Systematic Literature Review on Wheel-over Point Techniques for Efficient Ship Manoeuvre

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This study aims to review the methods that can be used to identify the wheel-over point for a ship's effective course alteration. Using the systematic literature-review technique with reference to the PRISMA model, this study was able to collate the methods identified through a thematic analysis that was appropriate to the technique's fundamental principle. As a result, four themes were identified: ROT Turns, Fixed Radius Turns, RADAR Turns, and Fixed Rudder Angle Turns. It was also discovered that the techniques applied by mariners varied according to the navigation region. The navigation regions can be categorised into three areas, i.e. ocean navigation, coastal navigation, and harbour and confined-water navigation. The methods found in this research can be used aboard ship to aid the navigators in making more efficient course alterations for the purpose of enhancing the safety of navigation.

KEY WORDS

~ Systematic literature review
~ Wheel over point
~ Rate of turn
~ Radius turn
~ Blind pilotage

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e-mail: amirsyawal87@gmail.com
doi: 10.7225/toms.v11.n02.006
Received: Jul 18, 2022 / Revised: Aug 7, 2022 / Accepted: Oct 3, 2022 / Published: Oct 21, 2022

1. INTRODUCTION

The primary purpose of merchant shipping is to transport cargo safely from a place to its destination. According to Resolution A.1119(30)-Procedures for Port State Control, a ship may be detained if it fails to provide evidence in implementing any constitution relating to the ship's construction, equipment, or operation essential to protect human health, marine environment, or navigational safety; where the deviation from these requirements could pose unreasonable imminent harm to the aforementioned protection aspects where it should not exist. International Convention for the Safety of Life at Sea (SOLAS), Chapter V-Safety of Navigation states that in order for a ship to navigate safely, the master must first verify that the planned route utilised the necessary nautical charts and publications for the region in general, taking into consideration the IMO standards and guidelines (ICS, 2016; IMO, 2020; Lušić et al., 2014).

As a result, it can be deduced that the navigation officer must be proficient in maintaining safe navigation and watchkeeping while navigating. Moreover, the officer must communicate efficiently, manoeuvre effectively and, most notably, carry out a proper voyage plan (IMO, 2018).

The process of planning the voyage results in the development of the most advantageous and cost-effective course line. According to Resolution A.893(21) - Guidelines for Voyage Planning, the process of presenting a clear and comprehensive description of the voyage that the vessel will take from the port of departure to the port of arrival is referred to as "voyage planning" (IMO, 1999). Upon completion, a navigation officer needs to follow the agreed courses (Lušić et al., 2014). When changing from one course to another, the alteration needs to be carried out at a sufficient distance; otherwise, there will be a cross-track distance (XTD) due to the ship overshooting the course, as seen in Figure 1 (Lekkas & Fossen, 2014). Thus, a wheel-over point (WOP) needs to be shown on the charted course as an indication of the point of alteration.

XTD is the perpendicular distance of a vessel from its original intended track (Lekkas & Fossen, 2014). The occurrence of XTD at the open sea is not alarming, although shipowners may find it unpleasant as it increases fuel consumption (Reid, 1978). However, looking from the vessel-safety point of view as required by IMO (Srivastava, 2007), the XTD can be considered to be a critical aspect in navigation (Vujičić et al., 2018), as reported in a few cases where accidents happened due to ships manoeuvring off-track (Gale & Patraiko, 2007; MAIB, 2015; Steamship Mutual, 2014; TAIC, 2016). Furthermore, if navigators do not understand the fundamentals of hydrodynamics, overshooting a planned course may result in disaster. For example, if the vessel is in confined and restricted waterways such as a river, the XTD will bring the ship closer to the riverbank, thus causing a phenomenon known as bow cushion and bank suction, which can result in accidents such as grounding (Du et al., 2018). Besides, shallow water will make the ship sluggish and difficult to be manoeuvred, hence worsening the situation (Mucha et al., 2019). Consequently, the ship may run aground or collide with a land structure such as a jetty due to overshooting the planned track, especially when passing a narrow channel (Du et al., 2018; Molland, 2008).

WOP is the location on the planned course that acts as a warning to the navigation officer to start the course adjustment so that the ship does not veer off the planned route (Anwar, 2015). WOP may also save fuel consumption by optimising the vessel's journey by maintaining an ideal course (Chaal, 2018; Lu et al., 2015; Reid, 1978). Most significantly, it has a substantial effect on the ship's navigational safety since failing to identify WOP was identified as one of the contributing elements to the ship's off-course manoeuvring-related disaster (Kamis et al, 2022a; Vujičić et al., 2018).

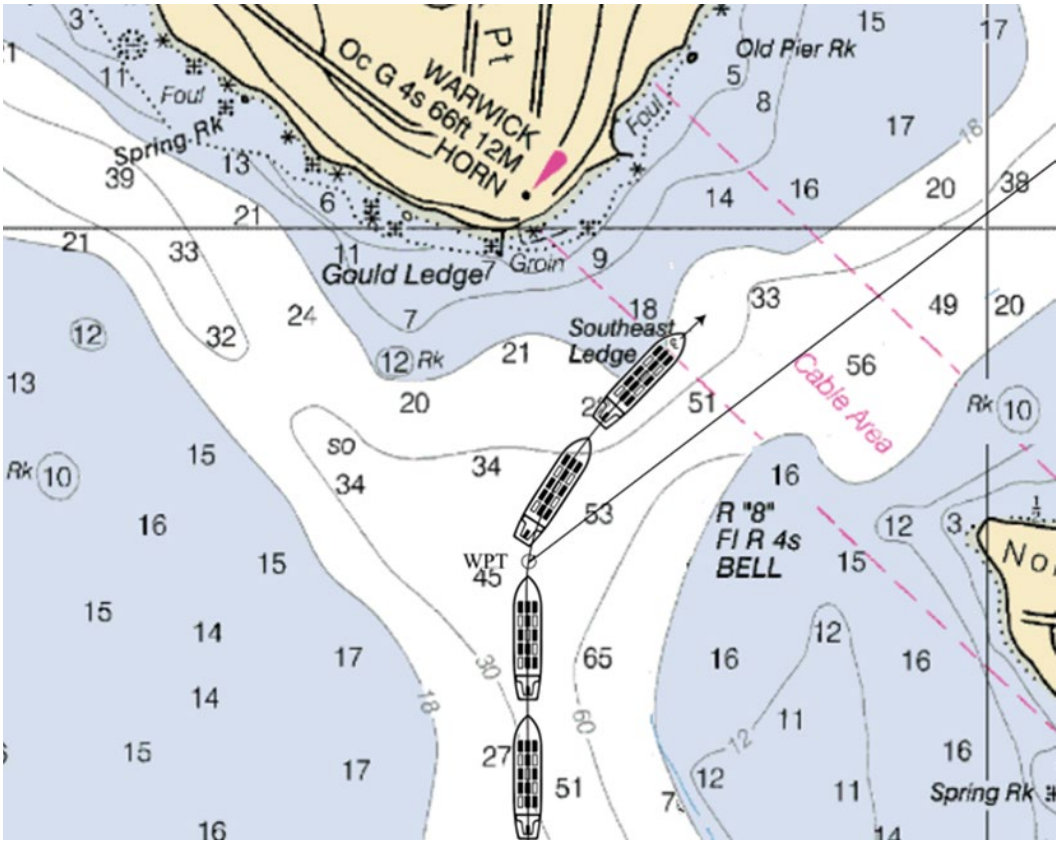


Figure 1. A vessel overshot the charted course and produced XTD due to an incorrect calculation of WOP that caused the ship to manoeuvre towards shallow water (Kamis et al., 2022a).

