Simulation of Collision Avoidance by Considering Potential Area of Water for Maneuvering based on MMG Model and AIS Data

I. Putu Sindhu Asmara[1,2], Eiichi Kobayashi[1] and Trika Pitana[3]
[1]Graduate School of Maritime Sciences, Kobe University, 5-1-1 Fukae-Minami Higashinada, Kobe, Japan
[2]Department of Shipbuilding and Naval Architecture, Surabaya Shipbuilding State Polytechnic, Surabaya, Indonesia
[3]Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Keywords: Collision Avoidance, PAW for Maneuvering, Ship Maneuverability, MMG Model, AIS Data.

Abstract: A vessel should follow a planned route. However, when a target ship deviates from its original track, the subject ship should maneuver to avoid a ship-to-ship collision. This paper presents a trial maneuver-based method for collision avoidance that considers the potential area of water (PAW) for maneuvering that is available to the target ship. The initial conditions, including the position, speed, rudder angle, drift angle, and yaw rate of the target ship, are derived from automatic identification system (AIS) data. AIS data from Madura Strait were used to simulate collision avoidance. The PAW of the target ship was predicted based on a probability distribution of the initial conditions using a mathematical maneuvering group (MMG) model. Finally, a trial maneuver method for the subject ship was simulated to avoid a ship-to-ship collision. The MMG model for the simulation was developed to consider the effects of shallow water and wind and current disturbances.

1 INTRODUCTION

The potential area of water (PAW) for maneuvering is defined as the water area that can be used before a ship's movement is completed if the navigator encounters an emergency, such as the need to perform a crash astern (Inoue, 1990). The PAW was originally developed by superimposing ship paths predicted by a ship navigating simulator. These ship paths resulted from variations in the times needed for a crash astern.

In this study, the PAW was developed based on the variation in time needed to take action and by considering the uncertainty in ship maneuverability caused by the probability distribution of the initial conditions. The probability distribution of the ship maneuverability in terms of ship advancement is significantly affected by the probability distributions of the initial yaw rate and drift angle (Asmara et al., 2012). The PAW of the target ship was predicted based on initial conditions derived from automatic identification system (AIS) data. The maneuvers of a subject ship were simulated to restrict the PAW when trying to avoid a ship-to-ship collision. A trial maneuver-based method using a mathematical maneuvering group (MMG) model was simulated for collision avoidance.

The MMG model was developed by considering the effects of shallow water, wind forces and moment, and current. A Monte Carlo algorithm was developed for the MMG model to randomize the initial ship conditions based on the distribution derived from the AIS data.

AIS data for the Madura Strait were taken from a server in a laboratory at ITS, Indonesia. The Surabaya canal in the strait is the most important fairway located between Java and the Madura Islands. Tanjung Perak Port, which is located in the strait, plays an important role in domestic and international trading. A new port in Lamong Bay near Tanjung Perak is being developed in anticipation of an increase in the number of ship calls.

A subject ship exiting the new port in Lamong Bay was simulated to avoid collision with a target ship entering Tanjung Perak Port. Maneuvering parameters were proposed for ships to enter and exit the port area based on the PAW for maneuvering. Figure 1 shows the positions in the port area.

Putu Sindhu Asmara I., Kobayashi E. and Pitana T..
Simulation of Collision Avoidance by Considering Potential Area of Water for Maneuvering based on MMG Model and AIS Data.
DOI: 10.5220/0004478002430250
In *Proceedings of the 3rd International Conference on Simulation and Modeling Methodologies, Technologies and Applications* (SIMULTECH-2013), pages 243-250
ISBN: 978-989-8565-69-3

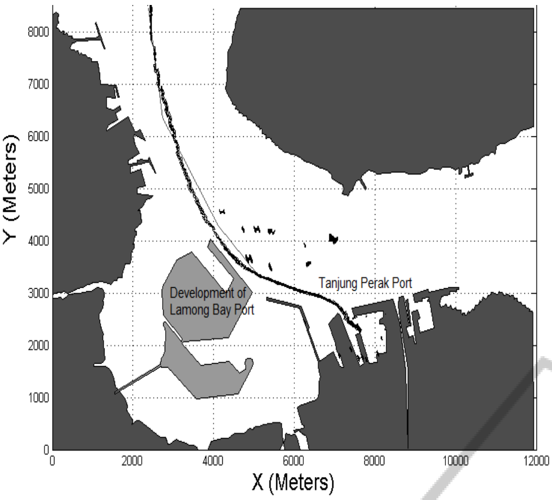

Figure 1: Area of Lamong Bay Port.

Figure 1 shows a target ship entering Tanjung Perak. The ship deviates from the passage to avoid collisions with vessels anchored out of the anchorage zones. This paper proposes a method for analyzing the maneuvering safety in a port area.

