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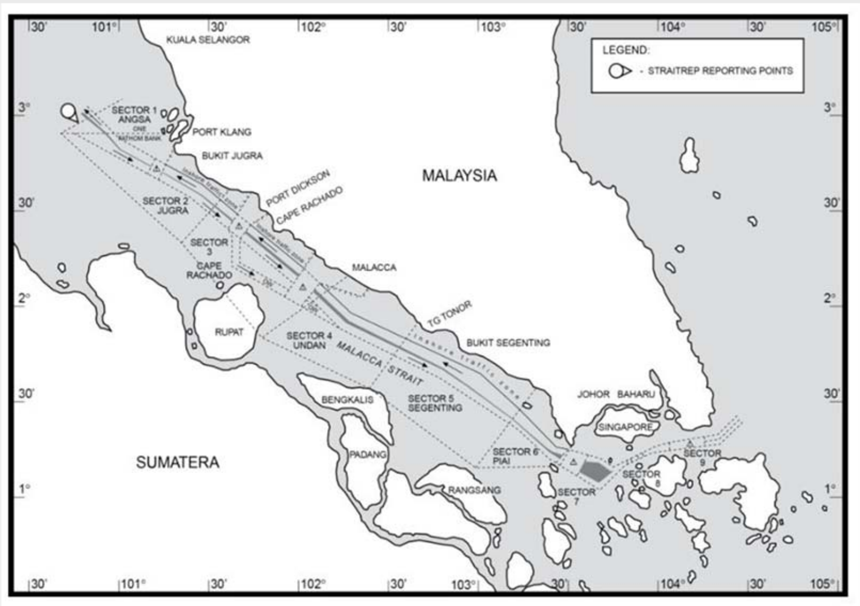
FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait

Part 1: Main Report

February 20, 2015



Summary

FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait

Part 1: Main Report

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Executive Summary

This study was undertaken to perform a formal safety assessment (FSA) for the use of three green lights night signal for vessels crossing the traffic separation scheme (TSS) and precautionary areas in the Singapore Strait. In order to demonstrate the applicability of the study results to other areas worldwide with TSS, investigations of the traffic and navigational risks in two other selected areas with TSS, namely, the English Channel and San Francisco Bay were also undertaken. The study was carried out in accordance with IMO's FSA guidelines. FSA, a rational and systematic process for assessing the risks relating to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks, involves the following five stages: (1) Identification of hazards; (2) Risk analysis; (3) Risk control options; (4) Cost-benefit assessment; and (5) Recommendation for decision-making. These FSA steps were addressed through a number of studies and activities, including a review of historical incidents/ data, expert opinion during a HAZID workshop, traffic and ship simulation exercises, and cost-benefit analysis.

Six types/categories of causal factors were identified, namely: (a) human factors; (b) environment; (c) physical surrounding; (d) shipboard technology; (e) policies; and (f) method (of identification and assessment), and were used to develop a hazards list. A number of hazards were identified, assessed and ranked. High risk hazards were subjected to risk control. A total of 31 Risk Control Options (RCOs) were identified in the study. These were rated and ranked in accordance with their ease of implementation and effectiveness in terms risk reduction. The 3 green lights night signal RCO had the highest weighted percent risk reduction of 19%.

This effectiveness of the three green lights was further studied in a ship simulator. The main objective was to evaluate if the three green lights night signal are beneficial to identifying vessels that are intending to cross, or are currently crossing, the traffic separation scheme. This was achieved by testing the ability of lookouts to identify crossing vessels in a traffic separation scheme (TSS) using the new combination of navigation lights as compared with those using only traditional navigation lights. It was observed that for vessels displaying the three green lights, the Lookouts were able to provide accurate information for 88% of the time, compared to 85% of the time for vessels not displaying the three green lights night signal, and 86% for all targets. There was thus some improvement in the correct identification of targets when the vessels displayed the three green lights.

On average, for vessels displaying the three green lights night signal, it took the Lookouts 23 s to detect the vessel after the vessel first appeared, compared to 28 s for vessels not displaying the three green lights, and 26 s overall. In addition, the simple tests conducted in the simulation exercise have demonstrated an approximately 18% improvement in the time it took the Lookout to correctly detect and identify the crossing vessels, if the vessels displayed the three green lights night signal. Additional support on the utility of the new navigation light was obtained through questionnaires administered by the MPA on vessels operating live within the vicinity of crossing vessels on an ongoing basis in the Singapore Strait. It was noticed that 91% of crossing vessels complied with the 3 green light night signal, and 97% of mariners in the vicinity of the crossing vessels, who were interviewed, stated that the RCO was effective.

Cost-benefit analysis demonstrated that the 3 green lights night signal RCO was very cost effective for collision incidents resulting in oil spills, for both existing ships and new builds. The RCO was also found to be cost effective for collisions resulting in fatalities for new builds. It was also shown that, for existing ships, the RCO could be moderately cost effective, if catastrophic events involving large passenger vessels or high speed crafts, resulting in large numbers of fatalities or situations where passenger costs are higher than IMO suggested cost of averting a fatality (CAF) value of 3m USD, were to happen.

In light of these demonstrated benefits of the utility/effectiveness of the 3 green lights night signal in Singapore Strait, it is concluded that this RCO will be beneficial to navigation in similar straits and bodies of water in other parts of the world, and it is recommended that efforts be made to introduce the RCO worldwide.

Although the mariners, both in the risk workshop and in the Singapore user surveys, found great utility in the three green lights they did not feel that a corresponding day signal, as per the collision regulations,

was either appropriate or useful. The difficulty in identifying day signals, coupled with the necessity of detailing a person to hoist a signal for a limited time during a critical navigational juncture was deemed not to be a useful measure for risk reduction.

The risk workshop participants showed a strong preference for trying a high-intensity green strobe light as a day signal provided appropriate technical specifications could be developed. Such a light could be easily switched on and off by a member of the bridge team with a minimum of distraction and could serve as an indication of, or intent to, cross the traffic separation scheme. However, as COLREGs does not allow high intensity flashing light for attention, at present the most feasible option would be to enforce the use the signal flag LZ1 indicating "I intend to pass through the channel/fairway" as per International Code of Signals, if considered necessary.

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Glossary and Acronyms

AIS	Automatic Identification System
AOI	Area of Interest
BRM	Bridge Resource Management
CATS	Cost of Averting a Tonne Spilt
COLREGs	Collision Regulations
DOF	Degrees of Freedom
FSA	Formal Safety Assessment
GCAF	Gross Cost of Averting a Fatality
GIS	Geographical Information System
GPS	Global Positioning System
HAZID	Hazard Identification
HF	Human Factors
HSC	High Speed Craft
IMO	International Maritime Organization
km	Kilometer
LRA	Lloyd's Register Asia
MISLE	Marine Information for Safety and Law Enforcement
MPA	Maritime and Port Authority of Singapore
RCO	Risk Control Option
SME	Subject Matter Expert
SMS	Ship Management System
TSS	Traffic Separation Scheme
UK MAIB	United Kingdom Marine Accident Investigation Branch
UK MCA	United Kingdom Maritime and Coastguard Agency
UKC	Under Keel Clearance
USCG	United States Coast Guard
VHF	Very High Frequency
VLCC	Very Large Crude Carrier
VTS	Vessel Traffic System

1. Introduction

1.1 Background

The Maritime and Port Authority (MPA), in a recent study, found that one of the contributing factors of incidents in the Singapore Strait was that vessels transiting the Strait were unable to distinguish whether a vessel would be crossing the Traffic Separation Scheme (TSS). This is due to the difficulties in visually identifying the vessel, especially at night when there are background lights from landward facilities. To address this issue, the MPA introduced the three green lights night signal for crossing vessels in the Singapore Strait as a recommendatory measure, in July 2011 [1]. The night signals identify these vessels crossing the TSS during hours of darkness, thus allowing other vessels in the appropriate lanes to take actions if required, thereby enhancing navigational safety. To date the recommendatory measure is observed to be complied with by 91% of mariners crossing in the Singapore Strait, and 97% of vessels surveyed found the measures to be effective. As the usefulness of this measure may have application in other parts of the world, MPA is considering having this measure implemented globally and made mandatory. It is recommended to carry out a Formal Safety Assessment (FSA) as per IMO Guidelines [2] to assess the risks associated with shipping activity and to evaluate the costs and benefits. MPA contracted Lloyd's Register Asia (LRA) to conduct this FSA for the vessels crossing the TSS and precautionary areas in the Singapore Strait and other selected areas worldwide having TSS.

1.2 Objectives and Scope

The main objective of this study was to undertake a FSA for the vessels crossing the TSS and precautionary areas in the Singapore Strait. In order to demonstrate the applicability of the study results to other areas worldwide with TSS, investigations of the traffic and navigational risks in two other selected areas with TSS, namely, the English Channel and San Francisco Bay were also undertaken.

The study was carried out in accordance with IMO's FSA guidelines. FSA is a rational and systematic process for assessing the risks relating to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks, and involves the following five stages:

1. Identification of hazards,
2. Risk analysis,
3. Risk control options,
4. Cost-benefit assessment, and
5. Recommendation for decision-making.

Figure 1 shows a map of the study area. The study will focus mainly on collision scenarios. The scope of the study included the following:

- Summary ship traffic density and pattern in the Singapore Strait
- Characterization of marine accidents and lessons learned
- Assessment of the effectiveness of the three green lights night signal for crossing vessels
- Cost-benefit analysis of risk control options; and recommendations for decision making.
- Evaluation of the need for a Day Signal.
- Evaluation of the traffic in straits in other parts of the world (English Channel and San Francisco Bay area) to obtain feedback from other Traffic Separation Schemes.

