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Original article

Safety Domain Measurement for Vessels in an Overtaking Situation*

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Abstract

Marine traffic engineering has been pushed to the limits due to a rising demand in the shipping business. Merchant ships are growing dramatically, both in numbers and in size. To keep pace with current developments, automation seems to be one viable option when it comes to keeping ships running with fewer seafarers available. The aim of this paper is to monitor a modern day mariners' performance while working in a tense situation. The objective is to define the size of the safety domain whilst overtaking a vessel. The approach was to assess the ship's domain area within a 3 nm wide traffic separation scheme by using a ship handling simulator. From the simulation results, an overtaking domain was determined as 1.36nm long and 0.4nm wide. Safety domains in real-life situations were experienced on a much smaller scale compared to the previous findings. The working load for this particular operation is expected to be stressful and highly skilled orientated.

Keywords: marine traffic engineering, ship domain, simulation, shipping lane

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I. Introduction

The status of merchant shipping today can be described as ships that are faster and larger and that are handled by the least number of seafarers as possible. A highly automated merchant ship might be the answer to keeping a shipping business running. Hence, people are expecting that most ordinary jobs can now be accomplished by all kinds of machines and electronics. Nevertheless, historically concerns have arisen from endless shipping casualties. Recently, a Turkish bulker, the *Beks Halil* was overtaking and collided with a Vietnamese cargo ship in the Malacca Straits on March 4^{th}, 2013. Attention was drawn by mariners to how these vessels equipped with sophisticated navigation aids ended up colliding into each other. Certainly, it is not easy to identify that there is a correlation between the use of modern navigational equipment and fewer accidents. In fact, many cases lead to a justified conclusion between casualties and human errors. In the era of electronic navigation, mariners are needed to study thoroughly modern bridge operation.

An over reliance on technology combined with an inexperienced operation can lead to an accident (Syms, 2004). When a navigational warning is issued, mariners will have to bear in mind that equipment cannot replace the role of human beings working on the bridge. Nevertheless, modern day technology does serve a role to ease the working load by providing mariners with more accurate and up-to-date information. A prudent deck officer will know when to use it wisely, but not to become irresponsibly over-reliant on this kind of technology.

II. Marine Traffic Engineering

Marine traffic engineering is applied to investigate marine traffic conditions and to seek a better arrangement (Toyota and Fujii, 1971). The application of these research results is aimed at improving the facilities of ports, fairways, and their traffic regulations. This study aims to examine the effect of an officers' performance when it comes to a ship's safety domain considerations while manoeuvring through a traffic lane. An overtaking situation will be the first to be discussed, followed by marine traffic management and ship domain.

2.1. Overtaking Situation

Part B, Collision Regulations (COLREGs), steering and sailing rules are divided into three sections in terms of degrees of visibility (IMO 2003). The first section defines the conduct of vessels irrespective of what visibility conditions they encounter. The *Rules of the Road* define how vessels should behave at any time under any conditions. An overtaking situation is not mentioned until the second section, which applies to vessels in sight of one another. Taking Rule 3(k) into consideration, an overtaking situation only exists when vessels were able to observe each other. The last section applies to ship encountering in restricted visibility.

Rule 13, COLREGs, defines a situation where one vessel is intending to overtake another (IMO 2003). The vessel is simply defined as the overtaken vessel when another one, the overtaking vessel, is coming up from a direction more than 22.5 degrees abaft her beam (Cockcroft and Lameijer, 2003). If there is any doubt as to whether an overtaking situation is developing, the vessels concerned should always assume the answer is yes. Additionally, an overtaking vessel should not assume it is exempted from any liability when it decides to overtake another vessel at any particular time.

Section III (Rule 19) states the proper conduct of vessels within a restricted visibility environment. It applies to approaching vessels not in sight of one another. In general, two approaching vessels not in visual contact are both seen as the give-way vessels (Cockcroft and Lameijer, 2003). In order to prevent a close-quarter situation, Rule 19 (d) recommends two basic actions for a vessel forward of its beam and for a vessel abeam or abaft of its beam. In short, when being overtaken by a faster-moving vessel, the overtaken ship shall not alter course towards an approaching vessel. When a ship is trying to overtake another one ahead of it and they are not within visual contact of each other, port or starboard course alterations are both allowed.