2 LITERATURE REVIEW

The distance to the closest point of approach (DCPA) and time to reach the point (TCPA) are generally used in collision risk assessment and collision avoidance systems. Szlapczynski (2006) introduced the approach factor *f* as a new measure of collision risk that considers the courses of both ships and can be used for any type of ship domain. Wang et al. (2009) proposed mathematical descriptions for each type of ship domain.

The minimum distance to a collision (MDTC) is simulated based on the position, course, speed, and maneuverability of ships to develop a quantitative assessment of marine traffic safety (Montewka et al., 2009). The effects of external disturbances and the possibility of a crash astern are not considered in the simulation.

Fujiwara et al. (2001) developed a method to estimate the wind forces and moments acting on a ship. They developed a linear multiple regression model based on experimental results for ships built after Isherwood and Yamano's experiment in the 1970s.

Terada (2009) developed a method to estimate the maneuverability of a ship under an external disturbance using a linear maneuvering model; the estimated ship trajectory is compared with that of the nonlinear maneuvering of an MMG model. Kobayashi (1995) developed an MMG model to evaluate ship maneuverability in shallow water.

Soda et al. (2012) numerically simulated the weather and ocean in a bay by using the Princeton oceanography model for tidal currents, a fifth-generation mesoscale model for the wind over the sea, and simulated waves in Osaka Bay for research on ship navigation. They used the MMG model to estimate the ship positions in the simulations.

Xia et al. (2006) investigated the ability of a small ship to sail on a planned route by studying navigation simulation in coastal water. The navigation simulation results based on an MMG model were compared with the results of onboard experiments.

Inoue and Usui (1998) systematically analyzed the difficulty of maneuvering a ship between anchored ships by using an environmental stress model; the arrangement of the anchorages was designed based on the allowable level of difficulty for mariners.

Zhuo et al. (2008) used the MMG model for trial maneuvers to develop a ship-based intelligent anti-collision decision-making support system. This system assumes that the AIS is installed onboard, and an offline adaptive neuro-fuzzy inference system is used to obtain the time to take action for ship-to-ship collision avoidance. The time to take action and the angle between the original and new courses are determined.

Tsou et al. (2010) did not use an MMG model when studying ship collision avoidance. An ant colony algorithm was implemented on a GIS platform to provide collision avoidance route planning.

In this study, a trial maneuver-based collision avoidance method was developed based on the uncertainty of the PAW. The safe distance was determined based on the uncertainty of the maneuverability expressed by the PAW. A simulation was developed using an MMG model that considers the effects of shallow water and wind and current disturbances.

3 MMG MODEL

The MMG model was developed based on a practical simulation system to evaluate ship maneuverability in shallow water (Kobayashi, 1995). The coordinate system is shown in Figure 2. The effect of shallow water on ship maneuverability is calculated based on Equations 1–5 (Kobayashi,

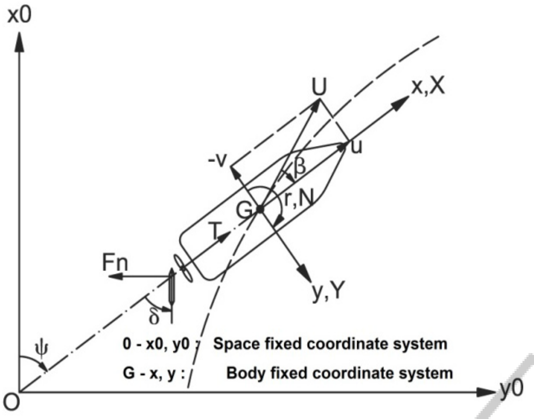

Figure 2: Coordinate system.

1995). The effect of shallow water on ship maneuverability is calculated based on Equations 1–5 (Kobayashi, 1995). The hull resistance in shallow water is corrected based on the Millward formula, as shown in Equation 1.

$$K_s = K_d + 0.644(\mathrm{d/H})^{1.72} \tag{1}$$

where K_d and K_s are resistance form factors in deep and shallow waters, respectively, and H is the water depth.

Linear swaying derivative Y_v' is refined according to Equation 2 as follows.

$$(Y_v')_s = (Y_v')_d \left\{ \frac{\frac{\pi}{2}(1 / (\frac{d}{2H}(k + \pi\, cot \frac{\pi}{2}\frac{d}{H})))^{q_1} + pC_b\, B/L}{\pi k/2 + pC_b\, B/L} \right\} \tag{2}$$

where $k = 2d/L$ is the aspect ratio, Cb is the block coefficient, B is the width of the ship, and p is equal to 1.4 (Yoshimura and Masumoto, 2012). Other linear derivatives are expressed in Equation 3.