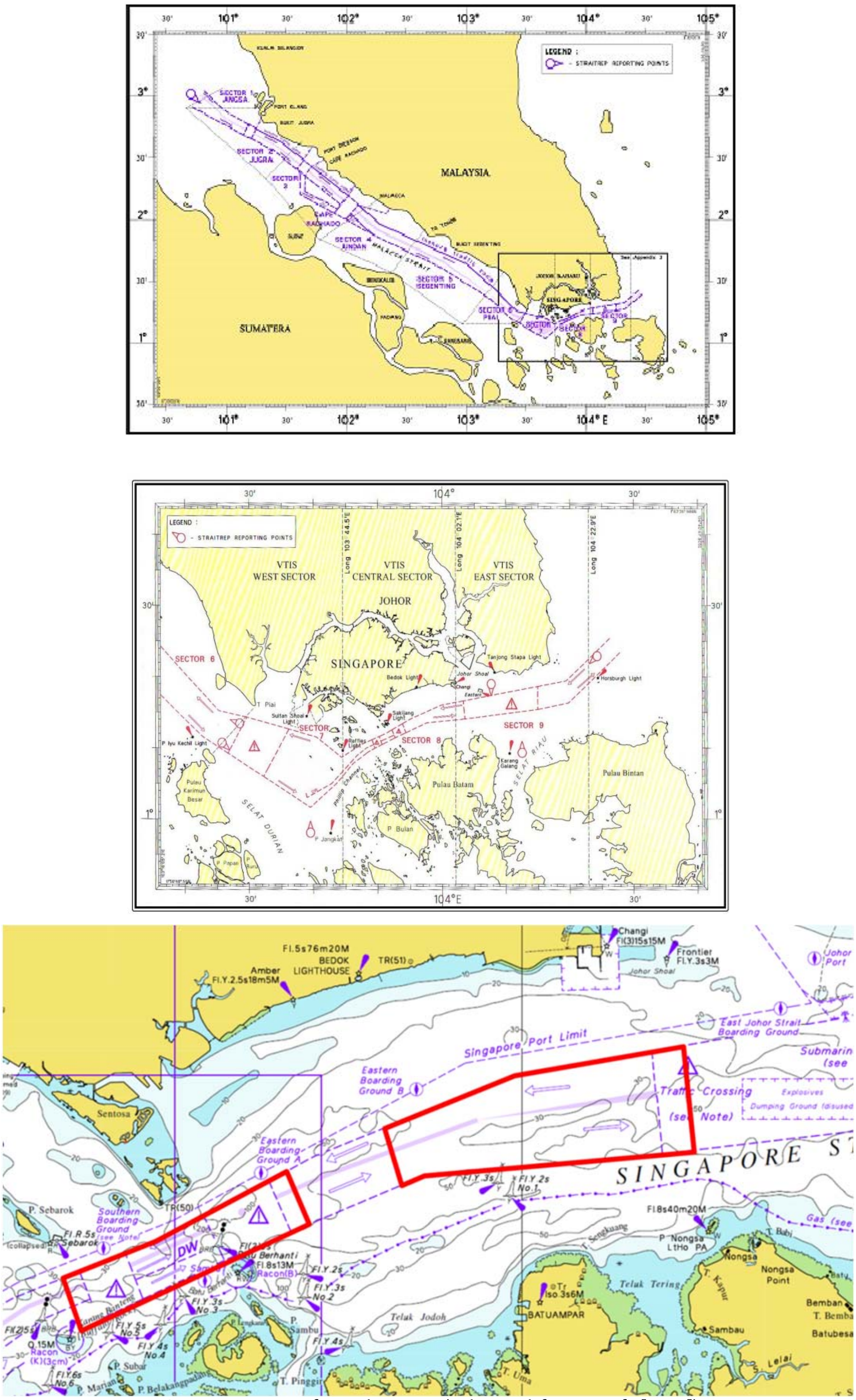


Figure 1 Map of Study Area (adapted from Ref. [3, 4])

1.3 Report Structure

This document (Part 1) is the main report on the FSA for the use of three green lights night signal for vessels crossing the TSS. It is provided as a self-contained report that describes the methodologies and results obtained for each of the FSA steps. Detailed descriptions of the activities undertaken in the study are provided in additional accompanying documents as follows:

- Part 2: Report on risk workshop that informs FSA Step 1 - identification of hazards; Step 2 - risk analysis; and Step 3 - risk control options.
- Part 3: Report on traffic simulation that informs FSA Step 1 - identification of hazards; and Step 2 - risk analysis; and
- Part 4: Report on simulation of 3 green lights night signal that informs FSA Step 3 - risk control options.

The remainder of this document is structured as follows:

- Chapter 2 describes the methodology, including an overview of the FSA steps, data sources and the approach/ activities undertaken to address the FSA steps.
- Chapters 3, 4, 5, 6 and 7 provide details of methods and results for each of the FSA steps 1, 2, 3, 4, and 5, respectively.
- Chapter 8 discusses the uncertainties and limitations of the study.
- Summary and conclusions are provided in Chapter 9.
- Chapter 10 provides a list of references used in the study.

2. Methodology

2.1 FSA Steps and Study Approach

The FSA process is shown diagrammatically in Figure 2.

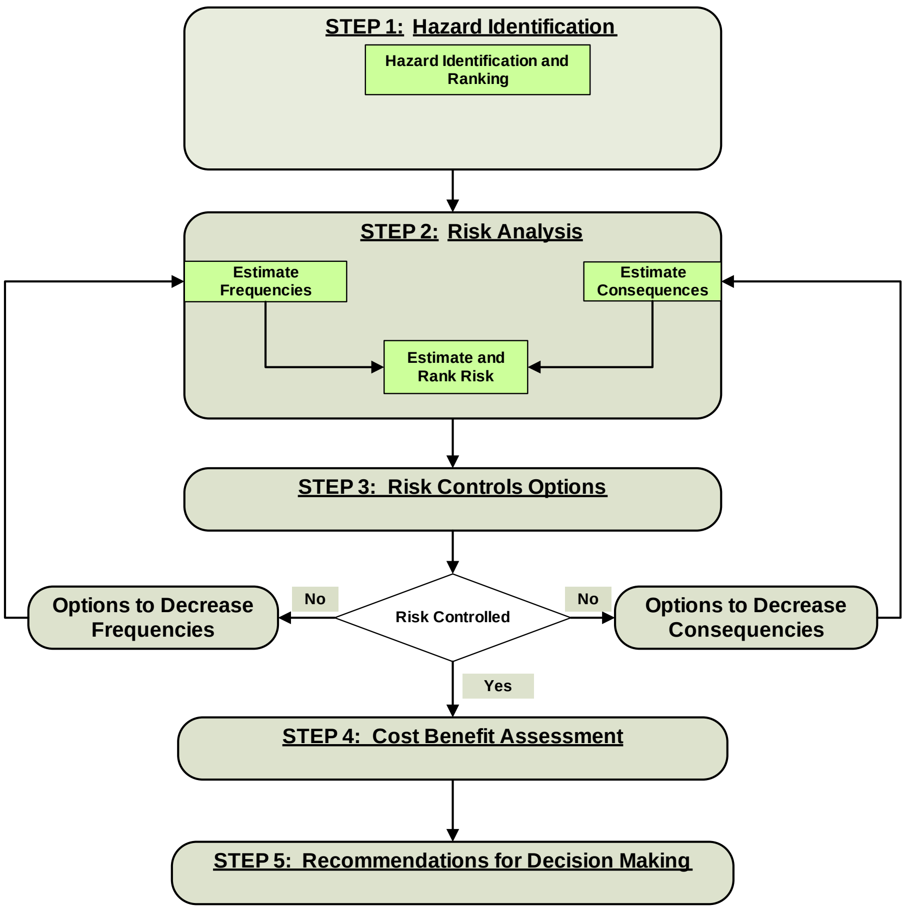


Figure 2. Flow Chart of FSA Methodology

Step 1 involves the identification of significant operations and associated hazards and scenarios that are likely to cause a loss of life, and/or spill of oil and dangerous goods, with and without the Night Signals (and possibly Day Signals). For this study, the focus was on hazards that could lead to collision scenarios in the TSS. This was achieved through three main activities, including: (i) a review of historical incidents; (ii) expert opinion during a HAZID workshop; and (iii) traffic simulation exercise.

Step 2 involves the determination of the frequency and consequences of the identified hazards in order to assess the risk. In this study, due to the nature of the issue being addressed, the focus is on the frequency/probability of occurrence of collision events. The intent is to reduce the number of collisions. Again, the goals of this step were achieved through three main activities, including: (i) a review of historical incidents; (ii) expert opinion during a HAZID workshop; and (iii) traffic simulation exercise.

Step 3 involves the assessment of risk control options (RCO) for the high risk hazards/ scenarios. Although the main issue in this study involved the 3 green lights night signal RCO, other RCO were identified and assess for completeness. This was undertaken through a brainstorming exercise of experts during the HAZID workshop. Further assessment of the effectiveness of the 3 green lights night signal was undertaken using a full mission bridge simulator.

Step 4 of the FSA process involves cost benefit analysis (CBA). In this study, the CBA was performed on the 3 green lights night signal RCO. Measures for assessing the effectiveness of the RCOs were discussed during the HAZID workshop, and used for the CBA. This included the percent reduction in likelihood of hazards to avert collision scenarios, due to potential implementation of the RCO. Consequences of collision were deduced from historical collision incidents in the Singapore Strait and worldwide. Measures such as the Gross Cost of Averting a fatality (GCAF) and Cost of Averting a Tonne Spilt (CATS), as proposed by the FSA guidelines [2], were used in the CBA.

Step 5 involves recommendations and decision making. Based on the CBA results of the 3 green lights night signal RCOs, recommendations on the use of three green lights night signal and/or Day Signal in the Singapore Strait are provided.

Details of the methods and results obtained for each of the FSA steps are presented in the following five chapters.

2.2 Data Sources and Applicable Documents

Significant documents, data sources and regulations used in this study are listed in Table 1

Table 1: Reference Documents and Databases

No.	Document, Database Title, Reference and Date	Issued By
1	Revised Guidelines for the Formal Safety Assessment, MSC-MEPC.2/Circ.12, 2013	IMO
2	MPA Port Marine Circular, Circular No. 4, 2013	MPA
3	AIS data for Singapore Strait for years 2012, 2013, 2014	MPA
4	AIS data for English Channel for year 2012	United Kingdom Maritime and Coastguard Agency
5	AIS data for San Francisco Bay for year 2013	United States Coast Guard (USCG)
6	Electronic Nautical Charts (ENC), 5C4037, 5C4036, 5C4035, 5C4034 and 5C4041	Singapore MPA
7	US National Oceanic and Atmospheric Administration (NOAA) ENC Direct to GIS service	NOAA
8	COLREG.2/Circ.42	IMO
7	COLREG.2/Circ.59	IMO
8	NOAA GSHHG dataset	NOAA
9	USCG Marine Information for Safety and Law Enforcement (MISLE)	USCG
10	Singapore MPA news release site	MPA
11	UK Marine Accident Investigation Branch site	UK MAIB

3. FSA Step 1 – Identification of Hazards

3.1 Historical Incidents

A review of historical collision incidents was undertaken in order to identify hazards and associated causes leading to collisions in the TSS, and to inform the HAZID workshop discussed in Section 3.3. The main focus was on incidents in the Singapore Strait, however, as per the project mandate, an attempt was also made to review incidents in two other locations, namely the English Channel and San Francisco Bay, in order to provide a global view.

