

Preliminary Study of Ship Maneuvering Prediction of Container Ship

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Abstract. Ship maneuvering is defined as the inherent capability of a vessel to turn its path based on the hydrodynamics principles. The maneuvering performance becomes important to the safety of navigation when a ship operates. In case of vessel turning motion, International Maritime Organization (IMO) requires the maximum tactical diameter is five times of the ship lengths. Tactical diameter is the distance travelled by the ship's center of gravity in a parallel direction to the ship's initial path. In this paper, semi-empirical approach proposed by Clarke (1983) was used to obtain the first derivative of hydrodynamics equation. After that, the maneuvering performance was calculated using Son and Nomoto's mathematical model (1981). Based on IMO regulations, the calculation of tactical diameter was conducted with 35° of rudder position. The calculation and analysis of tactical diameter was carried out according to relevant procedure of the ship maneuvering provided by IMO. The calculation result shows satisfactory result based on IMO regulations. The maximum tactical diameter does not exceed the requirements of IMO maneuvering standards. A further investigation was performed to see whether there was any impact on ship's main dimensions to the maneuverability performance. In the future study, the development of open source software program to analyze the ship maneuvering performance is considered. It is expected to be able to contribute for facilitating in the preliminary ship design process.

1. Introduction

In the last years, cargo ships have been built to a larger size to meet the increasing load capacity leading to the transport efficiency. However, a larger size of ship has an impact on the limitation of maneuverability performance, especially in channels or crowded port, hence the likelihood of accidents caused by collision and contact is high [1]. With a good maneuver, a ship can turn easily to avoid a collision. Therefore, the ship maneuverability is one of the important factors that needs to be ensured for the passenger and cargo safety.

Analysis of ship maneuvering is typically related to the seakeeping performance. For example, side forces induced by turning circle maneuver effect to the transverse movement, i.e. sway motion. This is a concern of static transverse stability problem that should be convinced when a ship maneuver [2]. In addition, the hull form of the ship is also a factor that effects the magnitude of hydrodynamics forces naturally dominating in maneuvering performance. In numerical simulation, estimation of this hydrodynamics coefficient is indispensable to complete the calculation of maneuvering equation.



Moreover, the ship motions have also significantly contributed to its maneuverability, especially for the calm water [3] and wave conditions [4]. It is well known that the strategy to optimize such design stage is using parametric study with respect to hull sizing [5]. Therefore in this paper, parametric study involving 10 main dimensions variation had been carried out for various L/B, L/D, and B/D ratios. Such main dimension variations were derived based on the existing and available data in BKI.

Prediction of ship trajectory is usually carried out to estimate the future position in the vessel maneuvers. Free-running model for maneuvering was carried out to perform the turning circle test by varying the propeller and rudder types and sizes [6]. Experimental results were satisfactory; however, it is costly in time to prepare the model compared to numerical method. Some papers have analyzed the maneuvering performance of ship and its hydrodynamics performances. Hydrodynamics derivatives for ship are calculated to confirm the maneuvering equation using analytical approach [7] and computational fluid dynamics (CFD) [8] which the solution of mathematical model is complicated. In another paper, Clarke et al. [9] proposed the development of semi-empirical formula to calculate hydrodynamics coefficient of a ship.

The aim of this paper is to analyze the turning ability of containerships based on the International Maritime Organization (IMO) regulation. IMO criteria for turning circle maneuver provides that the tactical diameter should not exceed five ship lengths, see in Figure 1. In order to obtain the prediction of tactical diameter when a ship operates, a simplification formula introduced by Son and Nomoto [10] is used. Hydrodynamics coefficients in this formula were calculated using Clarke approach [9]. In addition, the principal dimensions associated with the ship were required. Finally, the estimation of tactical diameter for turning circle test was obtained and compared to the IMO criteria.