1.1. Problem statement and research aim

Executing an efficient course alteration through precise WOP establishment is essential for navigation safety. However, there is a scarcity of documented evidence regarding the optimal approach for determining WOP for different navigation areas.

This research intends to identify and classify the existing methods for determining the WOP that can be used to assist navigators in carrying out efficient course alteration while reducing the XTD. The identified method will be categorised according to its basic working principle. Then, the identified method can be utilised in assisting the navigation officer in determining WOP position to carry out course alteration. Besides, as in other systematic literature-review studies, this study hopes to identify a gap that exists in identifying WOP; subsequently, better techniques can be developed.

2. METHODOLOGY

2.1. Selecting literature through systematic literature review

This study used a systematic literature-review analysis based on the structure drawn up by Mohamed Shaffril et al. (2021). The methodology is deemed to meet the required standard because it assesses the context, collects, collates, and summarises the literature based on a specific issue as well as categorises all current research, including material from numerous publications, manuals and other sources. The systematic literature-review strategy started with identifying keywords and locating relevant materials. This process was then followed by selecting literature, data charting, and analysis of the review findings.

2.1.1. Identifying relevant literature

Published literature was searched in the Scopus and Web of Science (WOS) databases, with no exclusions on the period. The search string was created by combining text terms from all of the authors' discussions. The following are the search strings for the literature search:

Sources	Search string
Scopus	TITLE-ABS-KEY (((ship* OR vessel*) AND (wheel* OR steer*) AND (over) AND (point* OR position* OR mark*)) OR ((ship* OR vessel*) AND (course*) AND (alteration* OR turning*) AND (point* OR position* OR mark*)))
Web of Science	TS = (((ship* OR vessel*) AND (wheel* OR steer*) AND (over) AND (point* OR position* OR mark*)) OR ((ship* OR vessel*) AND (course*) AND (alteration* OR turning*) AND (point* OR position* OR mark*)))

Table 1. Search strings

2.1.2. Selection of literature

Initially, using the established search strings, a combination of 551 publications from the Scopus and WOS databases was identified, considering all the duplicates from each archive. In addition, an internet search engine was used to identify eleven more unindexed publications from diverse sources and three websites. Thus, 562 pieces of literature were selected for screening. Next, 520 literature items were eliminated based on the exclusion and inclusion criteria specified in Table 2. Then, 42 items of literature were evaluated for eligibility. It was discovered that 22 works of literature were unrelated to the study's aim. Thus, 20 publications were chosen for in-depth analysis. While the first and second authors studied all of this material in its entirety, the third author was assigned the task of collating the techniques discovered. Finally, 12 journal articles, four books, and three web pages were selected for the thematic analysis. The procedure is clarified in Figure 2.

Criterion	Inclusion	Exclusion
Additional keyword	Ships, navigation, collision avoidance	Other than the inclusion list

Table 2. Inclusion and exclusion criteria

2.1.3. Charting, collating and summarising data

Data charting is a technique that uses a systematic approach to extract data from documents that are relevant to the research (Prescott et al., 2020). In essence, the approach is used to analyse and interpret the acquired data by categorising them according to the anticipated analysis (Mohamed Shaffril et al., 2021). Each article or technical publication was categorised into a thematic table based on author, type of literature, country, and WOP technique. The techniques extracted and explained in every piece of literature were analysed and collated into a table according to their fundamental principle. Table 3 provides summary descriptions of the information included.

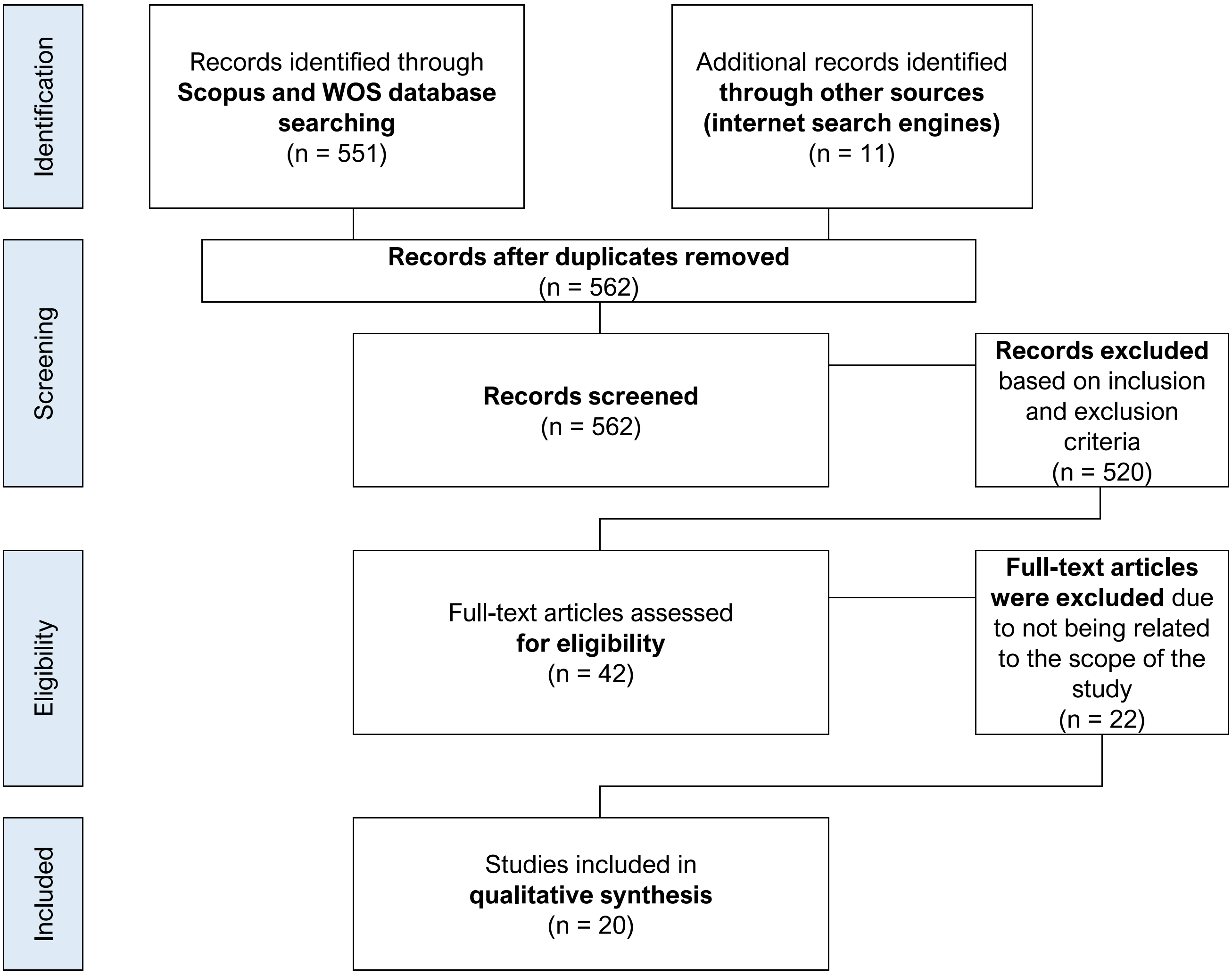


Figure 2. Summary of the selection of the literature through identification, screening, and eligibility assessment using the Prisma model as a guide (Mohamed Shaffril et al., 2021)