2.2. Marine Traffic Management

The layout of the traffic system, the traffic density, the pattern of the traffic flow and their encounter rates are necessary elements when it comes to having a general view of marine traffic management (Zhao, Wu et al., 1993). Under any traffic management system, safety always comes first. The concerned parties would like to see a maximum amount of traffic volume that a designated traffic system can provide safely.

For a harbour-type traffic fairway, a consistent direction of traffic flow is expected (Beattie, 1971). Furthermore, an overtaking situation is rare within narrow traffic lanes. Instead, when it comes to approaching orders, ships are normally arranged by a vessel traffic controller (Chao, 2003). Queuing for a traffic lane becomes one of the options for maintaining safe and smooth marine traffic (Hsu, Hu et al., 2007).

In order to keep vessels at a safe queuing distance, the authority in the Port of Kaohsiung came up with recommendations for various types of approaching merchant vessels. Fundamentally, a safe distance in between two queuing ships corresponds to the ships’ sizes. The distance between two queuing vessels is as follows:

- 1 nautical mile (nm) in between (over 20,000 g.r.t.)
- 0.5 nm in between (500 g.r.t ~ 20,000 g.r.t.)
- 4 times a ship’s length for ships under 500 g.r.t.

By comparison, when it comes to straits traffic management, Hsu (2014) measured the distance among ships within a boundary of a traffic separation scheme. 0.8 nautical miles (1 nm was recommended by the Port traffic control) was determined for vessels travelling in line, under the same speed forward, and with similar headings.

2.3. Ship Domain

An effective ship domain is an area that surrounds a vessel and is recognized by other ships as a zone they should not enter, and furthermore, keep clear of (Goodwin, 1975). In theory, two-dimensional domains include the shape of a circle, rectangle, ellipsis, polygon or complex plan figure were previously determined (Pietrzykowski and Uriasz, 2009). Moreover, any vessel that comes within this domain will trigger an action by mariners to prevent any impending collision.

Fuji (1981) established a model of a ship domain as an oval shape with the ship in the centre. The major axis of the oval shaped domain reflects a tolerated distance between the stand on vessel and the others, either ahead or aft of herself. The minor axis would be described as the closest range between ships while travelling abeam. The model that is used is based on a stand-on ship in terms of the COLREGs. In the 1970's, Fuji used a 3000 tons (g.r.t.) merchant ship, which defined the domain of an overtaken vessel. The major axis and minor axis for the selected vessel were about 8 times the ship's length and 3 times the ship's width respectively.

In the studies made by Pietrzykowski, Wielgosz, et al (2012), an example of overtaking a slow-moving tanker (261-metre long, 48-metre wide, travelling at 11kts), the ship domain of 2.04 nm × 0.88nm was measured. In comparison of traffic monitoring for overtaking situation involving tankers, the encounter distance was measured to be 2.5 nm (Marcjan, 2011).

III. Ship Simulation

The simulation experiments began in January of 2011 and involved 52 qualified Taiwanese deck officers who were invited to the simulator suite. The experiment ended on the 5th of July, 2013. The simulator was a TRANSAS Navi-Trainer Professional 5000 and two simulated bridges/stations were controlled and monitored by the instructor's station. An individual deck officer was invited to run the simulation experiment, and the task of the simulation was simply to enter a traffic fairway where a slow-moving bulk carrier was in the front. To be able to complete the voyage plan, the participants would have to overtake the bulk carrier ahead whilst travelling through the traffic lane.

3.1. Engine and Rudder Control

The selected vessel for the participants was a 32,000 g.r.t. container ship measuring 203 metres in length and 25.4 metres in width (Transas Ltd. 2004). As the scenario chosen was in a fairly open sea area, the engine order telegraph was, therefore, set at full sea speed. This condition allows the vessel to reach a speed as high as 19.4 knots. Should the participants need to slow down using the main engine, a five-minute advance notice is needed to be given to the instructor during the experiment.

With a stable and fast speed forward, the auto-pilot was also available and turned on for the rudder control. A course change can be altered through the auto-pilot control or follow-up steering functions.