For the Singapore Strait, a baseline set of incident reports was located within the Singapore MPA news release site [5], which was supplemented by media reports of incidents. In addition, a small number of incident reports were provided by the MPA. Due to the confidential nature of these reports, details are not provided in this report. Only information in the open literature is presented here. However, knowledge gained from review of these reports has informed the hazard identification exercise. Information regarding incidents in the English Channel was summarized from the UK MAIB site [6]. For the San Francisco Bay area, data were made available by the USCG via a subset of their MISLE database. In all three of these incident sets, it should be noted that it is likely that some incidents have been omitted, in particular those which are of a less serious nature, those still under investigation, and any of a contentious nature to the parties involved.

In the Singapore Strait area, 13 collision incidents were found between the years 2010 and 2014, inclusive. A collision incident log for the Singapore Strait is provided in Appendix 1A. A descriptive summary is presented in Table 2, and further detailed accounting of the incident sources is included in Part 3: Traffic Simulation Report. It should be noted that it is likely that some incidents have been omitted, in particular those which are of a less serious nature, those still under investigation, and any of a contentious nature to the parties involved.

Table 2: Collision Incidents in Singapore Strait Area (2010 - 2014)

Year	Vessels	Study-Relevant Collision Details
2010	Laptev Sea; PWP 1	Overtaking vessel alters course
2011	RHL Fidelitas; Voge Prestige	Crossing
2012	MV Seeb; MT Kota Tenaga	Night condition
2012	Sunny Horizon; DL Salvia	Fairway collision
2013	BOSUN; SC3566	Fairway collision
2013	Oriental Pioneer; Atlantic Hero	Early morning light condition
2013	Beks Halil; Unknown small tanker	Overtaking at close quarters
2014	Lime Galaxy; Feihe	Ineffective bridge resource management under conditions
2014	NYK Themis; AZ Fuzhou	Early morning light condition; Fairway collision
2014	Hammonia Thracium; Zoey	In TSS Precautionary Area; Collision in lane crossing
2014	Lord Vishnu; Skua	In TSS Precautionary Area; Collision in lane crossing
2014	Ye Chi; Hisui	In TSS Precautionary Area; Collision in lane crossing
2014	Best Unity; Southern Explorer	Collision in anchorage

Within these collated incidents, 3 were noted to occur under limited lighting conditions, 6 were noted within traffic control areas (either fairway or TSS), and 4 were noted to be the precise type of incident for which the "3 green lights" traffic control measure is intended to aid in reducing (collision in TSS lane crossing). It should be mentioned that it was not noted in the incident synopses whether the vessels were carrying or operating the prescribed signal at the time of the incidents. Figure 3 shows the locations of the incidents in the Singapore Strait area.

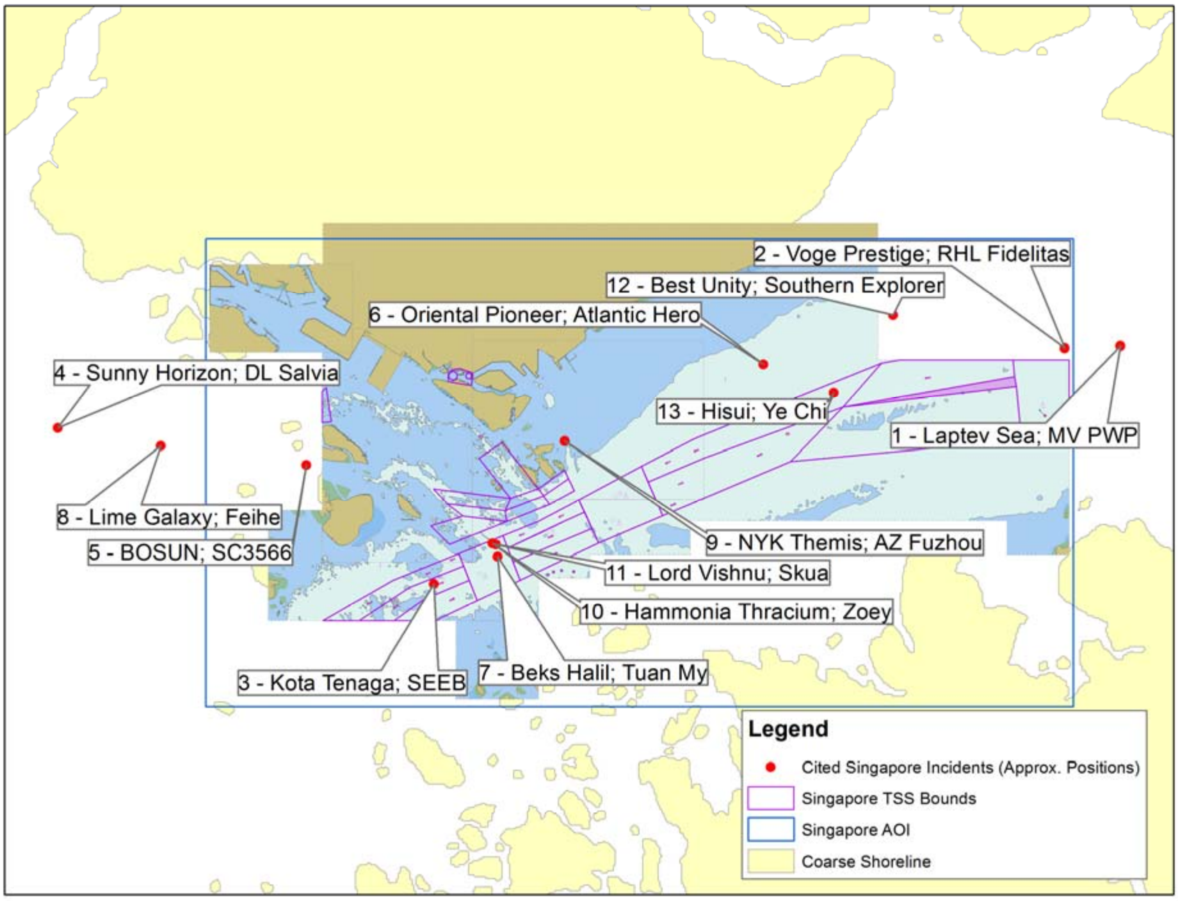


Figure 3. Identified Collision Incidents in Singapore Area (2010-2014)

Significant collision incidents occurring in the relevant UK waters were found to be well documented and investigated by the UK MAIB [7]. A total of 10 were noted to fall in the English Channel / Dover Strait region, and are described in Table 3. Further details are included in Part 3: Traffic Simulation Report. A collision incident log for the English Channel is provided in Appendix 1A.

Table 3: Collision Incidents in English Channel Area (2000 - 2014)

Year	Vessels	Study-Relevant Collision Details
2000	Pasadena Universal; Nordheim	Dover Strait; Congestion in overtaking; Lack of proper intention assessment
2000	East Fern; Kinsale	Collision SW of Dover; Poor BRM attention for conditions
2001	Gudermes; Saint Jacques II	TSS crossing; Night visibility conditions; Bad crossing bearing
2001	Hampoel; Atlantic Mermaid	TSS overtaking; Night visibility conditions
2001	MV Sand Heron; FV Celtit	TSS crossing; Fishing vessel, w/ unclear intentions
2001	MV Ash; Dutch Aquamarine	Close overtaking in TSS under good visibility
2002	Diamant; Northern Merchant	Ro - pax and HSC collision; Poor visibility
2008	Scot Isles; Wadi Halfa	TSS crossing; Early morning light conditions; Watchkeeping failure

Year	Vessels	Study-Relevant Collision Details
2013	Paula C; Barya Gayatri	Night conditions; In TSS
2014	Rickmers Dubai; Walcon Wizard	Overtaking in TSS; Morning light conditions

Of the collision incidents gathered, three were noted to involve TSS crossings, and all but two involved at least one factor of concern when considering implementation of the "three green lights" signal (attention, visibility, vessel intention assessment).

Despite no collision incidents in the San Francisco Bay Area having been analysed in detail by the NTSB [8], a total of 33 distinct events were retrieved from within the USCG MISLE database as falling within the SF Bay Area AOI, involving a total of 66 vessels over the time span 2002 - 2011. Summaries by year and type of collision are included in Table 4 for reference.

Table 4: Collision Incidents in San Francisco Bay Area by Year (2002 - 2011)

Year	Collision incidents in San Francisco Bay AOI
2002	5
2003	1
2004	3
2005	5
2006	3
2007	4
2008	2
2009	2
2010	5
2011	3
Total	33

Because of the source for this incident information (USCG), it is believed that this dataset is more comprehensive and reliable than the data obtained for the other areas due to active curation by the USCG. Additionally, it appears that the dataset includes vessels at the smaller end of the size spectrum, believed to be omitted from other regions. The combination of these two factors is believed to account for the relatively large volume of incidents noted. It is noteworthy that despite having relatively low traffic volumes in comparison to the other two regions (as discussed in Section 3.2), there are still a measurable quantity of collision incidents over the years surveyed. Within this dataset, crossings are also noted (4 of 33 incidents), though no particulars are provided as to the nature of the crossing encounters (e.g. in traffic lane or restricted navigation versus open water).

Overall, the following are some of the causes that led to the collision incidents:

- Lack of situational awareness;
- VHF not used;
- Deliberate inaction;
- Inadequate/ ineffective bridge team
- Inadequate passage planning

This information was used in the HAZID workshop.

3.2 Traffic Simulations

As part of the hazard identification process, traffic simulations were also carried out to study the traffic patterns and associated hazards. Again, although the main focus was the Singapore Strait area, the two other areas, namely the English Channel and San Francisco Bay, were also considered. Detailed descriptions of the traffic simulation methodologies, data sources' limitations and related uncertainties are provided in Traffic Simulation Report, Part 3. Brief descriptions of the traffic volumes and patterns in the AOIs are provided in this section.

3.2.1 Description of Areas of Interest (AOI)

The three areas of interest (AOI) are illustrated in Figure 4. The Singapore Strait AOI has been defined more specifically as bounded by meridians 103.71 and 104.08 east longitude and parallels 1.12 and 1.32 north latitude. These boundaries, as well as two areas denoted by Singapore MPA as being of particular concern, are shown in Figure 4(a). The Singapore AOI is roughly 40 kilometres from east to west, and just over 20 kilometres from north to south. A TSS with two major traffic lanes runs east-west through the centre of the AOI, with the East to West lane north and the West to East lane to the south. To the northwest of the AOI lies the port of Singapore, with a number of traffic lanes leading away from the primary TSS to serve the port. Additionally, outside the port area proper and to its east lies a large anchorage area, which is also to the north of the TSS. The primary traffic features are the east-west running traffic along the identified traffic lanes, traffic turning between these lanes and areas north of the lanes to head to or from the Port of Singapore / anchorages, and ferry traffic crossing the lanes north-south directly between ports on either side.