No	Authors	Literature type	Country	ROT turns		Fixed Radius Turn					RADAR Turn		Fixed Rudder Angle Turns	
				CROT	ROT	TCR	GFT	TP	RPC	CRT	BP	RT	RIP	ATT
1	Georgiana & Stefan (2010)	Journal article	Romania								✓			
2	Kamis et al (2021a)	Journal article	Malaysia											✓
3	Lušić et al. (2014)	Journal article	Croatia					✓						✓
4	Drachev (2012)	Journal article	N/A										✓	
5	Vujičić et al. (2018)	Journal article	Croatia						✓					
6	Reid (1978)	Book	USA		✓									
7	Van Hilten & Wolkenfelt (2000)	Journal article	Netherlands				✓							
8	NIMA (2001)	Book	USA											✓
9	Kamis et al. (2021b)	Journal article	Malaysia											✓
10	Aarsæther & Moan (2007)	Journal article	Norway			✓								
11	Westin et al. (2019)	Journal article	Sweden								✓			
12	Anwar (2015)	Book	United Kingdom						✓					✓
13	Jithin (2019)	Web Page	N/A							✓				
14	Kamis et al. (2021c)	Journal article	Malaysia	✓						✓				✓
15	Kamis et al. (2021d)	Journal article	Malaysia											✓
16	Mayank (2016)	Web Page	N/A		✓									
17	Chapman (2014)	Journal article	Canada									✓		
18	AMSAS (2016)	Book	Malaysia								✓			
19	Schlemmer (2020)	Web page	South Africa								✓			
20	Kamis et al. (2022b)	Journal article	Malaysia											✓

CROT: Constant rate of turn
ROT: Rate of Turn
TCR: Turning Circle Radius
GFT: Geographically Fixed Turns TP: Turning Point
RPC: Radius Path Curvature
CRT: Constant radius turn
BP: Blind pilotage
RT: RADAR Turn
RIP: Rudder in Position
ATT: Advance transfer technique

Table 3. Thematic table to summarise WOP technique

3. RESULTS

Through the thematic analysis, four themes were identified from the systematic literature-review results concerning the method used in determining WOP in maritime navigation, i.e. 1) ROT Turns, 2) Fixed Radius Turns, 3) RADAR Turns, and 4) Fixed Rudder Angle Turns.

In addition, the study also discovered that the methods were practised according to the region's navigational suitability. In summary, the regions can be categorised into 1) ocean navigation, 2) coastal navigation, and 3) harbour and confined water.

3.1. ROT Turns

The first technique to determine WOP noted in this study was through the establishment of the rate of turn (ROT). ROT is defined as the pace at which the ship's heading changes in degree per minute. A vessel's turning rate depends on the rudder angle and speed applied while the vessel is making course alteration. A study by Kamis et al. (2021c) referred to this turn as the constant rate of turn (CROT) since ROT should be constant while the course alteration is being executed. Meanwhile, in Reid's (1978) research, although it was not specifically mentioned that ROT was used for determining WOP, the study elaborated on ROT utilisation in making an efficient course alteration.

For the execution of this type of technique, a rate of turn indicator (ROTI), an instrument that indicates the ship's turning rate in degrees for every minute (θ°/min), is required to be used (van Hilten & Wolkenfelt, 2000). It is essential to highlight that high ROT requires a large rudder angle to be applied, which can indirectly cause high rudder torque. Moreover, the rudder pressure and torque increase as the speed increases (Jaeger, 1955; Mukundan, 2002). As a result, prior to the voyage, the master will decide the finest ROT to minimise the pressure exerted on the rudder. Then, WOP will be calculated and marked on the chart (Anwar, 2015).

This technique can be used while in blind navigation with restricted visibility. The phrase "restricted visibility" is defined as any situation in which visibility is impaired by snow, nebula, severe rainstorms, sandstorms, fog, or other similar causes (HOUSE, 2004). In such a situation, accurate position fixing is required to know when to initiate the turn. Position fixing can be accomplished by plotting the vessel's latitude and longitude as determined by the Global Navigation Satellite System (GNSS) devices such as Global Positioning System (GPS) (IHO, 2017). The plotting can be done manually on a paper chart or automatically by using Electronic Chart Display and Information System (ECDIS). Additionally, position fixing can also be done using cross-bearing by utilising a gyro or magnetic compass, vertical sextant angle, or horizontal sextant angle using a sextant (IHO, 2017, 2020).

In addition, this technique necessitates the helmsman to possess the steering skill to steer the ship in a manner that ensures ROT stays unvaried with no significant changes all through the turning period (Kamis et al., 2021b). Using ROT Turns to calculate WOP, the following formula is considered (Jithin, 2019; Kamis et al., 2021b):

$$WOP = \frac{\Theta \,.\, V \,.\, 0.5}{60 \; x \; ROT} + F \tag{1}$$

where ROT is the turning rate, and V is the ship's speed in knots at the time of execution. The vessel's length in nautical miles is F and the course alteration angle to be accomplished expressed in degrees (°) is ϴ. As seen in Figure 3, the value obtained will be measured from WPT along the present course line to determine the WOP line.