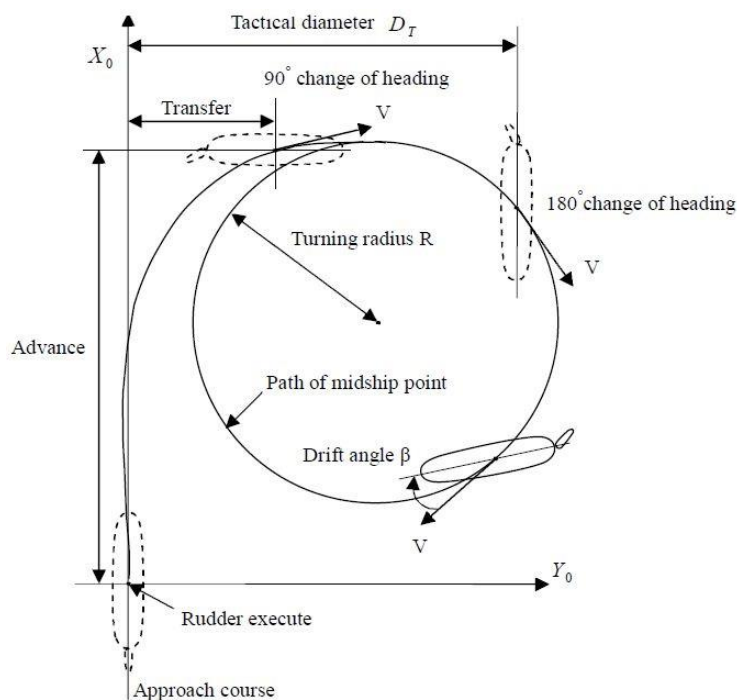


Figure 1. Turning Circle Diagram.

2. Method

Ship maneuvering is one of important parts in the area of ship performance. Many researchers are competing to find ways to solve maneuver problems in both testing and numerical approaches. International Towing Tank Conference (ITTC) has proposed the standard of ship maneuvers for sea trials such turning circle, zig-zag maneuver, pull-out maneuver, spiral maneuver, reverse spiral maneuver and stopping trial. Figure 2 shows the coordinate systems in the investigating of ship

maneuverability. It shows the earth-fixed coordinate system $O_0-x_0y_0z_0$ and the body-fixed coordinate system $O-xyz$ that moves together with the ship. The heading angle (ψ) can be defined as the angle between the direction of x_0 axis and x axis. In the earth-fixed coordinate system, the ship center of gravity (x_{oG} and y_{oG}) can be assigned as the position of ship and the heading angle (ψ) is determined as the orientation of ship [11].

