathematical model

A bi-dimensional approach is considered in this study, with two reference frames; one of them fixed and the other one moving with the vessel, as shown in Figure 7(a).

![Figure 7. (a) Reference frames and motion variables (Left), (b) Motion coordination system (Right).](image)

4.2 Equations of motion

When defining the equations of motions, moving coordination system in Figure 7(b), was used. Actual velocity (U) of vessel is resolved as transversal velocity (v) and advance velocity (u). (N) is the rotational velocity, r is the turning rate, and (β) is the drift angle, which is the angle between U and x-axis. ψ and δ are the ship heading angle and rudder angle, respectively.

Vessel is considered a solid object with three degrees of freedom; surge, sway and yaw. Dynamical model of the ship motion can be written as follows.

\[
\begin{align*}
(m' + m_x')(\frac{U}{U} \cos \beta - \beta \sin \beta) + (m' + m_y')r'\sin \beta &= X' \\
(m' + m_y')(\frac{U}{U} \sin \beta - \beta \cos \beta) + (m' + m_x')r'\cos \beta &= Y' \\
(L'x + J_{zz})(\frac{L'}{L} \frac{U}{u} + \frac{U}{L} \frac{r'}{r}) &= N'
\end{align*}
\]

Superscript (') in equations denotes the non-dimensional quantities and thus, X’, Y’ and N’ define the dimensionless surge, sway forces and yaw moment acting on ship, respectively. m’, m_x’, and m_y’ denote the dimensionless mass of vessel and added masses in x and y directions. Ship length and draft are denoted as L and T.

The forces and moments noted on the right side of the equations can be described separately, following the concept of maneuvering modeling group (MMG) model, as follows.

\[
\begin{align*}
X' &= X'_H + X'_P + X'_R \\
Y' &= Y'_H + Y'_P \\
N' &= N'_H + N'_R
\end{align*}
\]

Where, subscripts H, P and R denote hull, propeller and rudder, respectively. Subsequently, the forces are separately defined as follows.
4.2.1 Forces and moments acting on hull

\[ X_H = \{X'_{\beta r} r' \sin \beta + X'_{uu} \cos^2 \beta \} \] (7)

\[ Y_H = \{Y'_{\beta r} + Y'_{r' r} + Y'_{\beta \beta} \beta |r'| r' \} \] (8)

\[ N_H = \{N'_{\beta r} + N'_{r' r} + N'_{\beta \beta} \beta |r'| r' \} \] (9)

Longitudinal component of hydrodynamic force (\(X'_{H} \)), lateral force (\(Y'_{H}\)) and yaw moment (\(N'_{H}\)) are approximated at amidships by above polynomials. \(X'_{uu}\) in longitudinal component of hydrodynamic force denotes the ship resistance in forward straight motion. \(Y'_{\beta}, ..., N'_{\beta \beta}\) are non-linear hydrodynamic derivatives, derived from regression on various hull experimental tests. [19]

4.2.2 Forces and moments induced by propeller

Hydrodynamic forces created by the propeller are as follows, as proposed by Kajima et al. [20]

\[ X_P' = \frac{K_T(J_P)}{0.5pLdU^2} C_{rp}(1 - t_P)n^2D_P^4 \] (10)

\[ Y_P' = 0 \] (11)

\[ N_P' = 0 \] (12)

\[ K_T(J_P) = C_1 + C_2J_P + C_3\beta \] (13)

\[ J_P = \frac{U \cos \beta (1 - w_P)}{nD_P} \] (14)

Where, \(t_P\) is the thrust deduction coefficient, \(N\) is propeller revolutions, \(D_P\) is propeller diameter, and \(w_P\) is wake fraction coefficient. \(K_T\): thrust coefficient, \(C_{rp}, C_1, C_2, C_3\) are constant for propeller open water characteristics, and \(J_P\) is the advance coefficient. In this section, lateral force and yaw moment are neglected.

4.2.3 Forces and moments induced by rudder

Rudder induced forces and moments are defined following a proposed model. [20]

\[ X_R' = -(1 - t_R)F'_N \sin \delta \] (15)

\[ Y_R' = -(1 + a_H)F'_N \cos \delta \] (16)

\[ N_R' = -(x_R + a_H x_H)F'_N \cos \delta \] (17)

Where, \(F'_N\): dimensionless rudder normal force, \(\delta\): rudder angle, and \(a_H\) (ratio of additional lateral force), \(t_R\) (coefficient for additional drag), \(x_H\) and \(x_R\) denote the rudder-to-hull interaction coefficients. Total sway and surge forces and yaw moment were calculated following the MMG model as derived in equation 1 to equation 17, and consequently, the distance parameters (X and Y) were obtained. Simulation results of 35\(^{th}\) starboard and port turning tests are graphically illustrated in Figure 8, and the simulation conditions are tabulated in Table 8.