To address the English Channel TSS area, while avoiding the near shore traffic, an irregular AOI was drawn, roughly parallel to the south-west to north-east channel orientation. This AOI is defined as the polygon bounded by the four longitude, latitude coordinate pairs (East, North positive), proceeding clockwise from the northernmost point: {1.966, 51.920}, {3.075, 51.450}, {0.899, 49.942}, {-0.033, 50.724}. This region is depicted in Figure 4(b). This area runs approximately 200 kilometres along the TSS central axis and extends 100 kilometres wide along this length. The TSS in the area primarily describe northeast to southwest lanes between the North Sea and the southern extent of the English Channel. A branch to the TSS also runs east toward the Netherlands. Almost all traffic in this region travels along the northeast-southwest running lanes. A smaller portion splits from this route to head east-west through the TSS branch, while a number of vessels also cross the TSS directly between Dover and Calais.

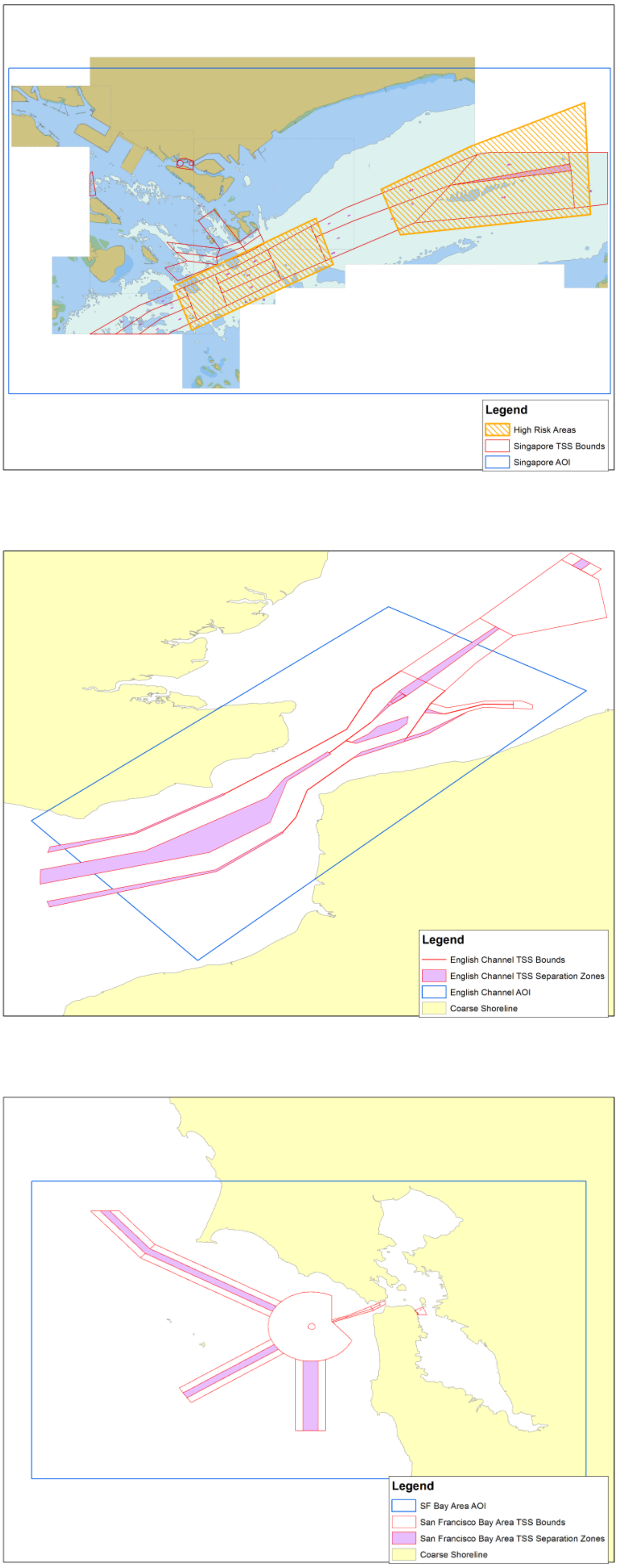


Figure 4: Areas of Interest for Traffic Simulations (a) Singapore Strait; (b) English Channel; and (c) San Francisco Bay

The AOI in the vicinity of the San Francisco Bay area includes the region bounded by the meridians 121.9 and 123.5 west longitude, and the parallels 37.312 and 38.169 north latitude. This region is depicted in the Figure 4(c). The area extends approximately 140 kilometres east to west and 95 kilometres north to south. At the west of the AOI, a TSS directs traffic into and out of the Bay Area. The TSS is composed of three sets of traffic lanes heading northwest-southeast, southwest-northeast, and south-north, into a central precautionary area hub, before extending east-west into the Bay under the Golden Gate Bridge. In addition to this TSS outside the Bay a smaller, roughly square, precautionary area exists along the San Francisco waterfront, alongside the San Francisco - Oakland Bay Bridge. Traffic approaching the area is generally constrained to the TSS, and then bottlenecked in the Golden Gate Bridge area. From this point, traffic then fans out to destinations in San Francisco, Oakland, Richmond, San Rafael and points north through the Carquinez Strait.

3.2.2 Data Sources

The key data resource upon which the simulated traffic paths were constructed for this project was ground station based AIS (Automatic Identification System) position reports. These were obtained through the Singapore MPA, U.K. Maritime and Coastguard Agency (MCA), and the United States Coast Guard (USCG), respectively for the Singapore, English Channel, and San Francisco Bay areas, respectively. Due to the high volume of AIS reports, it was decided to process only a representative quantity of data, that is, four 1-week periods spread across a given year, to explore any seasonal effects that might be present, while also ensuring that any intra-week effects are normalized (by avoiding discrete weekdays). In consultation with the Singapore MPA, the months of January, April, July and October were selected as the preferred months for obtaining sample data. The ranges of AIS data used for the traffic volume studies are shown in Table 5.

Table 5: AIS Data Ranges for AOIs

AOI	Year	Period 1	Period 2	Period 3	Period 4
Singapore	2013	January 4-10	April 1-7	July 11-17	October 3-9
English Channel	2012	January 9-15	April 9-15	July 9-15	October 4-14
San Francisco Bay	2013	January 7-13	April 8-14	July 8-14	October 7-13

3.2.3 Traffic Volumes

Three measures were used to assess the traffic volume in the three areas: total count of ship track segments, total track segment length sums, and elapsed transit time over the track segments. Total counts of segments are simple to compute, but only give rough estimates of traffic volume, can be biased by the methods used to divide the track segments, and give more weight to areas in which there are a larger number of discrete movements, which might not constitute "traffic" in a meaningful way. Track segment lengths provide a better assessment of traffic within a given area, as the length of track is a more accurate assessment of the spatial exposure of a vessel within a given environment. Elapsed time, on the other hand, provides an assessment of the temporal exposure of a vessel within a given environment. With uniform vessel speeds, these two measures would be roughly equivalent, however, the more the vessel speeds in a given area vary, the greater the expected difference between the measures. Otherwise, the critical difference between these two measures is in interpreting the result; whether it is more important to know the spatial measure of the vessels in the area, or the temporal extent. For this study, crossings involve both space and time (i.e. vessels in the same area at the same time), so it was considered helpful to review all available measures.

Table 6 and Figure 5 summarize the four-week traffic volumes for Singapore Strait. Projected annual traffic volumes can be obtained by multiplying the values in the table by 13. Unfortunately, vessels which were not successfully referenced were dominant in both segment count and total segment length. Putting these vessels aside, tankers, cargo vessels, passenger vessels and those of unknown (AIS) type made up the top four types for all three metrics. In segment length and elapsed time totals, cargo and tanker vessels were identified as the top two types, with tankers being top in total segment length and cargo ships top in elapsed time (again, putting aside unreferenceable vessels). As a known primary international shipping route, this meshes with expectations. Passenger vessels were noted as having moderately high total segment length, but lower elapsed time; this is most likely due to the comparatively high rates of speed for passenger carrying vessels. Fishing and pleasure craft were noted in fairly low numbers, though it is suspected that they are indeed present within the area. Their absence from these totals is most likely due to their lack of carriage of AIS transponders, placing most of them outside the scope of the available data.

Table 6: Singapore Strait Traffic by Vessel Type (2013 - 4 week totals)

	Total Segment Count	Total Segment Length (km)	Elapsed Time (Days)
C - Cargo	15831	221304.3	1755.3
F - Fishing	258	1972.9	14.8
G - Tug / Harbour Svc.	10581	38769.7	211.1
H - High Speed Craft	1688	11240.1	24.7
L - Pleasure Craft	368	446.7	2.7
N - Unreferenceable	76707	354262.3	1186.7
O - Other	313	2990.4	14.8
P - Passenger	21427	190899.9	342.0
T - Tanker	30997	258983.7	1177.6
U - Unknown	28537	122253.9	462.0
TOTAL	186,707	1,203,124	5,191.7

