TransNav
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 15
Number 4
December 2021
DOI: 10.12716/1001.15.04.11

A Concept Explanation on the Development of Wheel Over Point Mathematical Model for Efficient Course Alteration

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ABSTRACT: This concept paper described the process of bridging the gaps in one of the methods for determining wheel over point (WOP). WOP is a marking made on charted courses to indicate a point at which a ship should change course. Identifying WOP is vital to avoid the vessel overshooting the planned track. One method for determining WOP is the advanced transfer technique. However, two issues were identified while reviewing this technique. Therefore, an improved mathematical model could be developed to overcome these problems. A manoeuvring analysis using a ship simulator will be performed to test the developed mathematical model's efficacy. The data obtained from the simulation study can be validated further by its adherence to the cross track limit, reduction in percentage change, and using IBM SPSS for the Mann-Whitney U test. The developed mathematical model is expectantly capable of producing a better track-keeping function and suitable for use onboard a cargo ship. The mathematical model also could be implemented as an algorithm in the Electronic Chart Display and Information System to help navigators make more efficient course changes.

1 INTRODUCTION

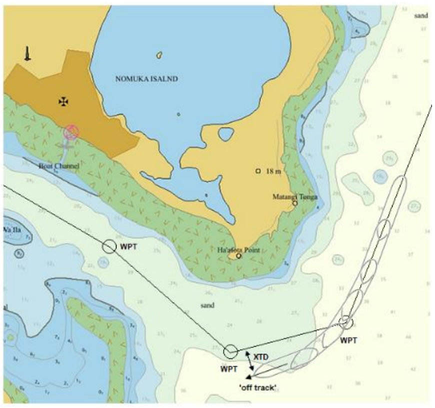

Figure 1. Various connected charted course in a voyage plan on a nautical chart

A ship is navigated by following one-course line to another to complete a voyage [7]. A charted course, as shown in Figure 1, is the course line drawn on the nautical chart and connected by waypoints (WPT) [7]. WPT is the point at which two different course lines are linked [7]. A navigator or watchkeeping officer must alter a course at an exact distance, or the ship will overshoot from the track. Unable to do this correctly may result in a cross track distance (XTD) (Figure 1), which can lead to an accident [5, 8]. Therefore, a wheel over point (WOP) must be marked on the charted course to indicate the point of change [7].

2 REVIEW ON ADVANCED TRANSFER TECHNIQUE IN DETERMINING WOP

The advanced transfer technique (ATT) is a method to identify the WOP [1]. The advance transfer technique by Anwar (2015) requires two variables from the maneuvring characteristics as shown in Figure 2 namely 1) advance and 2) transfer, hence the names. Advance and transfer distances are measured by referring to the positioning of the ship's centre of gravity (CG) [3].

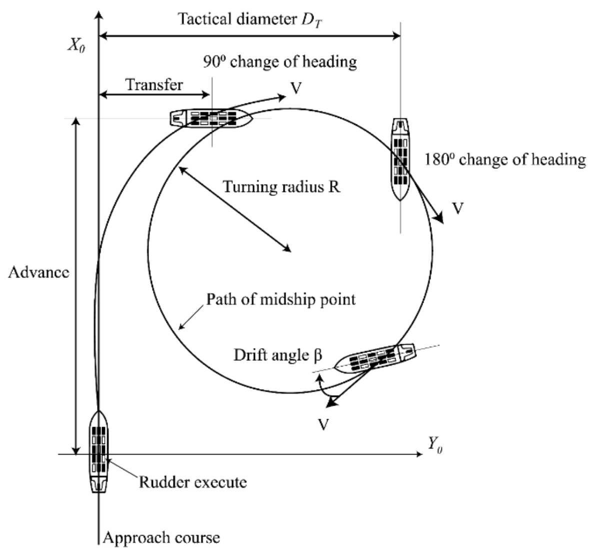

Figure 2. Typical manoeuvring characteristic of a ship [3]

Advance and transfer can be measured from the moment vessel initiates the turn by hard over the rudder until the ship's heading changes by 90° from the initial heading, where the distance of advance is on the X0 axis, and transfer Y0 axis as shown in Figure 2 [3]. The advance and the transfer distances are usually given in nautical miles that need to be extracted from the manoeuvring characteristic. Anwar [1] has found a way to use the given information to determine the WOP as explained below;