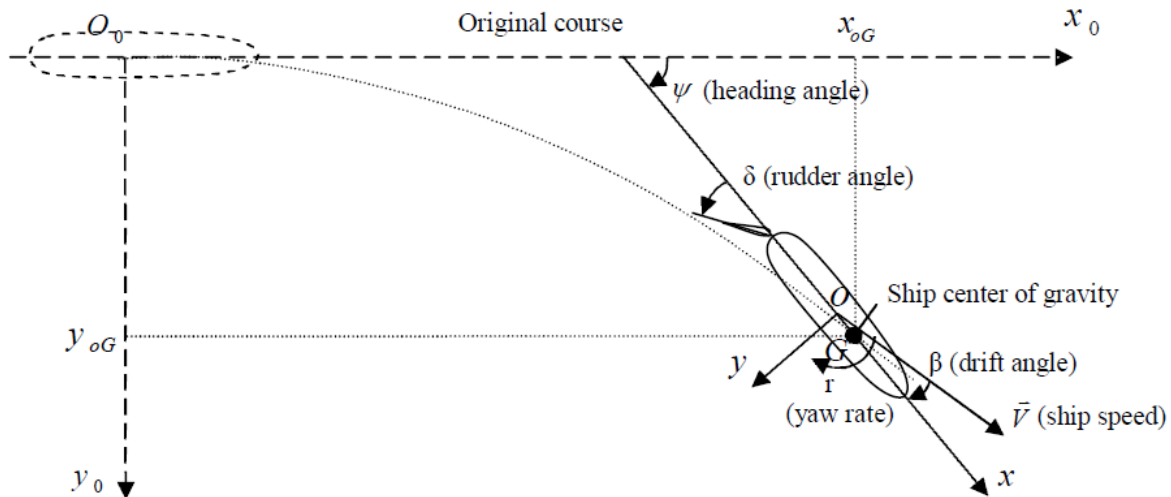


Figure 2. Coordinate System

In this paper, the analysis will focus for turning circle analysis. Turning circle is carried out to calculate the ship's steady turning radius. It also performs the steering ability of ship under course-changing maneuvers. The steering machine and rudder control have important role in the turning circle performance [12]. Tactical diameter will be important thing in the analysis part. The turning radius can be expressed by [12]:

$$R = \frac{Y'_v(N'_r - m'x'_{oG}) - N'_v(Y'_r - m')}{(Y'_vN'_\delta - N'_vY'_\delta)} \frac{1}{\delta} L \quad (1)$$

Where,

m: mass of ship

L: length of ship

Y: hydrodynamic force

N: moment

x_g : center of gravity

The ship speed factor does not give effect in the turning radius formula. It can be said that ship speed has independent role in terms of analysis [12]. The turning radius formula is based on linear theory which assume that δ (rudder angle) is small. Y'_v will be used to denote the y-component of the hydrodynamic force. N'_v is termed the virtual moment of inertia coefficient. The linearized y-component of the force created by rudder deflection acting at the center of gravity of the ship is Y'_δ and the linearized component of the moment created by rudder deflection about the z-axis of the ship is N'_δ [13]. The hydrodynamic derivatives are developed using Clarke approach to generate the turning radius of container ship [9]. Table 1 shows the ship data for maneuvering analysis [14]. There are ten variations of container ship that will be executed for turning circle. The ship data was obtained from the ship register of Biro Klasifikasi Indonesia (BKI). The prediction of mass and center of gravity

is an important part of ship maneuvering prediction. In this case, the mass and the center of gravity are derived based on Schneekluth's method [15].

In general, the relationship of ship main dimensions, ship length (L), breadth (B), and depth (D), can be shown as in Table 1. The ratio of main dimension has a significant role in the ship preliminary design. It can be seen the range of L/B is in between 4.02 and 6.74, L/D is in between 11.79 and 15.97, and B/D is in between 2.03 and 3.03. The acceptance criteria of maneuvering follow the regulation of IMO Resolution MSC 137 (76) annex. 6 [16]. It stated that the tactical diameter should be less than five times ship lengths.

Table 1. Ship Data for Maneuvering Analysis.

No.	Ship Name	Loa (m)	Lbp (m)	B (m)	D (m)	L/B	L/D	B/D
1	Kendhaga Nusantara 10	74.05	69.20	17.20	4.90	4.02	14.12	3.51
2	Akashia	95.90	89.00	15.20	7.20	5.86	12.36	2.11
3	Caraka Jaya III	98.00	92.00	16.50	7.80	5.58	11.79	2.12
4	Estuari Mas	119.90	115.00	21.80	7.20	5.28	15.97	3.03
5	Icon Perdana	84.60	78.00	16.00	6.50	4.88	12.00	2.46
6	Pulau Hoki	120.97	114.00	20.80	8.00	5.48	14.25	2.60
7	Sendang Mas	112.23	109.17	16.20	8.00	6.74	13.65	2.03
8	Spil Hana	135.70	133.00	22.50	10.20	5.91	13.04	2.21
9	Umbul Mas	119.90	115.03	21.80	7.30	5.28	15.76	2.99
10	Teluk Bintuni	114.30	107.60	16.00	7.80	6.73	13.79	2.05

3. Discussion and Result

The prediction of the turning circle for the selected containerships is presented in Table 2. According to the criterion for tactical diameter required by IMO, it can be seen from the table that all containerships have passed this criterion. As shown in the table, the vast majority of the prediction of the tactical diameter averaging at around 3 in ship lengths.