3.2. The Scenario

Participants were given a task - to sail into an east-bound fairway of the traffic separation scheme (under the title of TRANSAS sea area: open sea). The course of the eastbound traffic channel is recommended as 090° True.

The *Own Ship* (Code: *OS*) of the trial in Figure 1, had a heading of 090° true and started two nautical miles (nm) west of the TSS entry point. Once the OS overtook the slow-moving bulk carrier and altered her course back to its original voyage plan, the exercise was concluded.

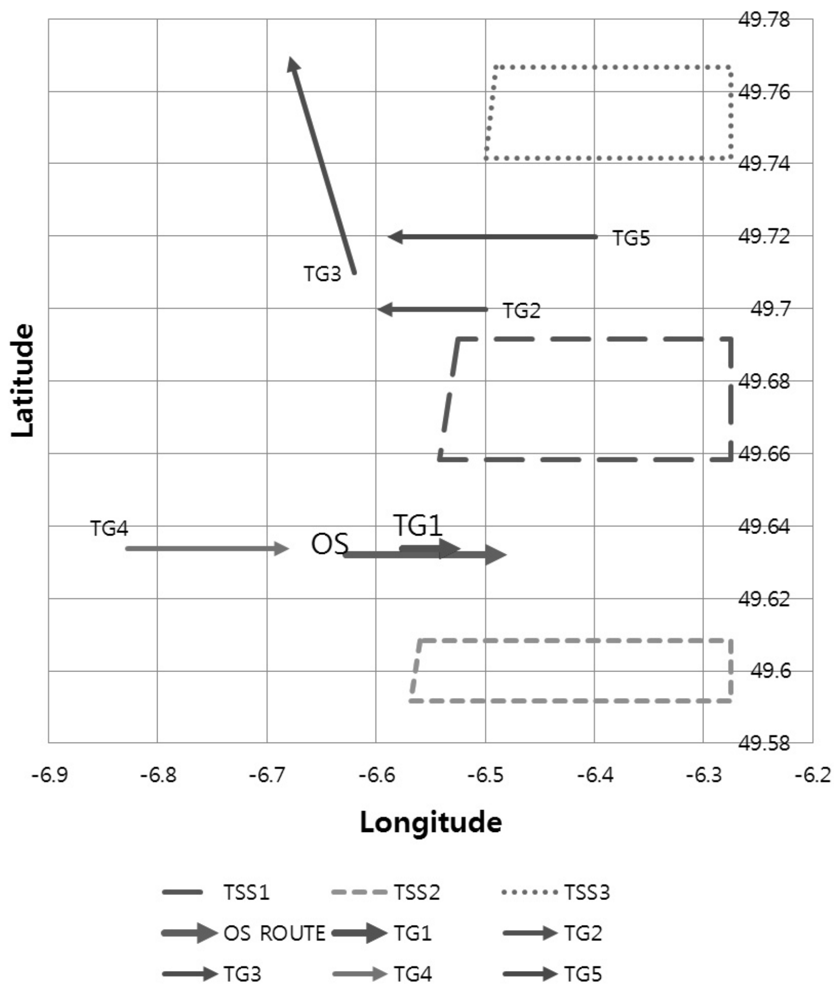

Figure 1: Overtaking scenario

Source: Author.

3.3. Traffic

Simulated traffic was applied to imitate a similar marine traffic condition in the same designated area as above (National Research Council (US) 1996).There were a few transiting target ships (Code: TGs) chosen. The projected arrows for each ship represent a 15-minute vector (see Figure 1 above). The location and intention of these target ships were mainly influenced by the previous investigation of the area through AIS broadcasting websites (Marine traffic.com

2014). It is left for the participants to decide if any of the target ships (*TG*) might or might not be a cause for concern to the own ship (*OS*).

The description of the traffic is listed in Table 1. Two bulk carriers (Code: *TG1* & *TG2*) and one LNG ship (*TG5*) were transiting in the correct fairway of the TSS from the beginning of the experiment. One vessel (*TG1*) was seen heading east and the others (*TG2* & *TG5*) were seen heading in an opposite direction. A car carrier (Code: *TG3*) was nearly abeam of the OS, heading northwest. A container ship (*TG4*) was 7nm far behind the OS and also heading east toward the TSS eastbound fairway.