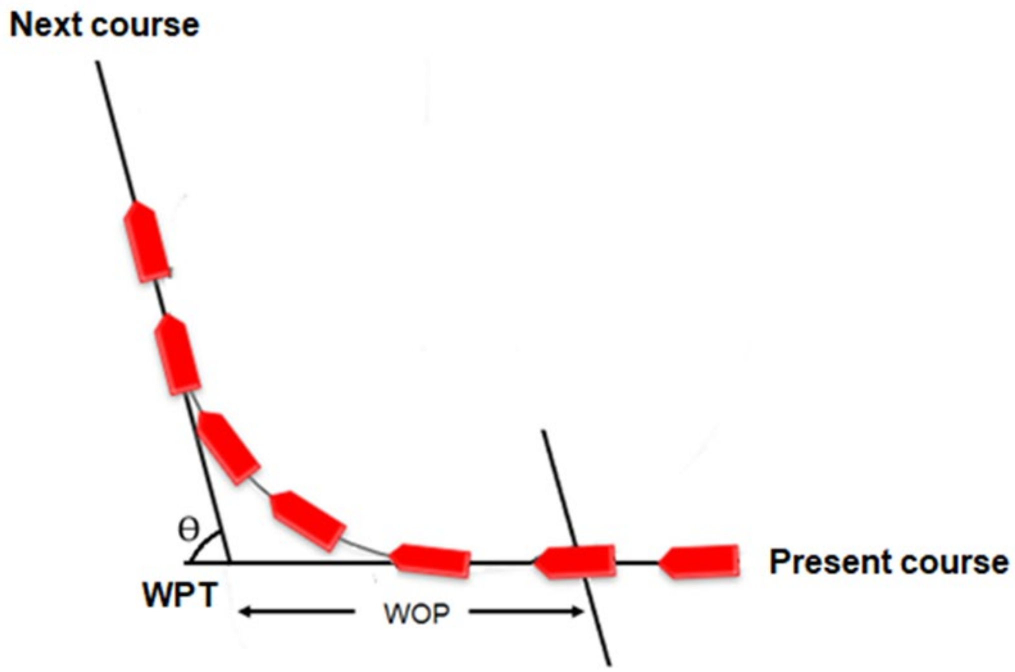


Figure 3. The basic principle for identifying WOP using the ROT turns technique, corresponding to Equation(1)

3.2. Fixed Radius Turn

Fixed Radius Turn (FRT) refers to a course alteration technique using the radius of an imaginary circle based on the course alteration angle Ө (Kamis et al., 2021d). This type of turn is referred to with many names in various studies, e.g. Turning Circle Radius (Aarsæther & Moan, 2007), Geographically Fixed Turns (van Hilten & Wolkenfelt, 2000), Turning Point (Lušić et al., 2014), Radius Path Curvature (Anwar, 2015; Vujičić et al., 2018), and Constant Radius Turn (Kamis et al.,2021d). Mariners use this technique to manoeuvre a commercial vessel during normal operations including berthing, mooring, and anchoring (ISC, 2012).

The uniqueness of this technique is that it can be used either by 1) monitoring ROT or 2) using an identified fixed charted object as the centre of the established imaginary circle. This implies that the FRT can be used in blind navigation, in which the course alteration will depend entirely on ROTI and the GNSS. If visibility permits, the course alteration can be visually carried out by maintaining an identified target's bearing on the vessel's beam.

Similar to ROT Turns, this method relies on the helmsman's ability to maintain ROT or keep the reference object on the ship's beam by adjusting the helm’s angle appropriately. Equation (2) is the formula for calculating WOP using the FRT (Kamis et al., 2021d):

$$WOP = \frac{57.3\ x\ V}{60\ x\ ROT}\ (1 - \cos\theta) + F\sin\theta \tag{2}$$

ROT is the agreed turning rate, and V is the ship's speed in knots at the time of execution. The vessel's length in nautical miles (F) and the course alteration angle to be accomplished expressed in degrees (°) is Ө. It is important to note that WOP obtained through this method should be measured perpendicular to the next course line, as seen in Figure 4.

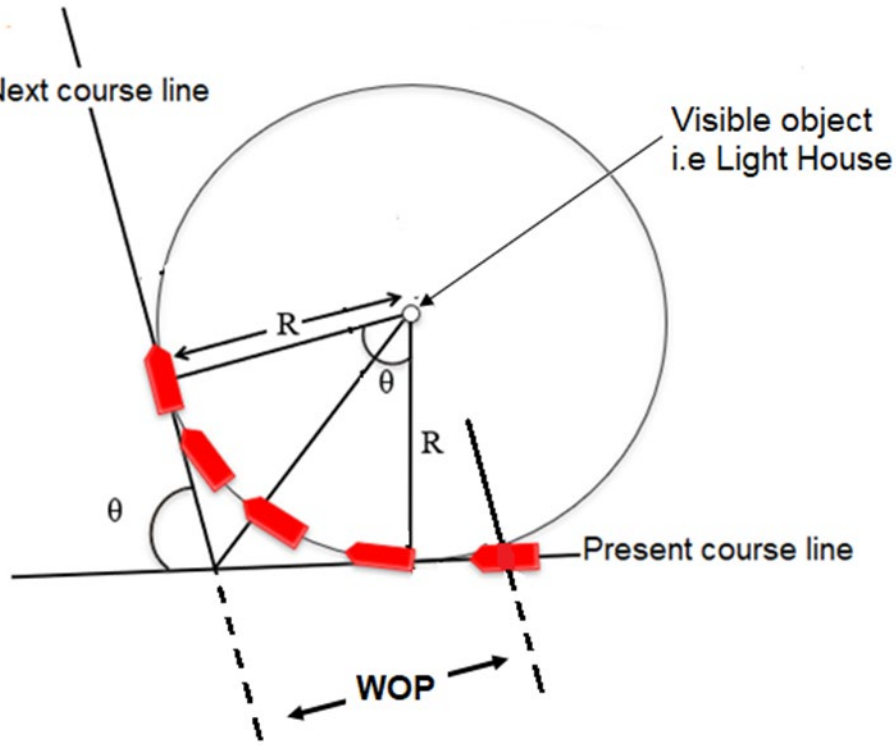


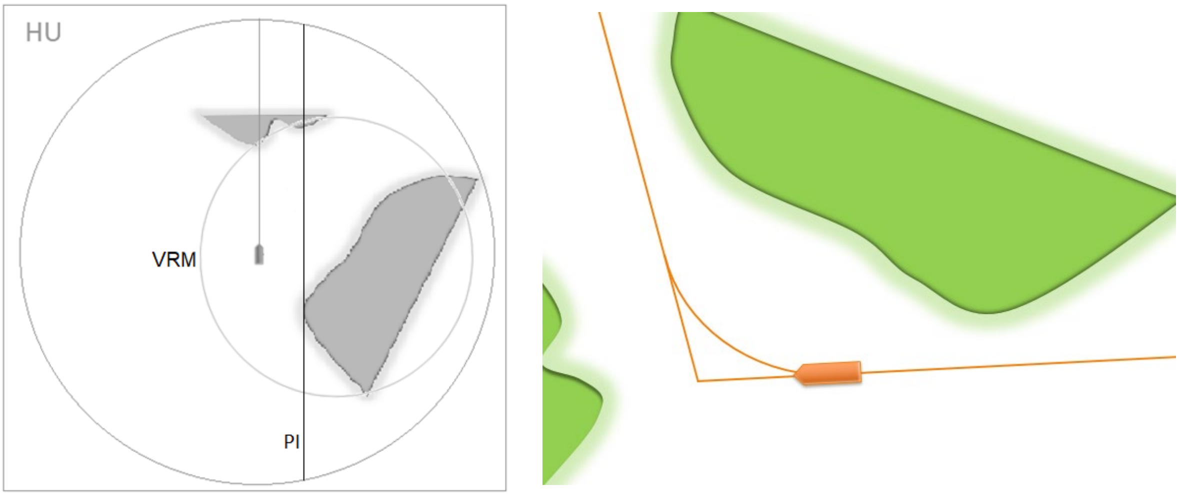
Figure 4. The basic principle for identifying WOP using the FRT technique, corresponding to Equation(2)

3.3. RADAR Turn

RADAR Turn (RT) refers to a technique that uses the ship's RADAR to execute the course alteration, hence its name. It utilises the RADAR's variable range markers (VRM) feature to indicate WOP without the need for visual navigation (Westin et al., 2019).