Table 2. Prediction of Turning Circle for the Containerships.

No	Ship Name	Tactical diameter (in ship lengths) TD/L
1	Kendhaga Nusantara 10	2.67
2	Akashia	3.22
3	Caraka Jaya III	3.54
4	Estuari Mas	3.00
5	Icon Perdana	3.20
6	Pulau Hoki	3.43
7	Sendang Mas	3.05
8	Spil Hana	4.61
9	Umbul Mas	3.04
10	Teluk Bintuni	3.07

A further analysis has been carried out to observe whether there was any influence on the ship's main particulars to the maneuverability capability. The tactical diameter predicted then was plotted against the containerships' L/B, L/D and B/D ratios as shown in Figure 3, Figure 4, and Figure 5 respectively.

Figure 3 shows the relationship between the containerships' L/B ratio and the tactical diameter over the ship's length. The scatter diagram shows a low degree of correlation between the two variables. It can be seen from the graph that along with increasing price ratio L/B, the tactical diameter in ship lengths are fluctuating. However, if we look closely from L/B 4.02 up to 5.58, there was an upward

trend despite the decreasing 2 figures at value of L/B 5.28 (which represents Estuari Mas and Umbul Mas).

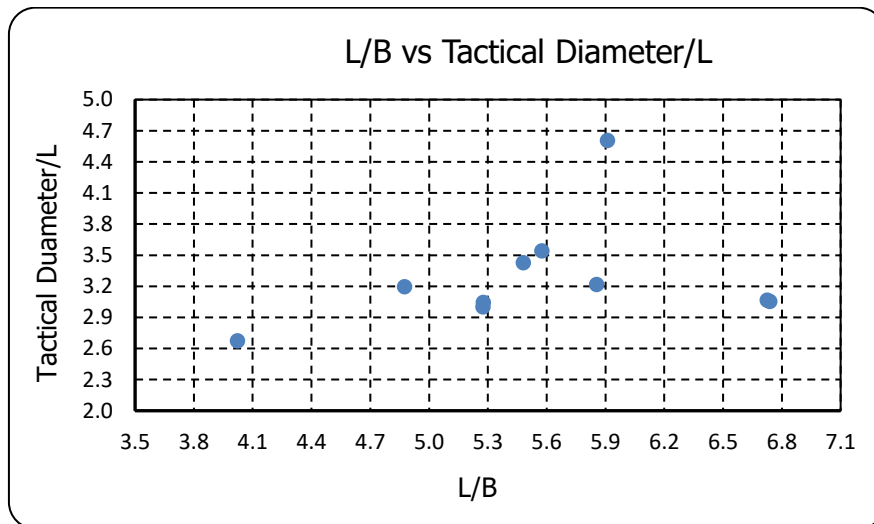


Figure 3. L/B vs. Tactical Diameter/L.

Figure 4 depicts the containerships L/D ratios against the predicted tactical diameter over ship lengths. Similar with Figure 3, the graph also shows a fluctuation over the value of L/D ratios, though it can be seen there was a downward trend in the overall. Because the data point spread in this figure is so random that we cannot draw a line through them, therefore, it is fair to say that the L/D and tactical diameter variables have no correlation.