$$\frac{(N_v')_s}{(N_v')_d}, \frac{(Y_r')_s}{(Y_r')_d}, \frac{(N_r')_s}{(N_r')_d}, etc. = \left(\frac{1}{1 / (\frac{d}{2H}(k + \pi co\, t \frac{\pi}{2}\frac{d}{H}))}\right)^{q_2} \tag{3}$$

where $q1$ = 3, $q2$ = 1.4 for N_v', $q2$ = 1.2 for Y_r', and q2 = 0.5 for N_r'. The added mass and added mass moment of inertia are corrected using Equation 4.

$$\frac{(Coefficient)_s}{(Coefficient)_d} = 1 + q_3(tan\frac{\pi}{2}(\frac{d}{H}))^{q_4} \tag{4}$$

where $q3$ = 0.21 and $q4$ = 1.2 for $m' + my'$, and $q3$ = 0.15 and $q4$ = 1.2 for $Izz' + Jzz'$. The effect of shallow water on other coefficients such as $f(v' + l_R'r'), \varepsilon$, and κ is expressed by Equation 5.

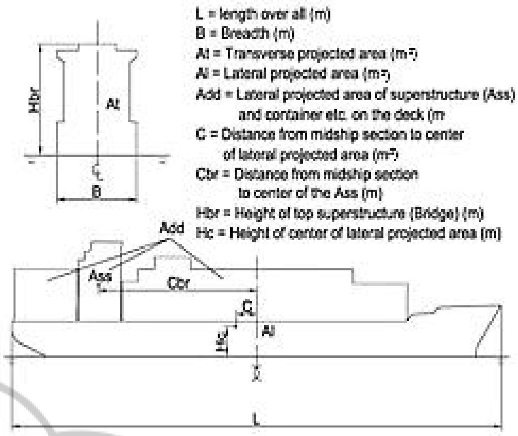

Figure 3: Variables of wind forces and moment.

$$\frac{(Coefficient)_s}{(Coefficient)_d} = 1 + q_5(\frac{d}{H})^{q_6} \tag{5}$$

where q5 = 1.4 and q6 = 3 for $\mathrm{f}(\mathrm{v}' + \mathrm{l}_\mathrm{r}' \mathrm{r}')\mathrm{f}(\mathrm{v}' + \mathrm{l}_\mathrm{r}' \mathrm{r}')$, q5 = 0.8 and q6 = 3 for ε, and q5 = –1.2 and q6 = 3 for κ.

The effect of wind on ship maneuvering is calculated in the mmg model based on the estimated wind forces and moment, as expressed by equations 6–8 (fujiwara et al., 2001).

$$X_w = \frac{1}{2}\rho_{air}U_w^2 A_T(X_0 + X_1 cos\Psi + X_3 cos3\Psi + X_5 cos5\Psi) \tag{6}$$

$$Y_w = \frac{1}{2}\rho_{air}U_w^2 A_L(Y_1 sin\Psi + Y_3 sin3\Psi + Y_5 sin5\Psi) \tag{7}$$

$$\mathrm{N}_w = \frac{1}{2}\rho_{air}U_w^2 L A_L(N_1 sin\Psi + N_2 sin2\Psi + N_3 sin3\Psi) \tag{8}$$

where ρ_{air} is the density of air, Uw is the velocity of wind, L is the length overall (LOA) of the ship, Ψ is the attack angle, A_T is the transverse projected area, and A_L is the lateral projected area. Other parameters are determined using regression equations based on the variables described in Figure 3.

Current forces and moment are calculated according to Equations 9–11 (Wichers, 1988).

$$\mathrm{X_c} = \frac{1}{2}\rho \mathrm{dL}.\, \mathrm{U_r^2}.\, \mathrm{C_{1c}}(\psi) \tag{9}$$

$$Y_c = \frac{1}{2}\rho dL.\, U_r^2.\, C_{2c}(\psi) \tag{10}$$

$$\mathrm{N}_c = \frac{1}{2}\rho dL^2.\, U_r^2.\, C_{6c}(\psi) \tag{11}$$

where ρ is the density of water, d is the ship draft, L is the LOA of the ship, and $U_r = \sqrt{(u-u_c)^2 + (v-v_c)^2}$ is the relative current velocity. The hydrodynamic coefficients of $C_{1c}(\psi)$, $C_{2c}(\psi)$, and $C_{6c}(\psi)$ are calculated based on other studies (Leite et al., 1998, and Souza and Fernandes, 2005), where $\psi = tan^{-1}(v-v_c, u-u_c)$ is the attack angle of the current.

4 AIS DATA

The AIS data were obtained from an AIS receiver installed at the Institut Teknologi Sepuluh Nopember, Indonesia. The installation was performed with the cooperation of Kobe University, Japan.

Table 1: AIS data of target ship, MMSI 370017000.