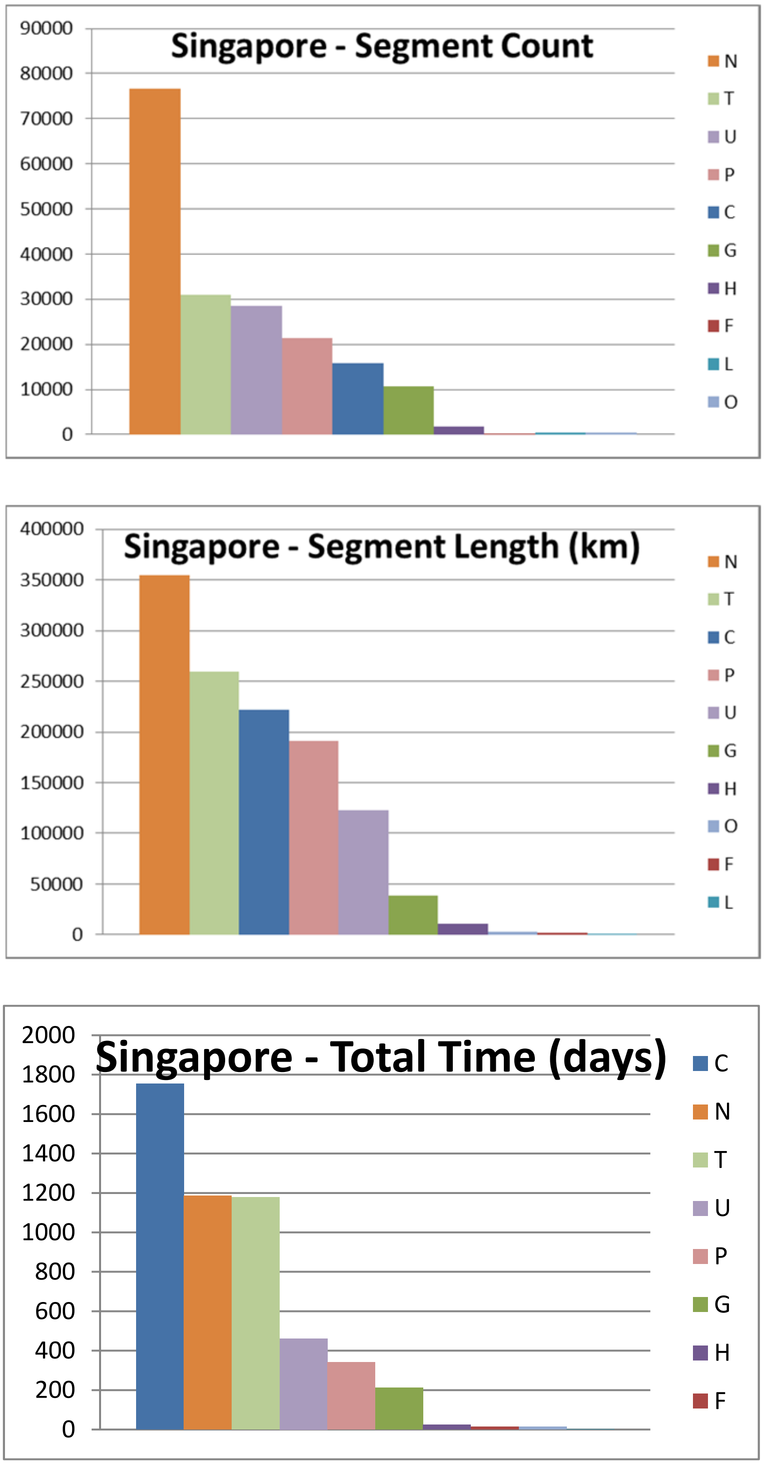


Figure 5: Singapore Traffic (4 –week totals) by Vessel Type (a) Segment Count; (b) Segment Length; and (c) Elapse Time

Table 7 and Figure 6 summarize the four-week traffic volumes for English Channel. Again, projections for annual traffic volumes can be obtained by multiplying the values in the table by 13. Cargo vessels were the primary vessel type noted within the English Channel across all measurements assessed. This is somewhat expected because of the Channel's role as a major shipping route for goods. Tanker traffic was also noted to be significant in terms of segment length total and elapsed time. Fishing Vessels and High Speed Craft were found in large quantities when assessing counts of traffic segments, but less so in the other measures. In terms of fishing vessels, their presence at all within the dataset suggests that the either the vessels themselves are of significant size, or that their operators are proactive in carriage of AIS. Their lower measure in terms of total segment length and time relative to segment count might be indicative of a large number of short transits with time spent primarily fishing rather than underway. With high speed craft transits, the limited totals for segment length and time are more likely due to the nature of the vessels' modes of operation: large numbers of short fast point-to-point transits, rather than long periods of extended cruising.

Table 7: English Channel Traffic by Vessel Type (2012 - 4 week totals)

	Total Segment Count	Total Segment Length (km)	Elapsed Time (Days)
C - Cargo	14382	707021.6	2448.8
F - Fishing	8417	57151.2	318.7
G - Tug / Harbour Svc.	4899	25755.6	101.4
H - High Speed Craft	7969	42730.1	102.4
L - Pleasure Craft	256	3369.0	17.4
N - Unreferenceable	2065	20372.2	63.4
O - Other	3219	40075.4	146.7
P - Passenger	4120	126231.3	196.4
T - Tanker	6034	284155.2	954.7
U - Unknown	4830	45063.2	180.0
TOTAL	56,191	1,351,925.0	4,530.0

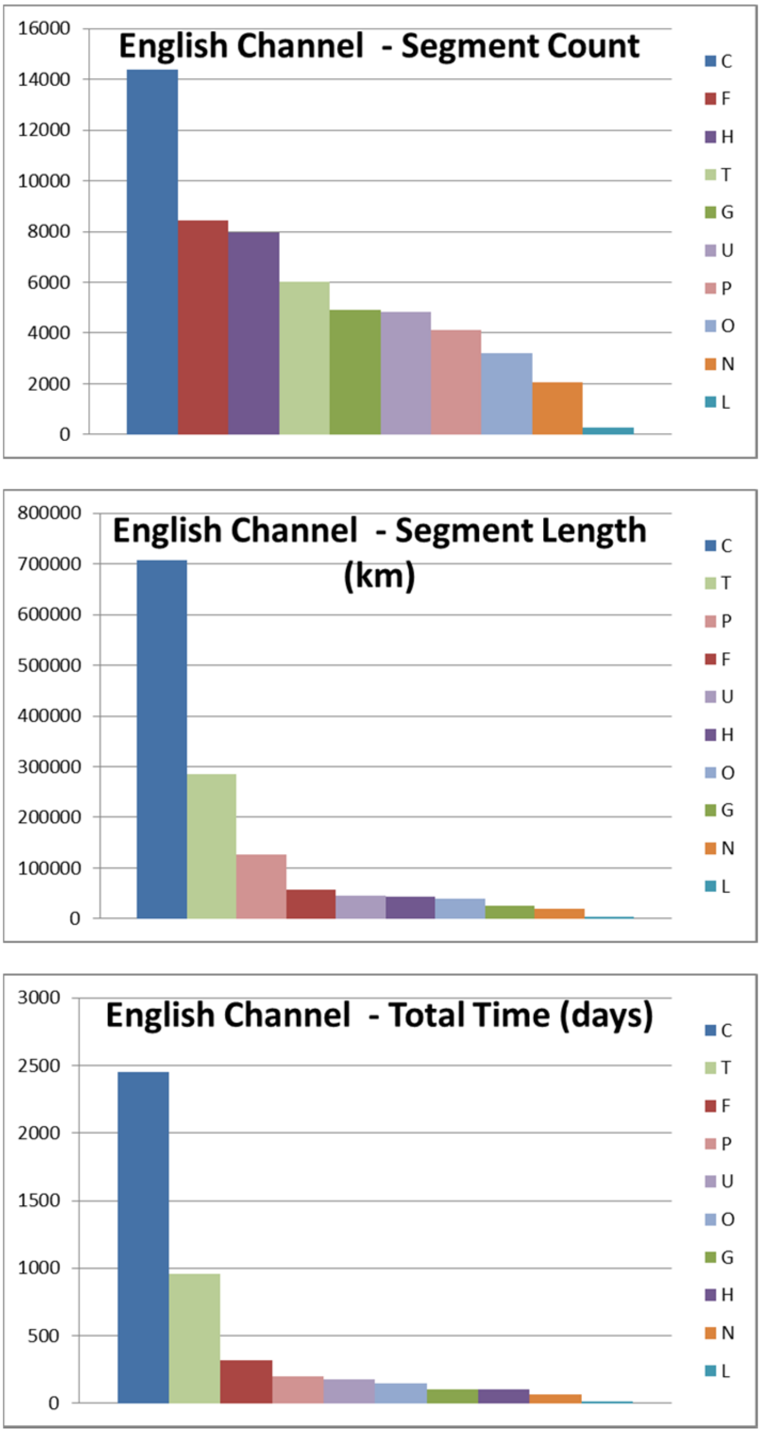


Figure 6: English Channel Traffic (4 week totals) by Vessel Type (a) Segment Count; (b) Segment Length; and (c) Elapse Time

Table 8 and Figure 7 summarize the four-week traffic volumes for San Francisco Bay. Annual traffic can be obtained by multiplying the values in the table by 13. Traffic from Tug and Harbour Service vessels were found to dominate all metrics within the San Francisco Bay area. This is not especially surprising, given that the bulk of the area is a sheltered bay with significant quantity of shoreline facilities. Passenger, cargo and pleasure craft round out the top four types noted in terms of total segment length and elapsed time. The higher numbers of passenger and pleasure craft in the traffic mix are most likely due to the highly populated shorelines within the AOI, as well as the general amenability of the area to recreational on-water activities. Because of the limited numbers of pleasure craft required to carry AIS, it might be expected that the actual on-water volume of pleasure craft in the area is quite high. Tanker vessels were not noted in this region to the same extent as in the others, a likely result of more constrained numbers of production facilities in this particular port, and the limited quantity of pass-through traffic in the AOI. Fishing vessels were again noted in limited numbers, likely due to limited AIS carriage relative to the size of vessels expected in the area.

Table 8: San Francisco Bay Traffic by Vessel Type (2013 - 4 week totals)

	Total Segment Count	Total Segment Length (km)	Elapsed Time (Days)
C - Cargo	1717	41938.1	78.0
F - Fishing	237	3009.1	10.3
G - Tug / Harbour Svc.	10246	72673.6	245.8
H - High Speed Craft	230	1883.7	2.8
L - Pleasure Craft	3443	20385.8	71.8
N - Unreferenceable	1	119.1	0.3
O - Other	967	3418.4	10.9
P - Passenger	7247	63969.8	102.2
T - Tanker	611	20073.3	44.6
U - Unknown	1800	9376.3	26.3
TOTAL	26,499	236,847.0	593.0