This technique is beneficial when there is restricted visibility, darkness, precipitation, or any phenomena that cause a lack of visual references (Georgiana & Stefan, 2010; Wepster, 1968), particularly for vessels that are not fitted with ECDIS. Therefore, in some literature, it was referred to as the blind pilotage technique (AMSAS, 2016; Georgiana & Stefan, 2010; Schlemmer, 2020; Westin et al., 2019), where it was described as a technique that is often used when the navigator's visual is impaired. RT uses RADAR's parallel indexing (PI) features to ensure the ship stays on track and VRM features for course alteration, as shown in Figure 5. Comparatively, for the other techniques outlined in this paper, navigators will need two separate devices: one for continuous position fixing to validate the vessel's position, such as GPS, and another device to monitor course changes, such as ROTI and compass. As a result, RADAR is the only equipment that can work independently in blind navigation.

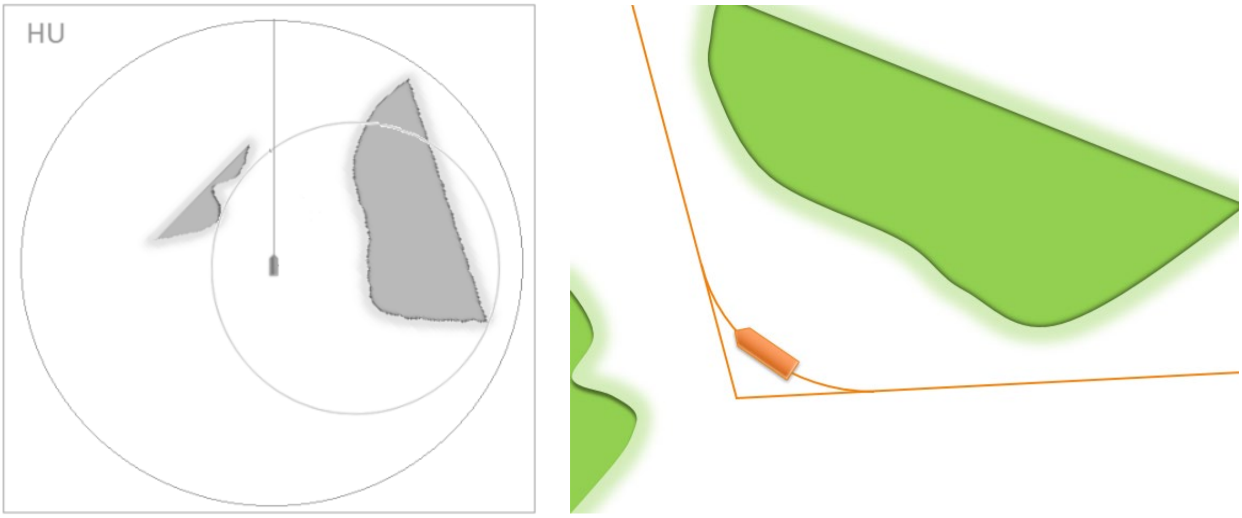
The navigator, with some help from the helmsman, manoeuvres the ship by following the established course line toward the reference point prior to executing this type of turn. The moment the established VRM touches the reference point, course alteration is executed, as seen in Figure 5. It requires reasonable control and adjustment of rudder angle while keeping the VRM on the reference point at all times. It is noteworthy to highlight that when the VRM touches the reference point, it implies that the ship has arrived at WOP, as seen in Figure 5 (actual view).



RADAR view Actual view

Figure 5. The vessel is kept on the course line using PI and, once the VRM is touching the reference point, course alteration can be executed.

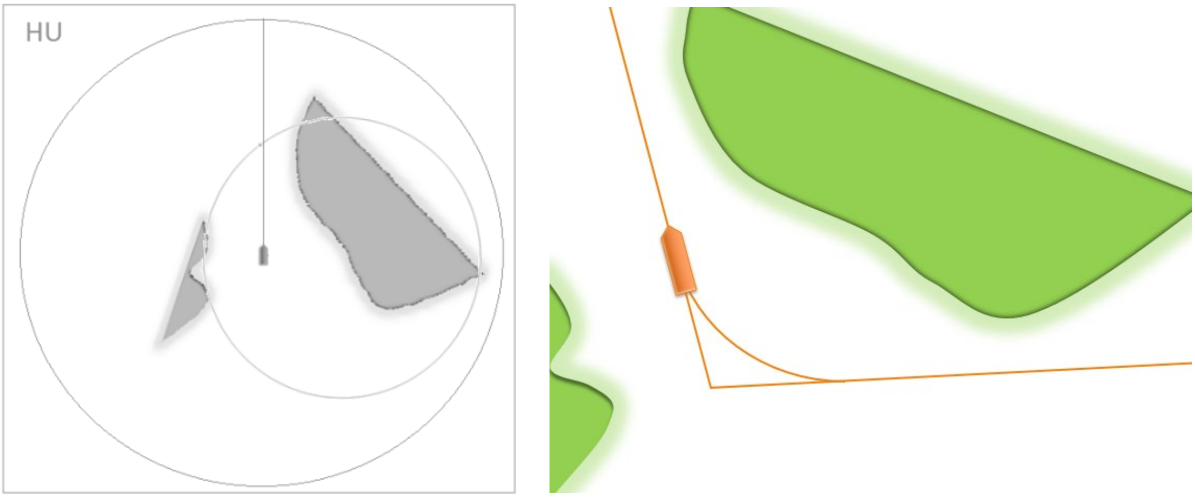
The helmsman will use his/her experience to control the rudder to make sure the VRM is constantly touching the reference point, as seen in Figure 6. In the actual view, the ship appears to be navigating along the turning curve as per the charted course.



RADAR view Actual view

Figure 6. The helmsman needs to steer the ship by applying the necessary rudder movement, ensuring the VRM is kept on the reference point

The navigator will instruct the helmsman to continue steadily on the final course when the navigator sees that the charted course and the ship's heading are matching. The helmsman will then control the rudder as necessary to put the ship on a steady course according to the charted course, as seen in Figure 7.