Time	Longitude	Latitude	COG (degrees)	Heading (degrees	SOG (knots)
83942	112.67886	-7.16600	160.00	157.14	8.79
84002	112.68019	-7.16915	157.42	154.03	8.76
84062	112.68103	-7.17101	154.89	150.00	8.58
84122	112.68186	-7.17272	151.56	150.00	8.08
84182	112.68319	-7.17519	149.42	145.81	7.54
84242	112.68403	-7.17675	147.00	144.89	7.29
84302	112.68486	-7.17814	147.00	141.56	7.13
84362	112.68639	-7.18018	142.00	139.81	6.78
84422	112.68803	-7.18130	141.97	138.94	6.70
84482	112.68886	-7.18267	141.14	137.28	6.61
84542	112.69019	-7.18453	136.22	133.22	6.48
84602	112.69106	-7.18558	132.92	129.86	6.40
84662	112.69272	-7.18661	130.42	125.69	6.31
84722	112.69419	-7.18803	125.22	123.22	6.40
84782	112.69506	-7.18890	121.92	119.83	6.39
84842	112.69672	-7.18963	119.42	114.83	6.23

The longitude and latitude position, speed on the ground (SOG), and course on the ground (COG) of a target ship based on AIS data from 2300 to midnight on January 1, 2011, are presented in Table 1. The AIS data presented in Table 1 were synchronized using the interpolation method. The initial time of 83942 in the table indicates a time of 23:19:02. The data were selected for a 15-min voyaging period, starting from the north side of the anchorage area.

At the same time, a simulated subject ship exiting the new port in Lamong Bay was assumed to have similar characteristics as the target ship. Based on the AIS data, the PAW of the target ship was predicted in the MMG model. Figure 4 shows an example of the PAW for turning without considering the effect of shallow water or wind and current disturbances.

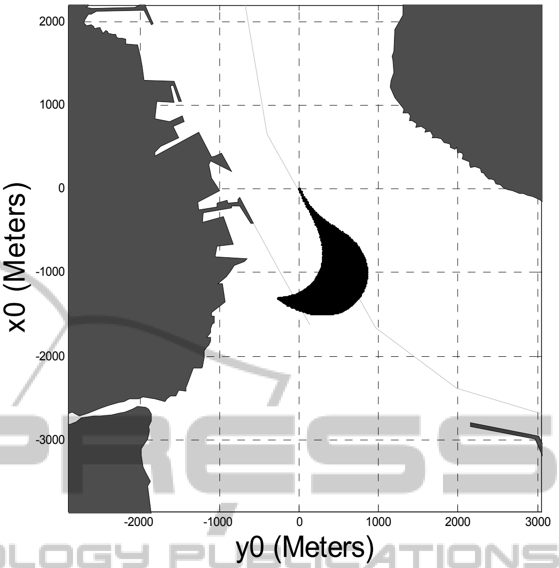

Figure 4: Potential area of water for turning (Asmara et al., 2012).

5 ENVIRONMENT

Figure 5 shows data pertaining to the average wind speed in 2011. The data were taken from the maritime climatology station in Tanjung Perak. In the rainy season (October–April), the prevailing wind direction in the area is from the west. The most extreme wind velocity of 55 knots occurred in June 1985. Based on data from the maritime climatology station, the tidal height when the subject ship entered the port was 0.3 m, as shown in Figure 6. The maximum tidal height in 2011 was 1.3 m, whereas the minimum tidal height was –1.4 m.

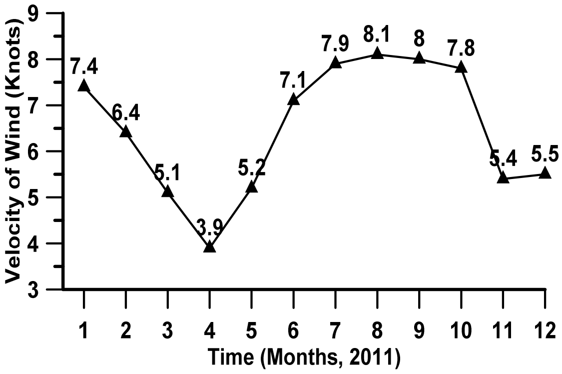

Figure 5: Velocity of wind in Tanjung Perak area.

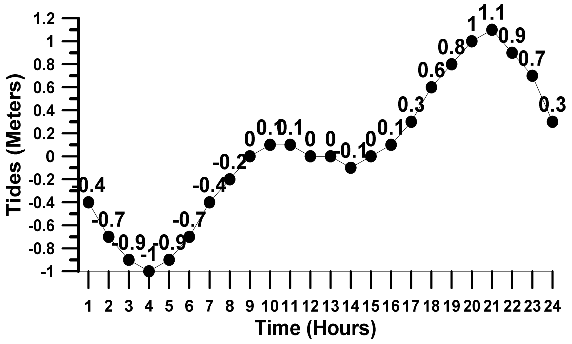

Figure 6: Height of tides in Tanjung Perak area.