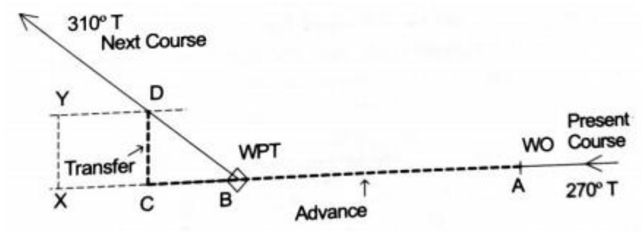

Figure 3. WOP identification using the advance transfer technique [4]

With references to Figure 5, the steps of determining WOP are as follows:

1. At point B, extend the present course line 270°T
2. At any point, 'X' is on this line, draw a perpendicular line 'XY' towards the alteration so that 'XY' = Transfer
3. At 'Y', draw a line parallel to 'BX' so that it cuts the course line 310°T. The point at which the parallel line cuts the next course line is 'D'. Now, if the line is drawn at 'D', which is parallel to 'XY', point 'C' would be obtained on the extension of the present course line.
4. From 'C', measure the advance backwards i.e. in the direction 090°T (reciprocal of 270°T) to obtain point 'A'. 'A' is the WOP, where 'CA' equals advance distance.

This study conducted a practical exercise on a nautical chart to better understand the use of the ATT. During this practice, two problems were identified.

2.1 *Issue 1 – Negative value for alteration is less than 20°*

The formula of WOP for ATT is as follows;

$$WOP = Adv - \frac{Trs}{Tan\theta}$$

Table 1 shows an example of WOP calculated for 20° and 50° course alteration for a ship with advance (Adv) of 0.24nm, and transfer (Trs) of 0.108nm.

Table 1. WOP distance from WPT

Situation	Change of a course	Adv	Trs	WOP
1	20°	0.24	0.108	- 0.057
2	50°	0.24	0.108	0.149

Based on Table 1, a negative value of WOP in Situation 1 indicates that the ship has deviated from the planned track, requiring a course alteration of 0.057nm after WPT.

2.2 *Issue 2 – The final heading of the ship does not match the charted course*

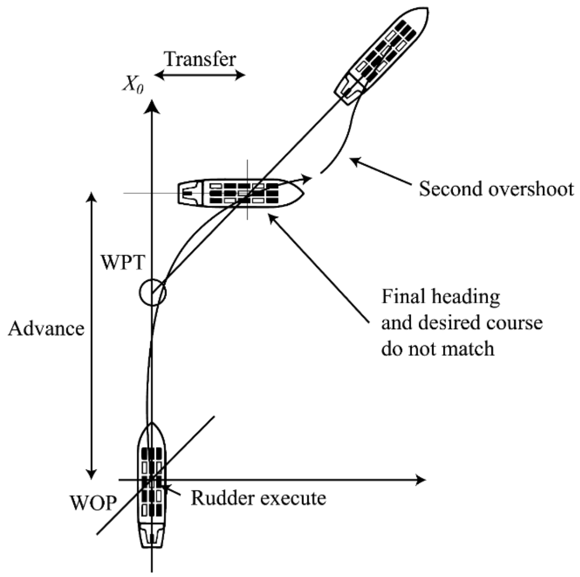

Figure 4. Advance transfer technique principle [4]

Meanwhile, Figure 4 illustrates the technique's principle. The ship's final heading is 090°T, which does not match the desired course of 045°T, resulting in a second overshoot.

3 PROBLEM STATEMENT AND NEED OF THE STUDY

Hence, based on the observations and review, the following situations were identified;

1. The ATT is not suitable for course alteration less than 20° as it will result in a negative value. A ship will start to make a course alteration after WPT.
2. The ship's final heading and the charted course are contrary.

Since an Electronic Chart Display and Information System (ECDIS) is currently preferred in maritime navigation; hence mathematical modelling will be a more appropriate approach in determining WOP. However, the formula provided by Anwar [1] in the advance and transfer technique cannot be applied in the electronic chart due to the negative value produced for alteration less than 20°. Therefore, this research intends to restructure and develop an advance transfer mathematical model (ATMM) that may solve the problems.

4 OBJECTIVE

1. To develop and improve the advance transfer mathematical model (ATMM);
2. To conduct a simulation study with a ship simulator;
3. To validate the improved mathematical model.

5 METHODOLOGY

The research started with reviewing the ATT to understand the WOP's concept. However, several flaws in the technique were discovered. The application of manoeuvring characteristics in determining WOP has been restructured and developed. Hence, the advance transfer mathematical model (ATMM) was proposed. Following the mathematical model's development, the ATT and ATMM will be tested with various cargo ships in a ship simulator for validation by determining their impact on the cross track distance (XTD) [9].