RADAR view

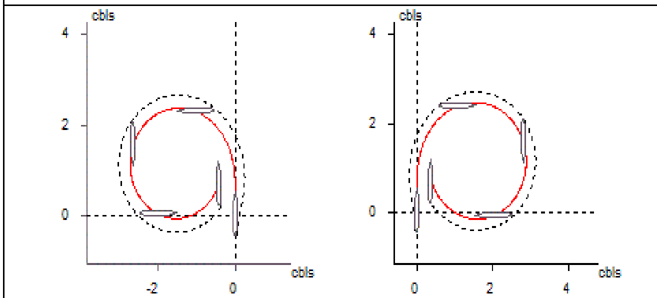
Actual view

Figure 7. The heading and the charted course are aligned. This implies that the vessel has completed the course alteration and is continuing steadily on the charted course

3.4. Fixed Rudder Angle Turns

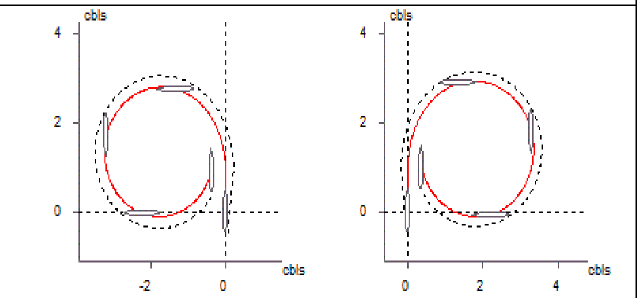
Ballast condition

Deep water



Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.4 cbls	1.08 cbls	2.81 cbls	59 deg/min	8 knots	359.6 s
100	-35	2.3 cbls	-1.02 cbls	-2.65 cbls	-60 deg/min	8 knots	348.6 s

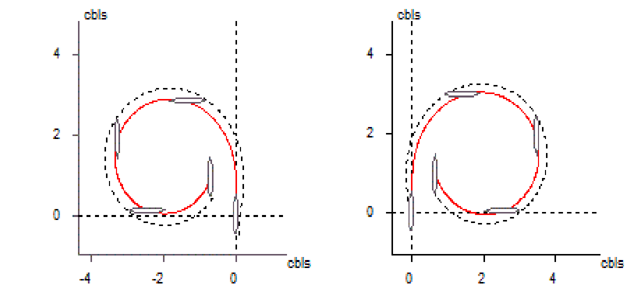
Shallow water



Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.9 cbls	1.39 cbls	3.29 cbls	54 deg/min	9 knots	400.6 s
100	-35	2.77 cbls	-1.32 cbls	-3.15 cbls	-55 deg/min	8 knots	389.6 s

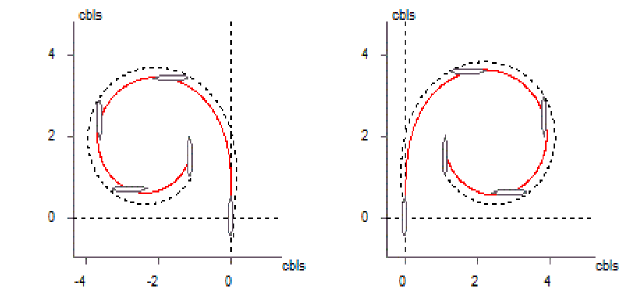
Loaded condition

Deep water



Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.96 cbls	1.44 cbls	3.48 cbls	42 deg/min	7 knots	488.6 s
100	-35	2.83 cbls	-1.37 cbls	-3.28 cbls	-44 deg/min	6 knots	470.6 s

Shallow water



Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	3.59 cbls	1.75 cbls	3.83 cbls	43 deg/min	6 knots	511.6 s
100	-35	3.41 cbls	-1.66 cbls	-3.62 cbls	-45 deg/min	6 knots	489.6 s

Figure 8. An example of a ship's turning circle taken from a ship simulator, which includes advance, transfer, tactical diameter, final ROT, speed, and time

The Fixed Rudder Angle Turn (FRAT) refers to the positioning of the rudder, starting at a fixed angle when the ship arrives at the marked WOP until the ship achieves a 90˚ heading change compared to the initial heading (Anwar, 2015; Drachev, 2012). A few studies referred to this technique as advance transfer technique (ATT) (Anwar, 2015; Kamis et al., 2021a, 2021b), as it requires the values of advance and transfer from the ship manoeuvring characteristics. Ideally, there are fixed values of advance and transfer (Kim et al., 2005), where setting the ship's rudder to a particular angle will lead to an unchanging turning circle (Drachev, 2012). However, on board most ships, only advance and transfer information for maximum rudder angle were given as required by IMO (IMO MSC, 2002). The figures were obtained during the ship delivery process when a sea trial manoeuvre was performed, thus resulting in a particular manoeuvring characteristic for that ship, where the manoeuvring data was recorded (IMO MSC, 2002). The diameter of the turning circle depends on the 1) loaded/ballast condition and 2) shallow/deep water area, which highlights that the selection of turning circle to be used depends upon the navigation area (IMO MSC, 2002; Kim et al., 2005). For example, if the turn is to be executed in shallow water while in ballast condition, the advance and transfer values shall be obtained from the shallow and ballast condition's turning circle, as shown in Figure 8.

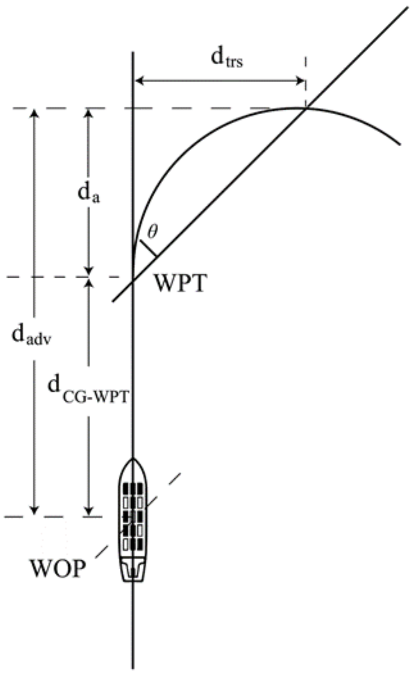


Figure 9. An illustration of the ATT based on the fundamental principle as explained by Anwar (2015) and further elaborated by Kamis et al. (2021b)

With reference to Figure 9, the following symbols and abbreviations are used to describe the formula:

d_{adv} = Advance as per ship turning circle

d_{trs} = Transfer as per ship turning circle

d_{CG-WPT} = Distance measured from CG to WPT

θ = Alteration angle

The ATT is constructed with references to the model, as seen in Figure 9. The formula to calculate the position of WOP was able to be created. According to Anwar (2015), WOP is measured from the WPT to the ship's centre of gravity (CG). Hence, it is termed as d_{CG-WPT} (Kamis et al., 2021b). To obtain d_{CG-WPT}, d_a is substracted from the advance distance d_{adv}:

$$d_{CG-WPT} = d_{adv} - d_a \tag{1}$$

d_a can be obtained as follows by applying the tangent rule:

$$tan\,\theta = \frac{d_{trs}}{d_a}$$

$$d_a = \frac{d_{trs}}{tan\,\theta}$$

Therefore, the formula of the ATT (Anwar, 2015) is obtained as below:

$$d_{CG-WPT} = d_{adv} - \frac{d_{trs}}{tan\,\theta} \tag{2}$$

However, this technique has a particular disadvantage where the final ship's heading and the desired course do not match, as seen in Figure 10. It happens because the advance and transfer values are measured based on the heading change of 90˚ from the initial heading (IMO MSC, 2002), whereas course alteration can occur at any angle (Kamis et al., 2022a). This drawback can cause a second overshoot if the helmsman does not carry out the necessary steering adjustment prior to meeting the desired course (Kamis, et al., 2021b). With the large rudder angle used, another downside of the approach is that it may cause a loss in the ship's speed (Ship Business, 2009) and cause the ship to be heavily heeled due to the centrifugal force (Biran & López-Pulido, 2014).