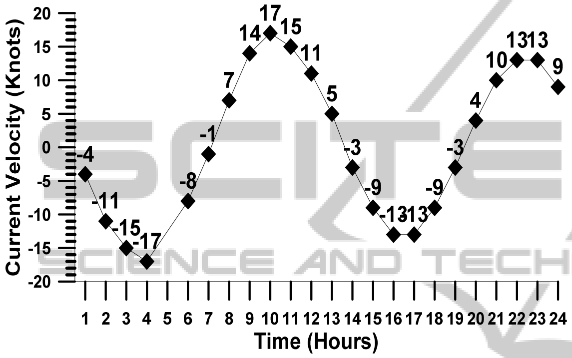

Figure 7: Velocity of current in Tanjung Perak area.

Data for the current velocity on January 1, 2011, were derived from the tidal stream table for the Indonesian archipelago, as shown in Figure 7. The direction of the current out of the channel (0°) to the Java Sea is represented by a positive sign. In contrast, the current direction toward the port area (180°) is represented using a negative sign. The maximum current velocities in 2011 occurred in March and April with magnitudes of 21 and –21 knots, respectively.

6 METHODS AND RESULTS

The rudder angle of the target ship entering the port area was predicted using a linear maneuvering model. The method was proposed as an attempt to predict maneuvering indices using AIS (Nakano and Hasegawa, 2012). The K′ and T′ correlations (Kobayashi, 1978) were used to implement the method. The results of this method are shown as a normal distribution of the rudder angle with a mean of -0.11° and standard deviation of 0.33.

Table 2 lists the distributions of the rudder angle, yaw rate, and drift angle of the target ship expressed as normal distributions. By randomizing the initial conditions of the ship for those variables, the PAW was developed and treated as an obstacle for a subject ship. The PAW of the target ship is shown in Figure 8. The PAW was also developed for the subject ship. In this simulation, the subject ship was assumed to have the same principle dimensions as the target ship.

Table 2: Distributions of rudder angle, yaw rate, and drift angle.

Parameters of Normal Distributions	Rudder Angle (rad)	Yaw Rate (rad/s)	Drift Angle (rad)
Mean	-0.00192	-0.00016	0.02
Standard Deviation	0.00576	0.0012	0.12

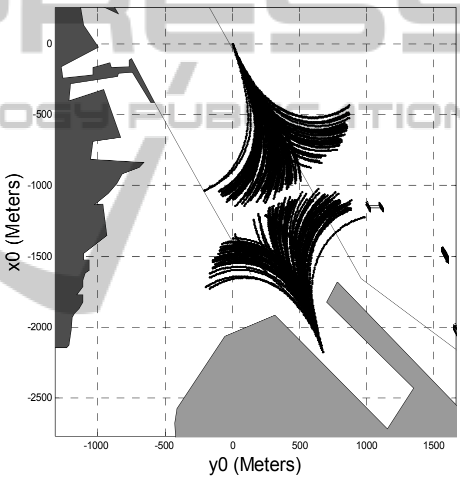

Figure 8: PAW of subject ship and target ship with initial speed of 3 knots.

Figure 9 shows the method used to consider the PAW in collision avoidance. The PAW of the target ship was considered an additional obstacle. The maneuvering parameters of the subject ship were simulated to avoid the PAW of the target ship.

Figure 10 shows a simulation of the subject ship exiting from Lamong Bay. The ship tried to determine a route out of the danger areas indicated by red lines; these include the PAW of the target ship and shallow water areas.

The initial heading angle of the target ship was 270° to allow it to face the wind force from the west direction and current force from the south direction. Figure 11 shows the time series of heading angles. To obtain the route, rudder angles and propeller revolutions were simulated under the criterion of

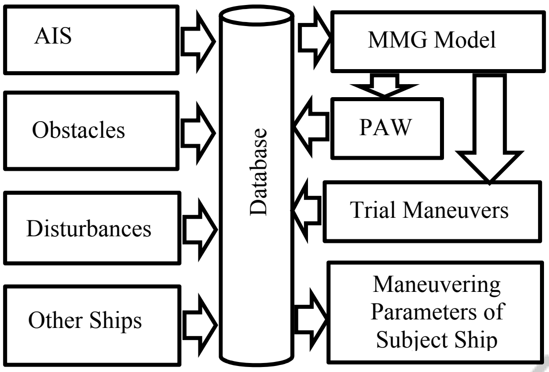

Figure 9: PAW-based collision avoidance method.