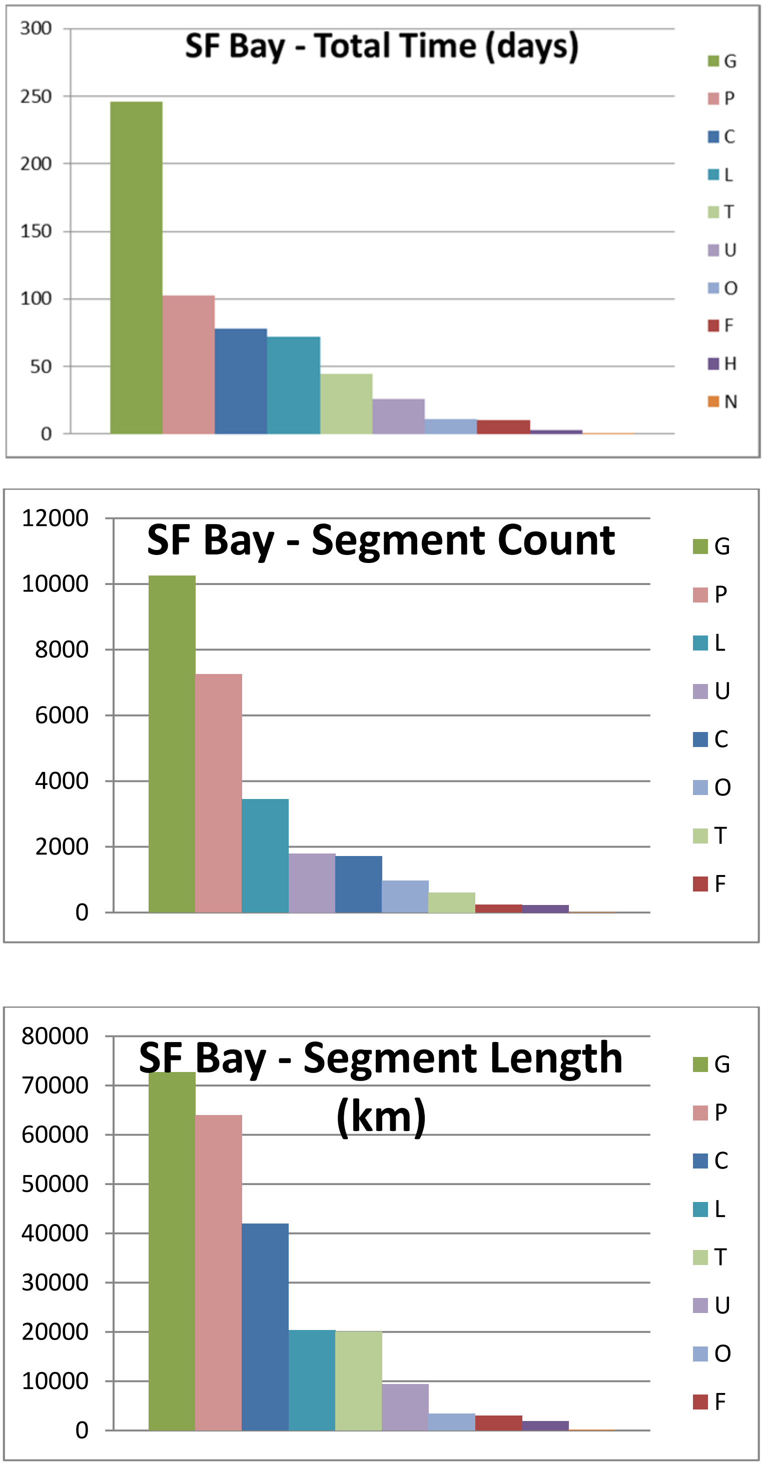


Figure 7: San Francisco Bay Traffic (4 week totals) by Vessel Type (a) Segment Count; (b) Segment Length; and (c) Elapse Time

Traffic densities depicting high risk areas in the three AOI are presented as part of the risk analysis step in Section 4.2.

3.3 Risk Workshop

A risk workshop was undertaken as part of the effort to identify hazards. This was a systematic hazard identification (HAZID) exercise of hazards that could lead to collisions in the Singapore Strait and other areas worldwide having TSS, using the collective knowledge and experience of various stakeholders, including MPA, APL Co. Ltd, BWFM Singapore, Eastern Pacific Shipping Pte Ltd, AET Ship Management Singapore PTE Ltd, Singapore VTIS, PSA Marine, Pacific International Lines PTE Ltd, and LRA. The workshop was conducted in Singapore on October 20-21, 2014. The workshop participants included risk experts and master mariners with navigational experience in the Singapore Strait. The detailed list of participants and their resumes are provided in Part 2 - Risk Workshop report.

Using the collective knowledge and experience of the workshop participants, a brainstorming exercise was undertaken to identify hazards and factors that could influence the risk of collision in the Singapore Strait. A fishbone diagram was used to develop the hazards and factors that could lead to collision. Starting with a partially completed fishbone diagram the workshop participants refined and populated the diagram to identify the collision causal factors. There was no intent to develop relationships between causes or rate them at this time, but simply to enumerate and categorize the factors. The purpose of the exercise is twofold. Firstly it develops a large list of factors that could contribute to a collision. Secondly it functions to get the group to think broadly about issues and not be narrowly looking at the problem or the solution.

Once the causal factors were identified, the group then brainstormed and identified the associated potential hazards.

Figure 8 shows the detailed fishbone diagram developed to identify the factors influencing risk of collision through the brainstorming exercise. Six types or categories of causal factors were identified, namely: (a) human factors; (b) environment; (c) physical surrounding; (d) shipboard technology; (e) policies; and (f) method (of identification and assessment). An effort was made to identify all possible factors for each category, followed by identification of the hazards associated with each risk factor.

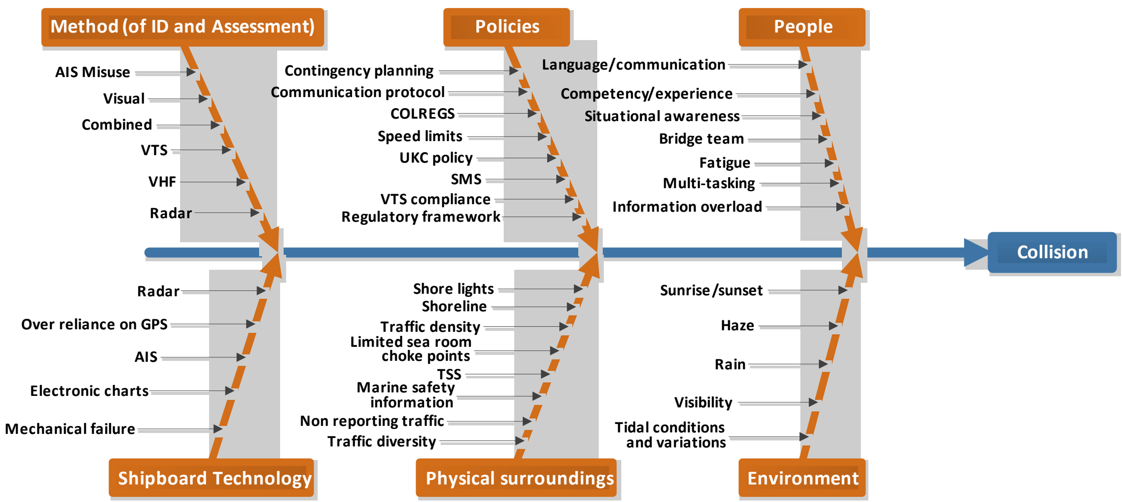


Figure 8 Fully Developed Fishbone Diagram

The complete list of hazards is presented in Table 9. A total of 50 hazards were identified, each being a unique combination of type/category, risk factor and hazard.

Table 9: List of Risk Factors and Associated Hazards

Hazard ID	Type/ Category	Factor	Hazard
1	Human Factors	Visual	Failure of identification
2			Absence / incomplete assessment
3		Radar	Failure of identification
4			Absence / incomplete assessment
5			Multiple users, different setting preferences
6		Competence / Capacity	Inattention
7			Divided attention
8			Numbers of targets
9			Lack of competence (wrong rules or inaccurate assessment)
10			Inappropriate delegation (BRM)
11			Unwillingness to speak up, power distance gap
12		AIS	Inappropriate user input, misuse
13		Language / Communication	Language barriers, personnel of different nationalities, Master-pilot exchange
14		Fatigue	Fatigue, leading to inappropriate analysis
15		Situational awareness	Lack or inadequate situational awareness, Master-Pilot-Master exchanges
16		Information overload	Too much information to process, not paying attention to high priority tasks
17		Multi-tasking	Too many activities, leading to loss of focus on high priority tasks
18		Commercial pressures	Pressures to make ETAs, others
19		Vessel early, lots of time on hand	Slowing, loitering, loss of manoeuvring, loss of attention
20	Environmental	Rain	Effect on radar detection and assessment
21			Effect of visual detection and assessment
22		Currents	High currents, affecting situational awareness and potential manoeuvring
23		Proximity of navigational hazards	Reduced safe manoeuvring room
24		Haze	Effect on visual detection and assessment
25		Squalls	Reduced visual and radar detection, and manoeuvrability of vessel
26		Close proximity of anchorages and harbour areas	Short time to detect and assess
27		Tidal conditions/ variations	Similar to UKC
28	Physical surrounding	Density of marine traffic	Overloading, inadequate reaction time
29		Mix of marine traffic	Increases assessment difficulty
30		Background lighting (shore and anchorage)	Identification & assessment
31		Shore line (reclamation)	Ability to determine position independently, and changes to current
32		Limited sea room (choke points)	Potential reduced manoeuvring
33		Congestion (pilot boarding grounds)	Potential reduced manoeuvring, complicated interactions with other vessels
34		TSS & Precautionary area	Limitations of current TSS and precautionary areas

Hazard ID	Type/ Category	Factor	Hazard
35		Marine safety information	Effect on passage plan
36		Non-reporting traffic	Cannot rely on VTS, cannot rely on them to comply with rules
37		Traffic diversity	Complexity of application of rules and manoeuvres
38	Shipboard Technology	Radar	Limitations of equipment
39		AIS	Limitations of equipment
40		Overreliance on GPS	Inadequate settings, no means to cross check
41		Electronic charts	Interfaces, updates and overlays
42		Mechanical failure	Inability to execute manoeuvre
43		Ship type and equipment	Manoeuvring capabilities and restrictions
44	Policies	COLREGs	
45		Speed limits	No speed limits for vessels other than VLCCs; lack of adequate space for manoeuvres
46		Under keel policy	Inadequate UKC, affecting manoeuvring
47		SMS, including passage plans and contingency plans	Inadequate SMS, SMS not used properly
48		Regulatory framework	Inadequate, misunderstood, unforced regulatory framework
49		VTS regime	Advisory vs control, quality
50		Communications protocol	Congestion of communication, delays in getting information

4. FSA Step 2 – Risk Analysis

4.1 Historical Incidents Analysis

The frequency and consequences (fatalities and oil spills) of collision incidents in the Singapore AOI were estimated using the historical incidents discussed in Section 3.1, and the traffic volume data presented in Section 3.2.2. The details are provided in **Table 10**. The exposure of all vessels in motion (and hence susceptible to collision event) was obtained from the four week sample of 2013 data presented in **Table 6**. This was extrapolated to provide an annual exposure rate of 185 ship years in one year (i.e. amount of time vessels are exposed to collision risk in a given year). This assumes that the 2013 data set used in this study was representative of the average yearly traffic volume/patterns, as discussed in Part 3: Traffic Simulation Report.

A total of 13 collision incidents were observed during the 5 year review period (2010 – 2014). Of this number, one incident resulted in a fatality and six incidents resulted in oil spills. Based on these, average numbers of collision per year were computed as 2.6 overall, 0.2 for fatality incidents and 1.2 for oil spill incidents. Corresponding frequencies (incidents per ship year) were obtained by considering the exposure of vessels in the area. The frequencies of collision incidents resulting in fatalities and oil spill were obtained as 1.082E-03 and 6.490E-03, respectively.