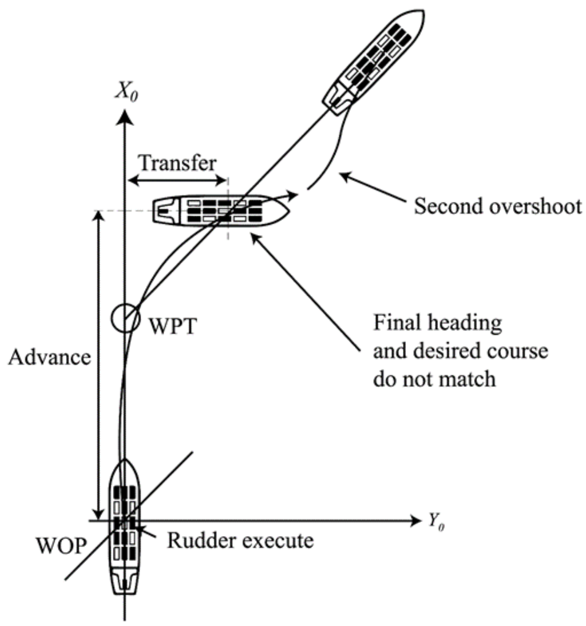


Figure 10. One of the drawbacks of the ATT is that the final heading and charted course are not aligned, causing a second overshoot (Kamis et al., 2021b)

4. DISCUSSION

4.1. Blind navigation

When it comes to blind navigation, the RT outperforms the other methods. This is due to the fact that, as described in Subsection 3.3, the equipment itself acts as a means of positioning and turning monitoring; thus, the RT can operate independently. The significant role of RADAR in blind navigation is highlighted in The Standards of Training, Certification & Watchkeeping for Seafarers (STCW) Code, which states that the OOW needs to be knowledgeable, understand, and be proficient in blind pilotage techniques, where the competency of such techniques will be evaluated through a practical RADAR exercise (IMO, 2018). In term of backup equipment, SOLAS, Chapter V, Regulations 19 requires vessels over 3,000 GT to carry at least two onboard RADARs (IMO, 1983, 2020).

ROTI is vital for the execution of ROT Turns and the FRT while altering course (Kamis et al., 2021c). Therefore, it is necessary for the ROTI to work properly to avoid mismanoeuvres, as described by TAIC (2017) in their accident report, in which the bridge team opted to make a course alteration while blindly navigating with ROTI without realising the instrument was defective. The incident might have been avoided if a second ROTI had been available. However, according to SOLAS Chapter V, regulation 19, ROTI is not obliged to have a backup system and is only required for ships of 50,000 GT and above (IMO, 2020).

Due to the current technological advancements, navigators can rely on ECDIS with the GNSS to determine the ship's position for blind navigation. However, it is essential to keep in mind that the operation of ECDIS is contingent on the input dependability of other devices. Additionally, it is possible that some ships do not have ECDIS as it is not made mandatory by IMO carriage requirements (Kamis et al.,2022b). Moreover, according to the MSC.1/Circ.1503/Rev.1-ECDIS-Guidance for Good Practice, ECDIS has been reported to exhibit operating anomalies. It refers to the unexpected or undesired behaviour of an ECDIS unit that may impede the user's ability to operate the equipment or make navigational decisions (IMO MSC, 2017). As a result, even though ECDIS is easier to use during blind pilotage, the anomalies may have reduced the equipment's reliability, as described in a study, where the behavioural intention to use ECDIS was not significantly influenced by either the assessed benefits or the ease of use (Tsai, 2016).

4.2. Minimising fuel consumption

As seen in Figure 11, staying on course will minimise the distance travelled by ship, which will optimise fuel consumption. Therefore, a ship that uses an effective track-keeping execution technique when altering course can achieve better fuel efficiency as opposed to a ship that frequently overshoots its planned track.

The findings of this study imply that the methods outlined can help to reduce fuel consumption; however, FRAT technique requires the ship to use its maximum rudder angle, which has the potential to significantly reduce the ship's speed, hence resulting in high fuel consumption as a direct result (Kamis et al., 2021b). While turning, the rudder maintains the hull at the drift angle to provide the lift required to propel the ship into the turn's centre. As with any other streamlined shape, the hull lift is only possible at the cost of higher drag. Without adjusting the engine parameters, the ship will decelerate as a result of the increased drag (Rawson & Tupper, 2001). Future research can be carried out in greater detail to understand better the influence of each method on fuel efficiency.

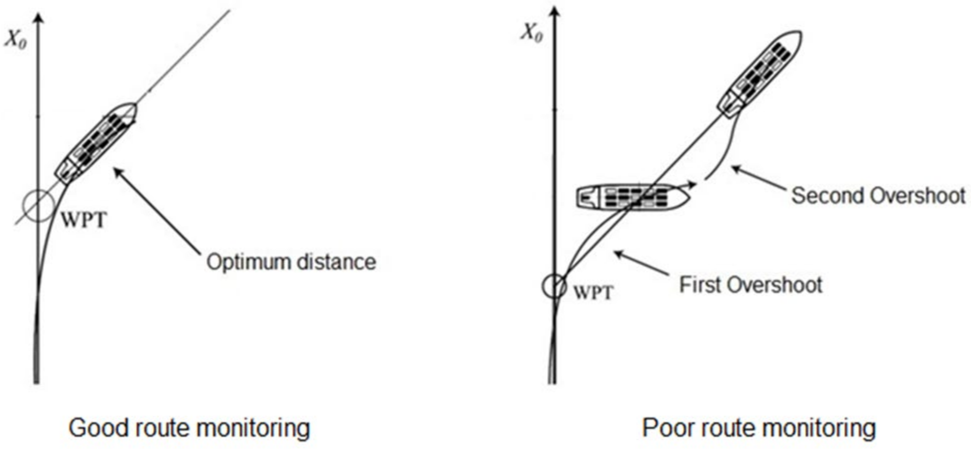


Figure 11. Comparison of good and poor route monitoring, in which good monitoring leads to the optimal distance while poor monitoring can increase the distance travelled

4.3. Rudder pressure and torque while turning

Rudder force and torque depend on the profile shape, cross-sectional shape and area of the rudder, square of the velocity of water passing the rudder, density of water, and rudder angle (Rawson & Tupper, 2001). Among the listed variables, the only variables within the navigators' control are the velocity of water caused by the ship's speed and the rudder angle.

For this reason, during ocean navigation, while the ship is moving at full sea ahead, ROT Turns and the FRT have been deemed the safest ways of executing a course change among the four techniques evaluated as they are computed according to an established ROT. ROT will be decided by the master, considering all parameters such as the ship's speed, rudder force, heeling moment, and other associated variables. As a result, the master will determine the most favourable ROT and consequently be able to instruct the navigators to perform the course change with the best possible rudder angle.

The RT can also be performed at an optimal rudder angle, provided the navigators plan the course alteration using big VRM to ensure the turning circle produced exceeds the vessel's tactical diameter.