Table 1: Traffic Lists

Code	Vessel type	Location	CPA/TCPA	Heading/Speed
OS1	Container Ship	-	-	**090°T/19.4kts**
TG1	**Bulk Carrier**	**087°T/1.98nm**	**0.094nm/8m44s**	**090°T/07.2kts**
TG2	Bulk Carrier	053°T/6.20nm	3.914nm/10m30s	270°T/14.6kts
TG3	Car Carrier	006°T/4.15nm	Not relevant	340°T/19.7kts
TG4	Container Ship	271°T/7.87nm	Not relevant	090°T/19.4kts
TG5	LNG	062°T/10.575nm	4.888nm/14m10s	270°T/20.3kts

Source: Author

3.4. Procedures

Before the simulator started, every participant was invited for a tour of the simulator suite. The conning panel, the Radar display, the ARPA function panel, and the chart display system were all thoroughly explained with regard to its operational usages. Next, a warm-up session was carried out for participants to be familiar with the control of the ship simulator. Shortly after the termination of the experiment, a debriefing session was held by the instructor where discussions with the participants took place and were recorded.

3.5. Data Measurement

There are a number of elements related to the creation of a ship's safety domain while overtaking a vessel. During the simulation exercise, the concerned data tracks were collected and the details of the elements are as follows,

- Overtaking range (in metres) between the *OS* and the *TG1*
- Action time of course alteration
- The bearing of the *TG1* while taking bold course alterations
  and
- The distance to the *TG1* while taking bold course alterations

IV. Simulation Results

4.1. Participants

There were 52 deck officers that made their contribution to the simulation test. At the end of the experiment, only 47 results were treated as valid data for an overtaking task scenario.

The majority of the participants (34 out of 47) worked as deck officers between one to five years. The ratio between a male (n=34) and a female officer (n=13) was 2.61 to one. There are a growing number of female Taiwanese deck officers aboard. Furthermore, most participants have experience working aboard container ships as well as bulk carriers where merely 6 out of 47 have also worked aboard liquefied cargo ships.

4.2. Tracks

The overtaking task is to transit an east-bound traffic lane with a slow-moving bulk carrier, which was blocking the middle of the own ship's route plan. Had the own ship kept its original course (heading 090° true) at full speed (19.4 knots), the CPA and TCPA to the concerning target ship (TG1) would have been less than one cable apart and shorter than 10 minutes see Table 1 above.

All the attending participants managed to keep the own ship in the east-bound fairway while overtaking the *TG1* (Figure 2). Among the 47 participants, only one (*OS25*) decided to overtake the *TG1* within a discernible range of 0.64nm (1288.8 yards) on her starboard side. Despite that, the rest of the participants took action to avoid a close encounter with the *TG1* by altering their course to starboard.

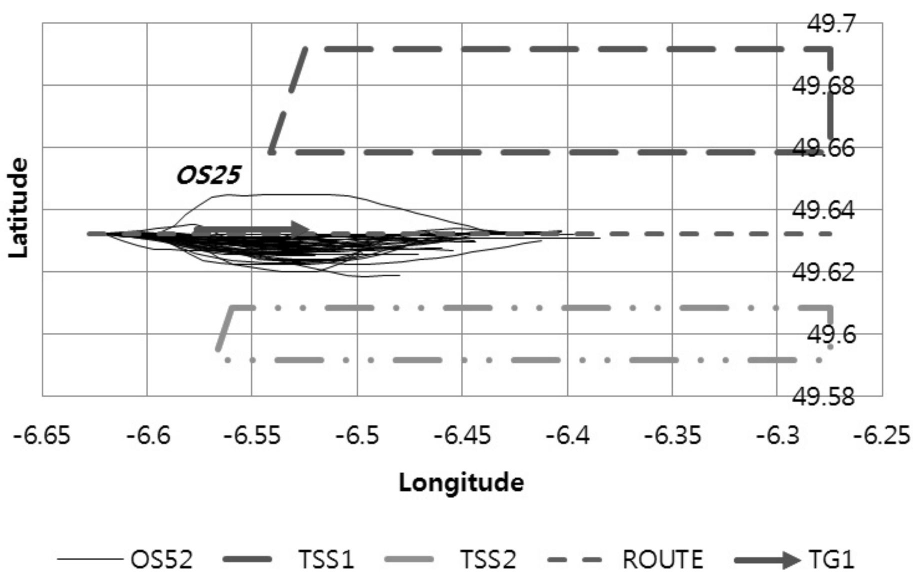

Figure 2: The own ship's track record

Source: Author.