Table 10: Estimated Frequencies of Collision Incidents in Singapore Strait

Exposure (4 week sample) in days			5191.7
Exposure (extrapolated to one year) in days			67492.1
Exposure* (extrapolated to one year) in ship years			185
Scenario	No. of Incidents over 5 year period	Average No. Of Incidents Per year	Average No. Of Incidents Per Ship year
All collisions	13	2.6	1.406E-02
Collisions Resulting in Fatality	1	0.2	1.082E-03
Collisions Resulting in Oil Spill	6	1.2	6.490E-03
*Amount of time vessels are exposed to collision risk in one year			

4.2 Traffic Simulations

Traffic densities and crossing rates were computed in the traffic simulations to provide an indication of the level of vessel exposure of the various types of vessels in the TSS, and vessel crossing rates. The detailed investigations are discussed in Part 3: Traffic Simulation Report. Highlights of the results are provided in the following subsections and used to inform the risk analysis in the HAZID workshop.

4.2.1 Traffic Densities

Singapore Strait

Figure 9 illustrates the overall traffic density in Singapore Strait based on the 2013 subset of data. It should be noted that for the traffic density plots, all traffic volumes are for the four one-week periods; yearly volumes can be obtained by multiplying by 13.

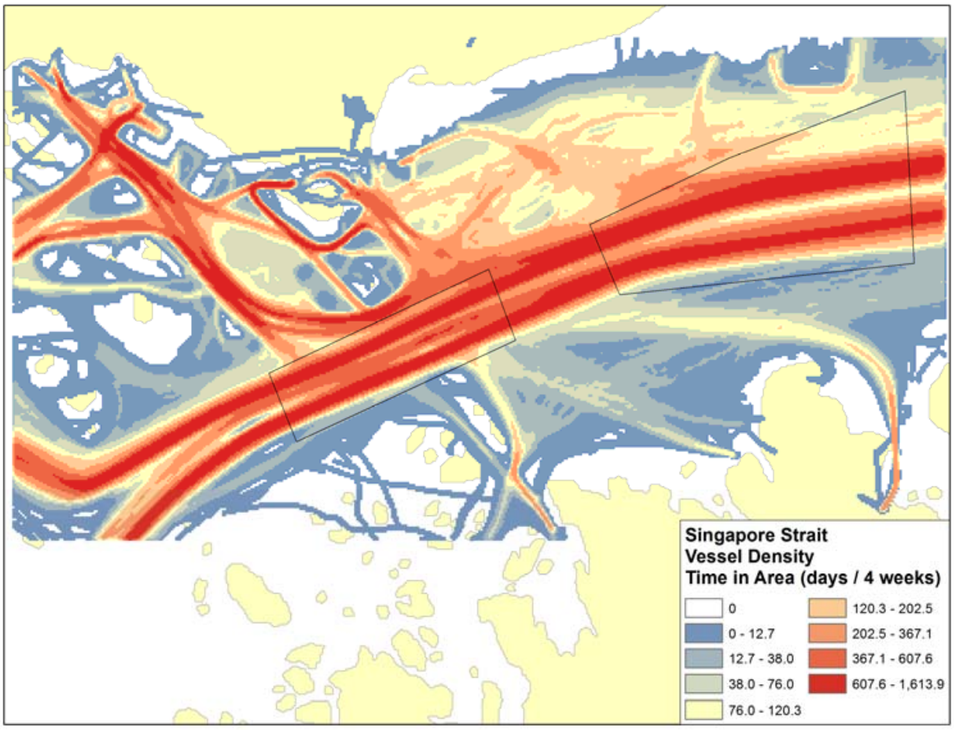


Figure 9 Singapore Strait Overall (2013) Vessel Density (Vessel - Days in area / 4 weeks)

The overall traffic in the Singapore Strait area is most heavily concentrated on the two primary traffic lanes running east-west through the AOI. Also densely populated are the primary routes running north-south from the western precautionary area into the centre of the Port of Singapore. Traffic can also be seen travelling between the anchorage area to the north of the traffic lanes and the port of Singapore via the smaller TSS lanes just north of the lanes passing through the area. Finally, paths running perpendicular to the TSS lanes (implying direct crossing) can be noted originating from several points on shore to the south of the TSS, of particular concern to the project at hand. Table 11 shows the main features of the traffic by vessel type. Figure 10 to Figure 14 show the traffic density plots for each of the following selected vessel categories – cargo; fishing vessels; high speed craft; passenger vessels; and tankers (see Part 3 for plots for all ten vessel categories).

Table 11: Observations in Singapore Strait AOI Traffic Plots (2013) by Type

Vessel Type	Observations
Cargo Vessels	• Primarily concentrated in traffic lanes • Make use of anchorages to north of traffic lanes • Transits noted in both primary fairways • No clear direct crossing paths
Fishing Vessels	• Very low volume • Appear to use landing north of western anchorage
Tug / Harbour Svc.	• Low volume • Some use of primary traffic lanes
High Speed Craft	• Appear to be mostly on TSS crossing routes • Same areas as passenger vessel traffic
Pleasure Craft	• Almost absent from plots
Unreferenced Vessels	• Higher volume, concentrated in port area
Other Type Vessels	• Almost absent from plots
Passenger Vessels	• Large volume on paths appearing to cross TSS • Multiple routes noted originating from southern shoreline, heading north

	• Several intra- Port of Singapore routes noted
Tankers	• Primarily concentrated in traffic lanes • Some traffic between anchorage and Port of Singapore via secondary lanes, north of main TSS lanes
Unknown Type Vessels	• Low volume, mostly in port • Some more significant traffic paths running south of Sentosa

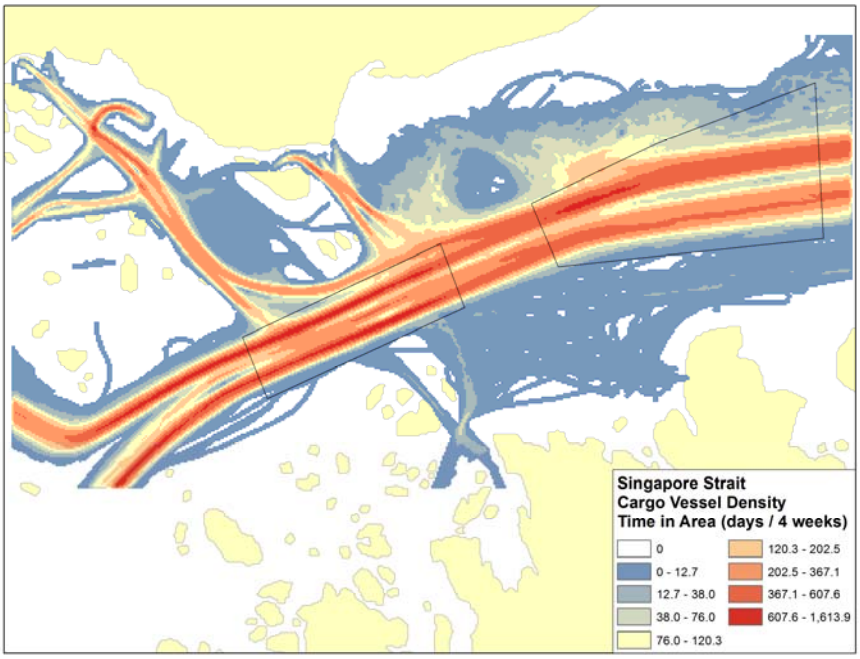


Figure 10 Singapore Strait (2013) Cargo Vessel Density (Vessel - Days in area / 4 weeks)

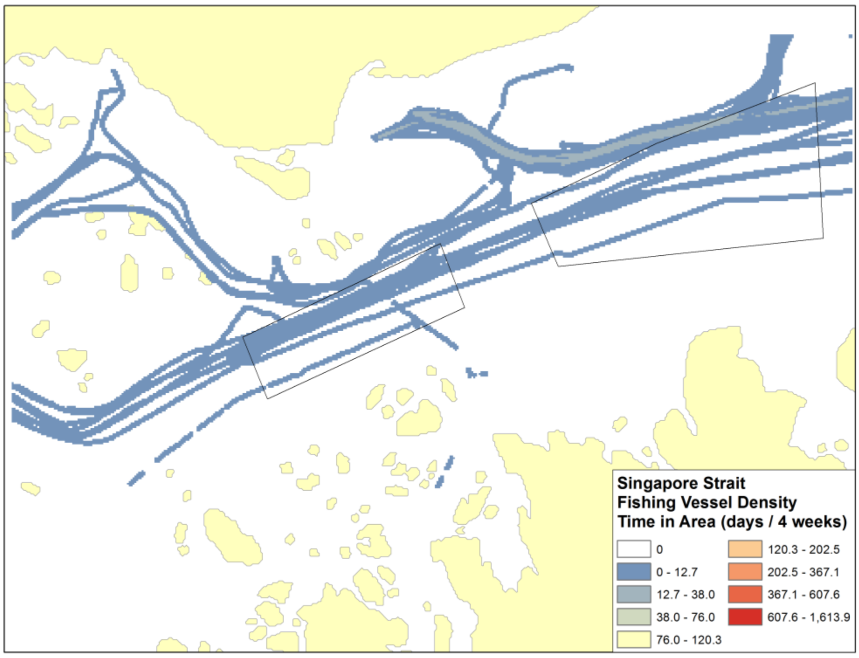


Figure 11 Singapore Strait (2013) Fishing Vessel Density (Vessel - Days in area / 4 weeks)

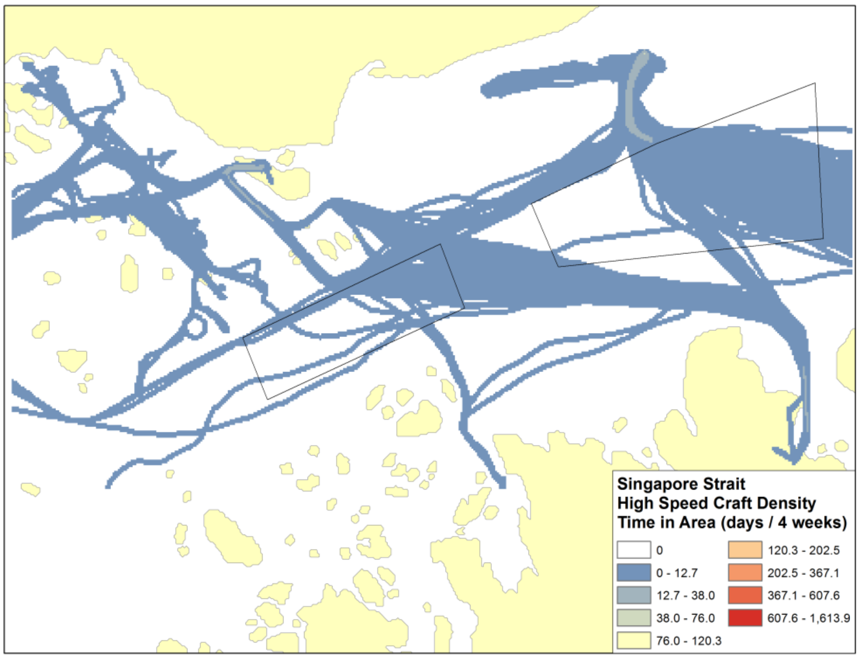


Figure 12 Singapore Strait (2013) High Speed Craft Density (Vessel - Days in area / 4 weeks))