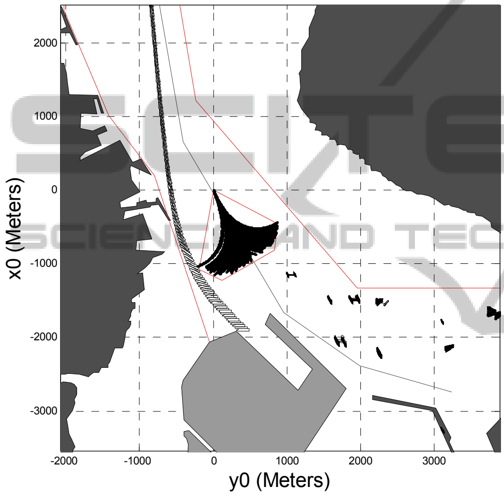

Figure 10: Collision and grounding avoidance for wind and current disturbances.

minimizing the emergency levels (ELs). The method to calculate the shortest distance of obstacle, shortest stopping time (SST), time to collision (TTC), and ELs are described in another paper (Asmara, et al., 2013).

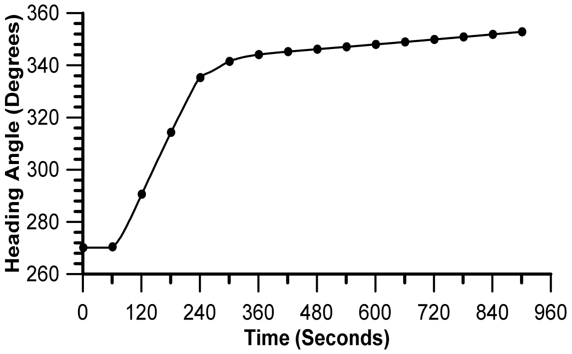

Figure 11: Time series of heading angle.

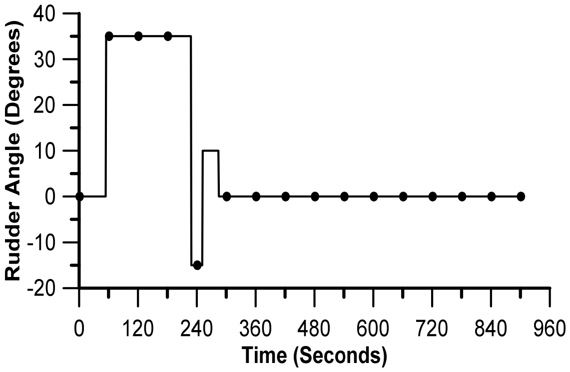

Figure 12: Time series of rudder angle.

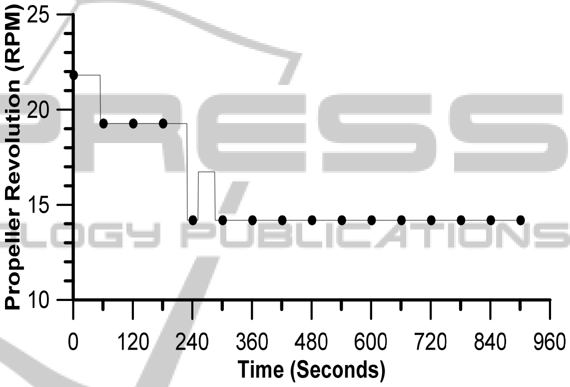

Figure 13: Time series of propeller revolution.

Figures 12 and 13 show the time series of the rudder angle and propeller revolutions. Figure 12 shows that, 60 s from the initial position, the subject ships should take the maximum rudder angle of 35° for a right turn to avoid grounding in shallow water. To avoid collision with the target ship in the danger area of the PAW, the subject ship should change the rudder angle to -15° within 180 s.

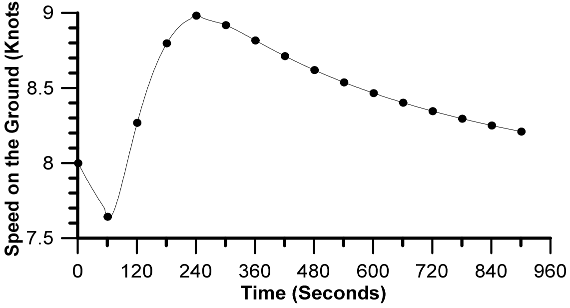

Figure 14: Speed of simulated subject ship.

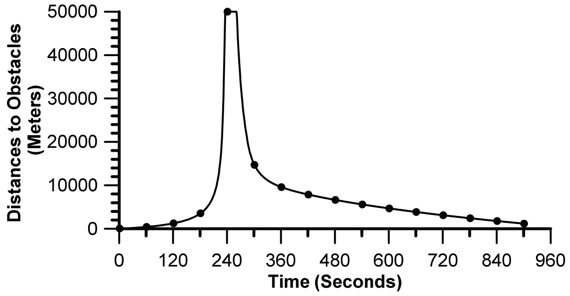

Figure 15: Distances to the shortest obstacle.