![Figure 8. Turning circle (35\(^{th}\)) simulation test results.](image-url)
Table 5. Simulation conditions for Port and STBD 35° turns.

|                     | Port turning test | STB turning test |
|---------------------|-------------------|------------------|
| Draft (m)           | 5.9               | 5.9              |
| Trim (m)            | 0.0               | 0.0              |
| Initial speed (kts) | 10.5              | 10.5             |
| Advance (LBP) a     | 3.578             | 3.48             |
| Turning circle diameter (LBP) | 4.5           | 4.32            |

a LBP = 104 (m)

Simulations were carried out to obtain $20^\circ/20^\circ$ zig-zag parameters. The simulation conditions are tabulated in Table 6, and the respective results are illustrated in Figure 9.

Table 6. Simulation conditions for $20^\circ/20^\circ$ zig-zag

|                       | $20^\circ/20^\circ$ Zig-zag test |
|-----------------------|----------------------------------|
| Draft (m)             | 5.9                              |
| Trim (m)              | 0.0                              |
| Initial speed (kts)   | 10.5                             |
| First overshoot angle (deg.) | 11.21                          |
| Second overshoot angle (deg.) | 9.52                           |

Figure 9. $20^\circ/20^\circ$ zig-zag simulation test results.

5. Result analysis

Analysis of preliminary results related to turning circle (port and starboard) and $20^\circ/20^\circ$ zig-zag test are tabulated in Table 7. All test results were compared and analyzed with IMO criterion and initial test values of the subject vessel. (Average result of each test represents the average value calculated using the series of respective real-ship test results, tabulated in Table 4.)

Table 7. Turning circle test results analysis.

|               | Turning circle diameter (LBP) a | $20^\circ/20^\circ$ zig-zag test |
|---------------|---------------------------------|----------------------------------|
| Portside      | 3.6                             | 3.9                              |
| Starboard side| 3.14                            | 3.53                             |
| First overshoot angle (deg.) | 8.85                          |
| IMO criterion | 5                               | 5                                |
| Simulation value | 3.57                          | 3.49                             |

When test results of turning circle maneuver are considered, it is clear that the simulation results are in par with both average and initial values of turning circle test. Based on the results, the simulation results obtained from the TCD simulations were validated and the vessel is recognized to be operating under maneuvering criterion recommended by the IMO. Comparison of aforementioned data is illustrated in Figure 10.
Similarly, 20°/20° zig-zag test results were analyzed, focusing on the first overshoot angle. As per the recommendation of IMO [15], value of the first overshoot angle in 20°/20° zig-zag test should not exceed 25 degrees. Average value of overshoot angle from each real-ship test was calculated and compared with the simulation results for validation. IMO criterion, first overshoot angles of each test, initial value of first overshoot angle and simulation results of 20°/20° zig-zag test are tabulated in Table 7 and graphically represented in Figure 11.

6. Conclusions

Purpose of carrying out the study was primarily to accumulate data through standard maneuvers, in order to analyze maneuvering characteristics of a training vessel with a gross tonnage of 6,700 ton. Secondary focus of the study was to develop and validate a comprehensive yet versatile simulation program for the specific vessel, to simulate and predict its vital maneuvers. Once adequate data were collected, maneuvering characteristics of the ship over a period of three years were analyzed to identify changes, which occurred over time as well as deviations due to different variables, such as displacement, and subsequently LCG and trim.

Analysis suggested that the advance and turning circle diameter of subject vessel tend to vary around base values, which were obtained initially after commissioning. Moreover, all the test results were evidently rested well within the limitations defined by the IMO, concluding the safety of operation in maneuvering of training vessel. Simulation program was used to obtain data for standard maneuvering tests and the data was then compared with values obtained from real-ship experiments. After successful comparisons, the simulation results were validated. Results obtained from simulations were identified to be within the safe limitations recommended by the IMO. Consequently, the developed simulation program was validated. In addition, the importance of accumulating real-ship data in different conditions with varying external factors in constructing simulation environments is emphasized.

Defining and using the external conditions and parameters within a simulated environment for the training vessel is identified as the future work of the study. Moreover, it is planned to carry out the standard maneuvering tests using the subject vessel to accumulate more data, in order to rectify and
further validate the results obtained through simulations. It is evident that more variations in parameters and, deviations in experimental values are caused by external factors. Therefore, data that is more continuous are identified to be useful in making an accurate simulator program, which can aid in autonomous decision making when standard maneuvers are needed to be carried out.

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