Researchers may find these data useful for their future use [9]. Therefore, the XTD result for both methods will be compared and analysed by examining their compliance to cross track limit (XTL), percentage change, and the Mann-Whitney U test. The test will allow a different conclusion between the ATMM and ATT in determining WOP.

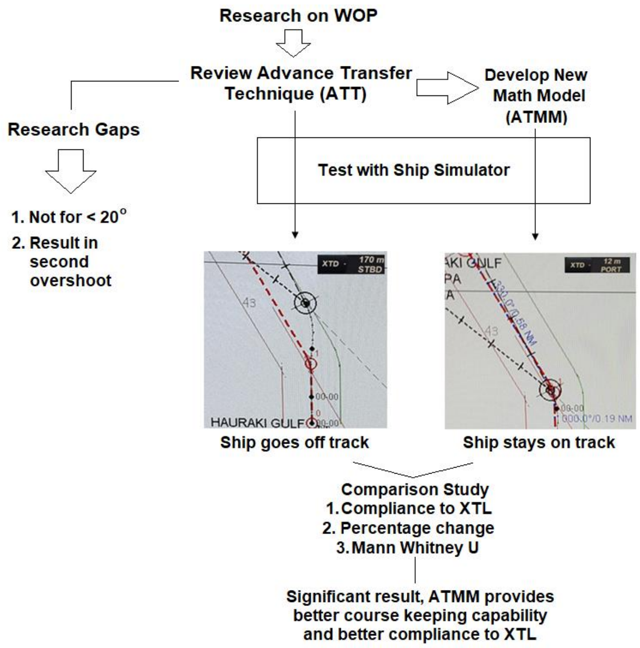

Figure 5. The research's graphical methodology

5.1 *Development of a mathematical model*

This research also aims to improve and enhance the ATT so that the final ship's course coincides with the charted course in the passage plan in determining WOP. Thus, to reach the last passage with the ship's heading, this study intends to redesign the technique, as depicted in Figure 5. The heading should match the desired next course to avoid second overshooting. The method's refinement will be translated into the form of a mathematical model.

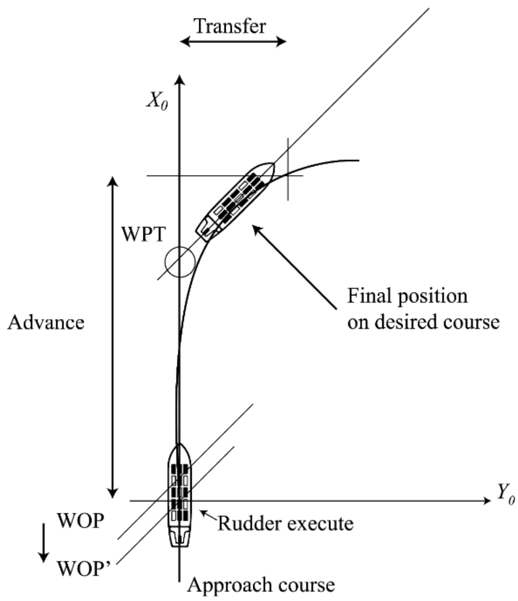

Figure 6. A study concept (ship heading and course are parallel at the end of alteration)

5.2 *Simulation study*

The ATT and ATMM will be tested using a ship simulator. The selected ship simulator should have core manoeuvring elements and deliver accurate navigation simulation for various ship types.

The simulator is used to obtain the necessary data and variables involving the preferred ship. It will generate a set of charted courses consisting of nine turning angles (each with a 10° change). Then, the developed mathematical model will be used to identify the WOP. The model's effectiveness is determined by comparing the XTD generated by the ATT and ATMM during the manoeuvring simulations.

5.3 *Data validation*

In this study, a WOP mathematical model will be developed for better track-keeping function when minimising the XTD. The particular ship simulator will test both the ATT and ATMM. Next, the data on the XTD will be compared to see if there is an improvement in the model. Finally, the ATT and ATMM will be validated through three stages, as follows:

1. Cross track limit (XTL). An XTL is a limit whereby a ship could safely deviate from the track [4]. This research will look into which method provides the best XTL compliance.
2. The XTD reduction. The reduction could be justified by modifying the formula to calculate percentage change [2].
3. A Mann-Whitney U test. A comparison study will be conducted using the Mann-Whitney U test to determine whether the mean XTD of the ATT and ATMM are significantly different [6].

5.4 *Timeline*

This research study is expected to be completed in four semesters (24 months), with the following activities listed in Table 2.

Table 2. Research Timeline

Research Section	Duration (month(s))
Introduction	1
Literature review	4
Development of the mathematical model	3
Simulation study	5
Validation analysis	5
Data interpretation and discussion	4
Conclusion	2

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