Finally, when a vessel is manoeuvring at high speed, executing FRAT at the maximum rudder angle is dangerous as it can cause excessive rudder torque and subsequently damage the rudder. Even though a rudder is built to retain pressure and torque at a maximum angle and speed (Rawson & Tupper, 2001), it is a good seamanship practice to execute FRAT at a modest pace to avoid excessive force on the rudder. The practices correspond to MSC/Circular.1053 – Explanatory Notes to the Standards for Ship Manoeuvrability, where the circular stated that the course-keeping quality is a measure of the steered ship's ability to maintain a course in a given course direction without excessive rudder or heading oscillations (IMO MSC, 2002).

4.4. WOP as a way of monitoring pilot decision

Other than being a point to remind navigators to initiate course alteration, it was discovered that WOP could be used as a safety barrier in monitoring a pilot's behaviour while making a course alteration. Many incidents involving pilotage have occurred over the years; for instance, there were occurrences of ship accidents that resulted from the pilot being asleep (USCG, 1949), pilot making a last-minute course change (GARD, 2000), decision errors (MAIB, 2002), ship repeatedly overshooting a planned track (Gard, 2014), and a lack of understanding of hydrodynamic effects (MAIB, 2018). In Korea, over a period of ten years between 2004 and

2013, 47 maritime accidents that occurred under pilotage were reported (Park et al., 2019). Thus, as reported by TAIC (2016), despite the delay in the pilot's turn, the accident analysis determined that there had been sufficient sea area for manoeuvring. On the other hand, the bridge team took no action, mainly because no WOP was appropriately formed due to a lack of knowledge regarding WOP calculation, resulting in their inability to recognise the pilot's error (Kamis et al, 2022a).

According to IMO Resolution A.960(23) – Recommendations on Training and Certification and Operational Procedures for Maritime Pilots other than Deep-Sea Pilots, the master and the officers are responsible for providing any assistance to the pilot and ensuring that the pilot's actions are constantly monitored. Regardless of the authorised obligations and responsibilities of the pilot, the pilot's existence on board does not absolve the master or officers of their duties for the ship's safety (IMO, 2004). This implies that the bridge team can intervene by taking over control from the pilot if the pilot misses the WOP specified on the chart since it is evident that the ship will overshoot the planned track. However, the navigators must be confident that the ship will overshoot before overriding the pilot's authority because challenging the pilot's actions can disrupt the pleasant bridge atmosphere. As stated in one event, a breakdown in communication between the master and pilot contributed to a grounding accident. The investigation concluded that the initial dispute between the master and pilot on the bridge had a detrimental effect on the master and pilot's relationship, leading to a communication breakdown (MSIU, 2020).

For this reason, FRAT is the best strategy to be used to monitor the pilot because the determined WOP represents the last point at which action can be taken as it is computed based on the hard-over rudder angle. For the other methods, a small rudder angle can be used to calculate WOP. This will lead to hesitation about whether the pilot did miss the turn or whether the pilot will use more rudder, which will influence the decision to override the pilot's decision.

4.5. Ocean, coastal or harbour and confined water?

In terms of determining WOP during passage planning prior to voyage commencement, ROT Turns technique is the best choice to determine WOP for the ocean and coastal passages. This is because while navigating in the ocean and coastal water, the vessel's speed is known by referring to the ship's service speed and ROT as decided by the master. The navigation officer then calculates and marks WOP on the charted course using the provided equation. Meanwhile, for harbour and confined water areas, whilst navigating under pilotage, the ship's speed and ROT are at the pilot's disposal as the ship's speed needs to be frequently adjusted. Not knowing the speed and ROT that will be used makes ROT Turns technique challenging to be pre-calculated while planning the voyage.

For the second technique, the FRT provides two options on whether to execute the technique using ROTI or visually based on a fixed object. For the first option, if the navigator chooses to rely on ROTI, this technique requires speed and ROT as the input to determine WOP; therefore, it is most suitable for use during ocean or coastal navigation, as these two variables are known. On the contrary, the manoeuvring speed is varied for harbour and confined water (Babicz, 2015), and while under pilotage, the speed and ROT depend on the pilot's order. Therefore, determining WOP using this technique for harbour and confined water is difficult as it is challenging for WOP to be calculated in advance in the planning stages. On the other hand, for the second option, if the navigator chooses to execute the technique by visually keeping a fixed object on the vessel's beam, the speed and ROT can be neglected. In this case, the technique is suitable for use in coastal water as well as harbour and confined waters, where a visible object such as a lighthouse, racon, or a land structure can be used as a reference point. As long as the object is visible and kept on the vessel's beam, the vessel will end up on the next charted course. Nonetheless, since WOP needs to be planned before the voyages start, the disadvantage of this technique is that there is no guarantee that clear visibility will be encountered at the moment the vessel arrives at the point of alteration.

Thirdly, the RT technique is highly dependent on a conspicuous RADAR object as the reference point to establish a clearing range; therefore, it is suitable to be used in coastal or harbour and confined waters, where fixed reference points are often available. This technique is unlikely to be used in open waters as there is a lack of RADAR conspicuous objects. In addition, the technique requires the navigator to prepare the VRM prior to each alteration. Therefore, it may cause the navigators to be distracted while preparing the VRM, mainly if there is a series of course alterations to be carried out in a short time.

Finally, the FRAT technique does not require the mariners to monitor the ship's ROT or speed. When the ship arrives at WOP, the helmsman needs to put the rudder on a hard rudder angle toward the course alteration direction and keep the rudder at a fixed angle until the course alteration is completed. This method is preferable during pilotage due to the characteristic of the turning circle, where it is not significantly affected by the speed of the vessel, which implies that when using this method, the mariners do not have to worry about the speed to be used by the pilot (Kamis et al., 2021a; Kim et al., 2005). Therefore, this method is widely used while navigating in the harbour and confined waters, particularly during pilotage.

5. CONCLUSION

The research aims to classify the methods used by mariners to determine WOP for an effective course alteration. The findings can be used as a reference for mariners, especially young seafarers and cadets, to enhance their navigational skills because identifying the correct WOP according to the navigational area will help to improve route monitoring. Moreover, while reviewing the related literature, this study uncovered the details of the methods of determining WOP. As a result, this study is able to classify the techniques used by the navigators; in addition, it also highlights the effects of each method on fuel efficiency, rudder pressure, and torque. Additionally, the research reveals the optimal approach for estimating WOP during blind navigation, including using WOP to monitor pilot behaviour and the appropriate area to utilise each technique. Perhaps this discovery will assist mariners in selecting the best method or combining methods to improve ship navigation safety and open up new directions for future research.

5.1. Suggestions for future research

This study conducted a systematic literature review to elicit information about the methods for determining WOP, where the key findings of this study centre on specific procedures for each distinct navigation area. From a technological point of view, it may be possible to utilise mathematical analysis to see how other variables, such as the weather, affect the course alteration, with the aim of developing a mathematical model that can be used to determine the best alteration approach. It will make a significant contribution to the development of autonomous ships, in which the ship's artificial intelligence will be able to decide which method to use in different conditions.

Additionally, there is a possibility that navigators used additional strategies that were not documented. Thus, an interview with seafarers to identify the technique used on board their ship can be conducted; this will result in a complete understanding of the approach based on the seafarers' experience.

CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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