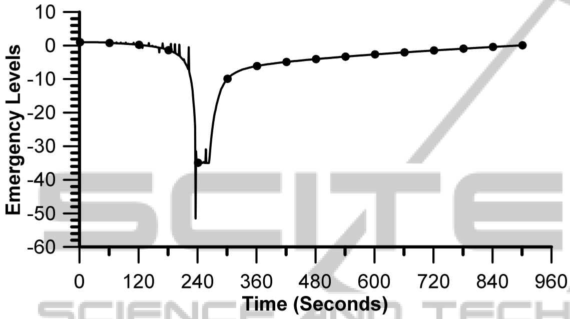

Figure 16: Time series of emergency levels.

Figure 14 shows the velocity of the ship required to cross the current at a speed of 11 knots to avoid the danger area (PAW). This causes the ELs of the ship to be positive at the beginning of the simulation, as shown in Figure 16. At the end of the simulation, the ELs were back to positive. This was caused by the steady rudder angle at the end of simulation. The extreme values for the distance to the shortest obstacle and EL at a simulation time of 238–264 s are shown in Figure 15 to clarify the low values during the rest of the simulation.

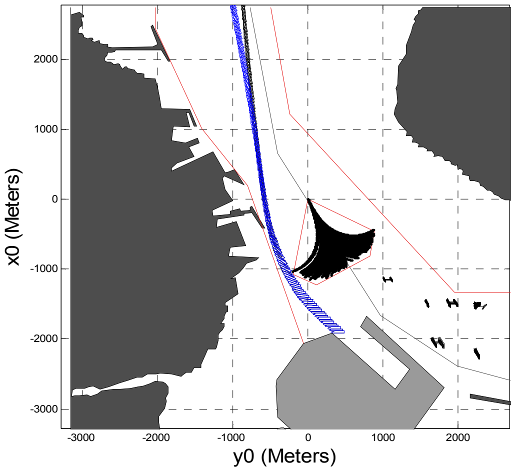

Figure 17: Improved emergency levels.

In another trial to simulate maneuvering, the conditions were improved by decreasing the ship speed and changing the rudder angle after the PAW was avoided, as shown in Figures 17–20. The improved ship track is shown in blue in Figure 17. However, because the ELs at the beginning of the simulation were still positive, as shown in Figure 18, the use of a tug before the ship leaves the danger area of the PAW is recommended. The recommended propeller revolutions and rudder angle are shown in Figures 19 and 20.

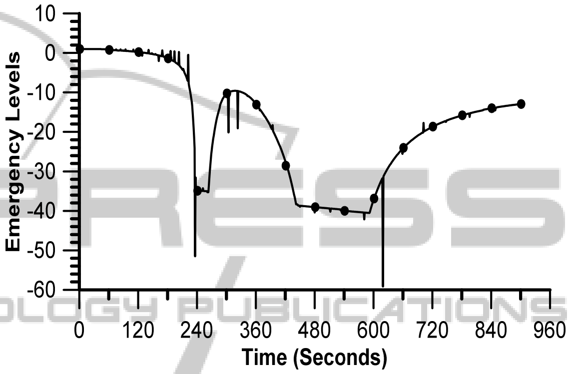

Figure 18: Improved emergency levels.

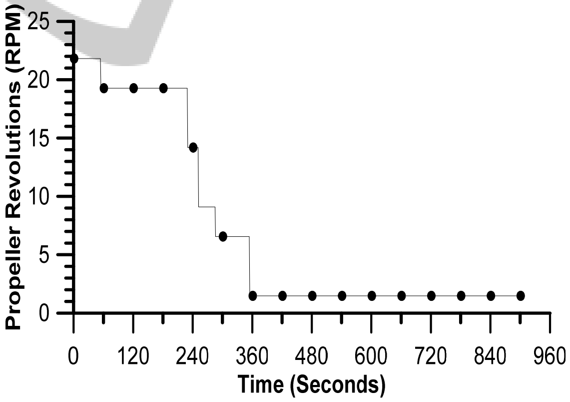

Figure 19: Propeller revolutions for improvement of emergency levels.

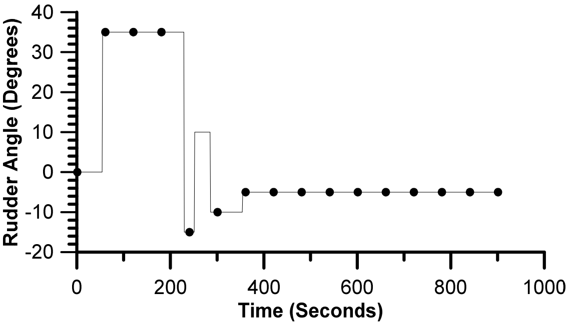

Figure 20: Recommended rudder angle.