4.3. Ship Domain/Overtaking Task.

The overtaking distance between the OS and the TG1 is shown in Table 2. The closest range to pass the TG1 was done by OS13 within a range of 238 metres. The farthest one was made by OS30 within a range of 1575 metres. On average, the participants completed the mission when it came to passing the TG1 within a distance of 734.2 metres (median: 748metres).

Table 2: Passing Distance

Number	Valid	47
	Missing	0
Average (metres)		734.2128
Median (metres)		748.0000
Range (metres)		1,337.00
Minimum (metres)		238.00
Maximum (metres)		1,575.00

Source: Author

The action time of a course alteration defines the tolerated distance between the overtaking vessel (the own ship) and the overtaken vessel (TG1). On average, the representative time of action is 3.18 minutes after the experiment commences (Table 3). At this point, the distance between the vessels concerned would be reduced from 2 nm (at the beginning of the exercise) to 1.36nm (3.18 minutes).

Table 3: Action Time

Number	Valid	47
	Missing	0
Average (min.)		3.18333
Median (min.)		3.27500
Range (min.)		9.267
Minimum (min.)		.633
Maximum (min.)		9.900

Source: Author

The collected simulation results above are to be used as a diagram concerning the safety margin of a ship's domain. Figure 3 shows an animated diagram of how participants aboard an own ship (red colour) alters course to starboard (the indicated green arrow) and overtakes the target ship (*TG1*; blue colour). At the appointed time (T_1), the blue coloured *TG1,* was nearly 2nm ahead of the red *OS* (D_{T1}). Using the averaged time (T_2) the participants actually altered course to starboard, the blue coloured *TG1* was only 1.36nm ahead of the red *OS* (D_{T2}). At that moment, it was deemed as the time to take action. Any closer range to the *TG1* ahead would have meant a dangerous distance in an overtaking/queuing situation. In terms of a safe passing distance in-between the *OS* and the *TG1* is concerned, 0.4nm was measured abeam at T_o.

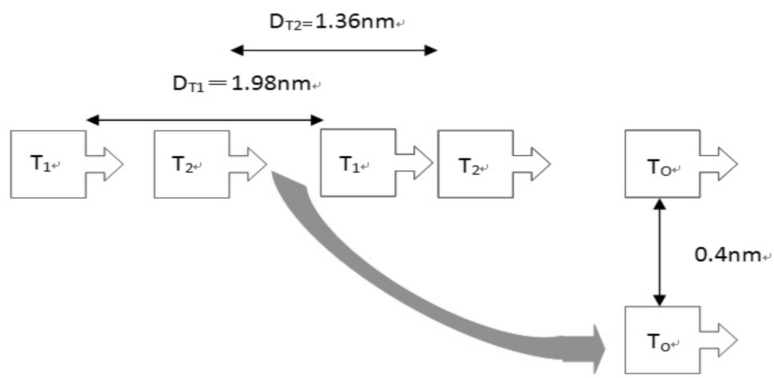

Figure 3: Safety Domain/overtaking ships

Source: Author

V. Conclusions

The measurement of a safety domain in an overtaking situation was carried out using a ship handling simulator. By inviting deck officers to the simulation suite, 52 deck officers volunteered to contribute to this research. The simulation scenario was to overtake a slow moving merchant ship through a designated traffic fairway. In terms of simulation results, CPA of 0.09nm and TCPA 4.55 minutes were measured as the time to take avoidance action. From the previous studies, distances over 2 nm between two encountered ships were generally defined as the safe distance in a fore-and-aft direction. This paper discovered a smaller semi oval-shape ship domain measuring 1.4nm × 0.37nm. Ships in waters under traffic separation scheme tended to navigate within a narrower range than out on the open sea.

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