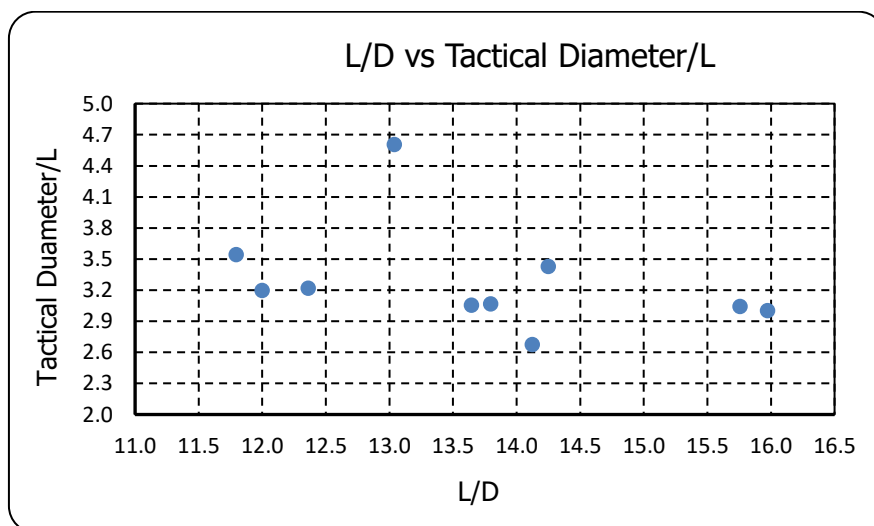


Figure 4. L/D vs. Tactical Diameter/L.

Lastly, the observation was made by plotting the tactical diameter against B/D ratios as seen in Figure 5. Unlike the previous figures, in this diagram, data points are close to each other and a line can be drawn by following their pattern. It was clear that there was an upward trend from the value of B/D 2.03 to the value of B/D 2.21, the scatter diagram presents a strong positive correlation between the two variables. Afterwards, the tactical diameter shows a downward trend along with the increasing

price ratio B/D excluding the increasing value at B/D 2.6, the scatter diagram presents a strong negative correlation between the two variables with a presence of an outlier.

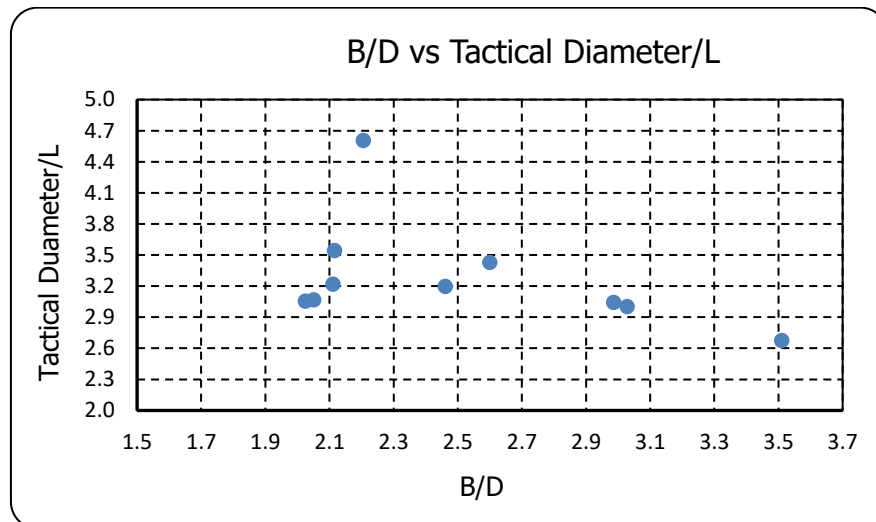


Figure 5. B/D vs. Tactical Diameter/L.

Based on the discussion from Figure 3 until Figure 5, the correlation between the ship's main particulars and tactical diameter are varied depends on the main dimensions ratios. In Figure 3 the scatter diagram has a moderate correlation with a few potential outliers, while in Figure 4 the scatter diagram shows no correlation between the two variables. However, in Figure 5, the scatter diagram has a high degree of correlation, with a strong positive correlation from the value of B/D 2.03 to the value of B/D 2.21, and a strong negative correlation from the value of B/D 2.21 to the value of B/D 3.51.

4. Conclusion

In this study, ship maneuvering prediction was carried out for several selected container ship. The calculation of turning circle radius has been conducted and obtained satisfactory result based on IMO Resolution MSC 137. According to ship data from Biro Klasifikasi Indonesia (BKI), the tactical diameter of ship maneuvering does not exceed than five times of ship length (L). The difference trend from the result might be caused by the limitation of the ship's sample that were taken. The development of open source code of ship maneuvering performance will be initiated in the future research. It will make easier for a naval architect in the ship design process, especially in the preliminary ship design.

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