7 CONCLUSIONS

The existing MMG model was refined in MATLAB to consider the shallow water of a port area and external disturbances. The simulation of a subject ship exiting a new port and obstacles such as shallow water and the PAW of a target ship are presented. The maneuvering parameters for propeller revolutions, rudder angles, initial ship heading, and recommended use of tugs in critical areas are presented for a developing port area. Future work will involve the use of more ship details in a database of the proposed navigation system for conducting research on maneuvering safety analysis in a port area based on ship maneuvering simulations using the MMG model and AIS data.

REFERENCES

Asmara, I. P. S., Kobayashi, E., Wakabayashi, N., Khanfir, S., and Pitana, T., 2012. Uncertainty Analysis for the Estimation of Ship Maneuverability in Tanjung Perak Port Area using MMG Model and AIS Data. *Proceedings of 15th the Autumn Conference of The Japan Society of Naval Architects and Ocean Engineers*, pp. 295–298.

Asmara, I. P. S., Kobayashi, E., Wakabayashi, N., Artana, K. B., Dinariyana, A.A.B, and Pitana, T., 2013. Trial Maneuvers Based Collision Avoidance between Anchorage Areas using MMG Model and AIS Data. *Proceedings of the Spring Conference of The Japan Society of Naval Architects and Ocean Engineers*.

Fujiwara, T., Ueno, M., and Nimura, T., 2001. An Estimation Method of Wind Forces and Moments Acting on Ships. *Mini Symposium on Prediction of Ship Maneuvering Performance*, pp. 83–92.

Inoue, K., 1990. Concept of Potential Area of Water as an Index for Risk Assessment in Ship Handling. The Journal of Navigation, Vol. 43 (1), pp. 1–7.

Inoue, K., and Usui, H., 1998. On the Navigating between Anchored Ships and Its Maneuvering Difficulty. *The Journal of Japan Institute of Navigation*, Vol. 99, pp. 155–168. (in Japanese)

Kobayashi, E., 1978. Prediction of Maneuvering Indices by Optimization Method. Master Thesis of Osaka University, Japan.

Kobayashi, E., 1995. The Development of Practical Simulation System to Evaluate Ship Maneuverability in Shallow Water. *Proceedings of the Sixth International Symposium on Practical Design of Ships and Mobile Units (PRADS '95)*, pp. 1.712–1.723.

Leite, A. J. P., Aranha, J. A. P., Umeda, C., and Conti, M. B. D., 1998. Current Forces in Tankers and Bifurcation of Equilibrium of Turret System: Hydrodynamics Model and Experiments. Applied Ocean Research, Vol. 29, pp. 145–156.

Montewka, J., Kujala, P., and Ylitalo, J., 2009. The Quantitative Assessment of Marine Traffic Safety in the Gulf of Finland, on the Basis of AIS Data. *Scientific Journals of Maritime University of Szczecin*, Vol. 18 (90), pp. 105–115.

Nakano, T., and Hasegawa, K., 2012. An Attempt to Predict Maneuvering Indices Using AIS Data for Automatic OD Data Acquisition. *The Japan Society of Naval Architects and Ocean Engineers*, Vol. 14, pp.49-52.

Soda, T., Shiotani, S., Makino, H., and Shimada, Y., 2012. Research on Ship Navigation in Numerical Simulation of Weather and Ocean in a Bay. *International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 6 (1), pp. 19–25.

Souza, Jr., J. R. D., and Fernandes, C. G., 2005. Nonlinear Dynamics of an Archetypal Model of Ships Motions in Tandem. *Applied Mathematics and Computation*, Vol. 164, pp. 649–665.

Szlapczynski, R., 2006. A Unified Measure of Collision Risk Derived from the Concept of a Ship Domain. *The Journal of Navigation*, Vol. 59, pp. 477–490.

Terada, D., 2009. Estimation of the Maneuverability under External Disturbance. *Proceedings of the 13th International Association of Institutes of Navigation*.

Tsou, M. C., and Hsueh, C. K., 2010. The Study of Ship Collision Avoidance Route Planning by Ant Colony Algorithm. *Journal of Marine Science and Technology*, pp. 746–756.

Wang, N., Xianyao, M., Qingyang, X., and Wang, Z., 2009. A Unified Analytical Framework for Ship Domain. *The Journal of Navigation*, Vol. 62, pp. 643–655.

Wichers, J. E. W., 1988. A Simulation Model for a Single Point Moored Tanker. *Maritime Research Institute Netherl*ands, Vol. 797, pp. 241.

Yoshimura, Y., and Masumoto, Y., 2012. Hydrodynamic Database and Maneuvering Prediction Method with Medium High-Speed Merchant Ships and Fishing Vessels. *International MARSIM Conference*, pp. 1–9.

Zhuo, Y., and Hearn, G. E., 2008. A Ship Based Intelligent Anti-Collision Decision-Making Support System Utilizing Trial Maneuvers. *Chinese Control and Decision Conference.*