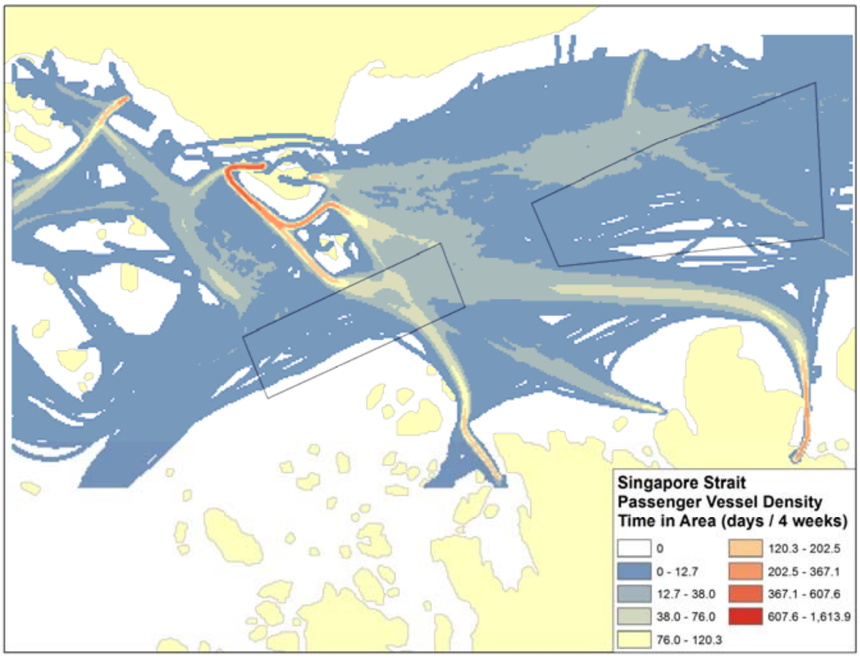


Figure 13 Singapore Strait (2013) Passenger Vessel Density (Vessel - Days in area / 4 weeks))

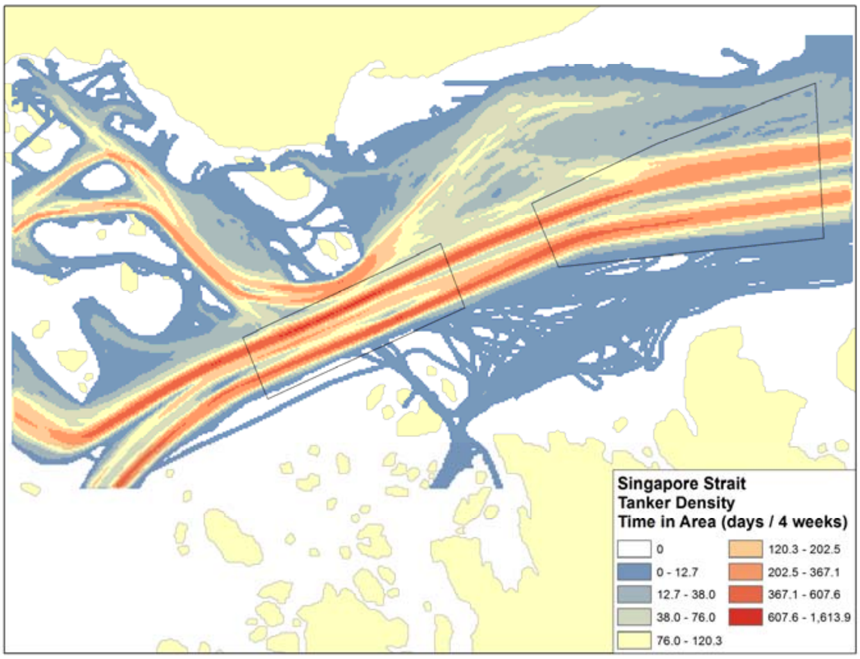


Figure 14 Singapore Strait (2013) Tanker Density (Vessel - Days in area / 4 weeks)

English Channel

Figure 15 illustrates the overall traffic density in the English Channel based on the 2012 subset of data. The key traffic feature in terms of density is the pair of southwest to northeast running traffic lanes. Traffic is also notable in the eastbound fork of the TSS ("At West Hinder") and around the Sunk Precautionary Area in the Thames Estuary. Most critical in terms of crossing assessment are the area around the TSS fork, and the crossings between Dover and Calais / Dunkirk. Table 12 shows the main features of the traffic by vessel type. Figure 16 to Figure 20 show the traffic density plots for each of the following selected vessel categories – cargo; fishing vessels; high speed craft; passenger vessels; and tankers (see Part 3 for plots for all ten vessel categories).

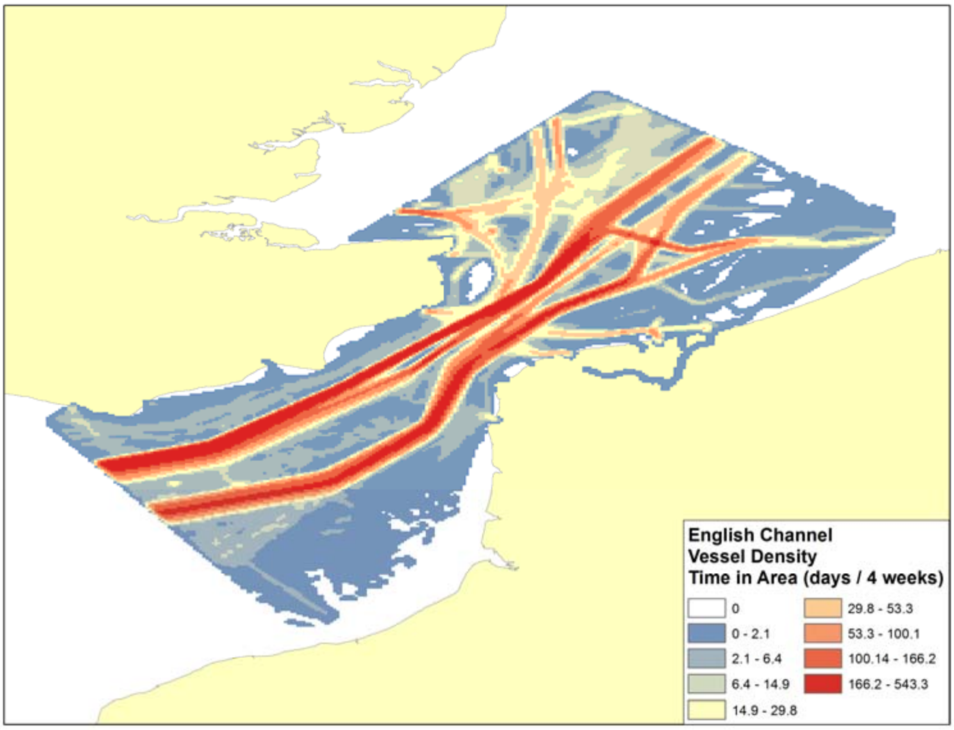


Figure 15 English Channel Area Overall (2012) Vessel Density (Vessel - Days in area / 4 weeks)

Table 12: Observations in English Channel AOI Traffic Plots (2012) by Type

Vessel Type	Observations
Cargo Vessels	• High volume noted • Densities primarily constrained to TSS lanes
Fishing Vessels	• Moderate to low volume noted • Densities diffused across much of AOI • Hotspots suggest homeports of Eastbourne and Boulogne-sur-Mer
Tug / Harbour Svc.	• Moderate to low volume noted • Densities diffused across much of AOI
High Speed Craft	• Single trajectory identified from Ramsgate heading north
Pleasure Craft	• Low volume noted • Densities diffused across much of AOI with some Dover to Calais crossing evident
Unreferenced Vessels	• Low volume noted • Densities diffused across much of AOI with some Dover to Calais crossing evident
Other Type Vessels	• Moderate to low volume noted • Some along-lane traffic noted • Hotspot noted near Dunkirk
Passenger Vessels	• Moderate volume noted • Dover to Calais and Dunkirk crossings clear
Tankers	• Moderate volume noted • Densities primarily constrained to TSS lanes
Unknown Type Vessels	• Low volume noted • Densities diffused across AOI with some traffic in TSS lanes

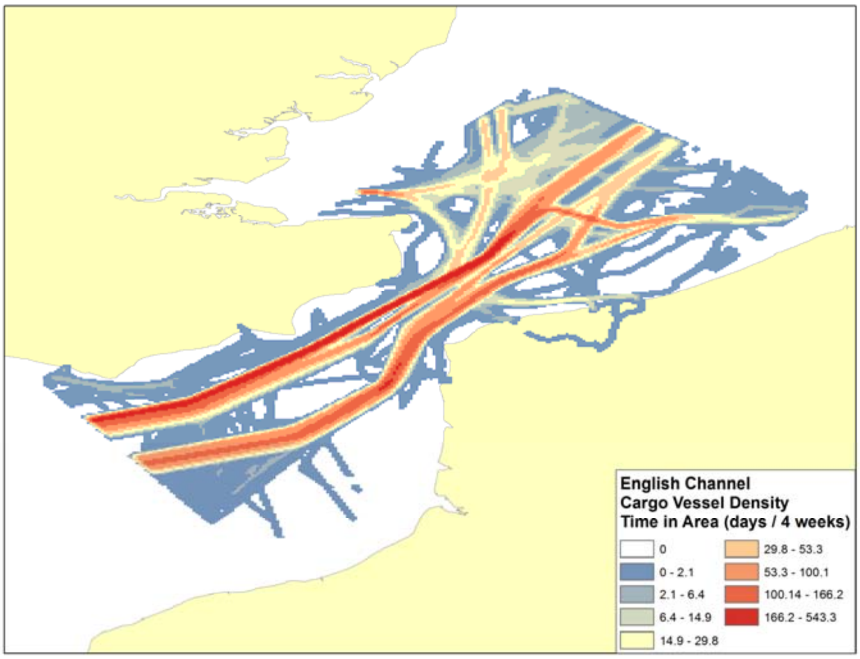


Figure 16 English Channel (2012) Cargo Vessel Density (Vessel - Days in area / 4 weeks)

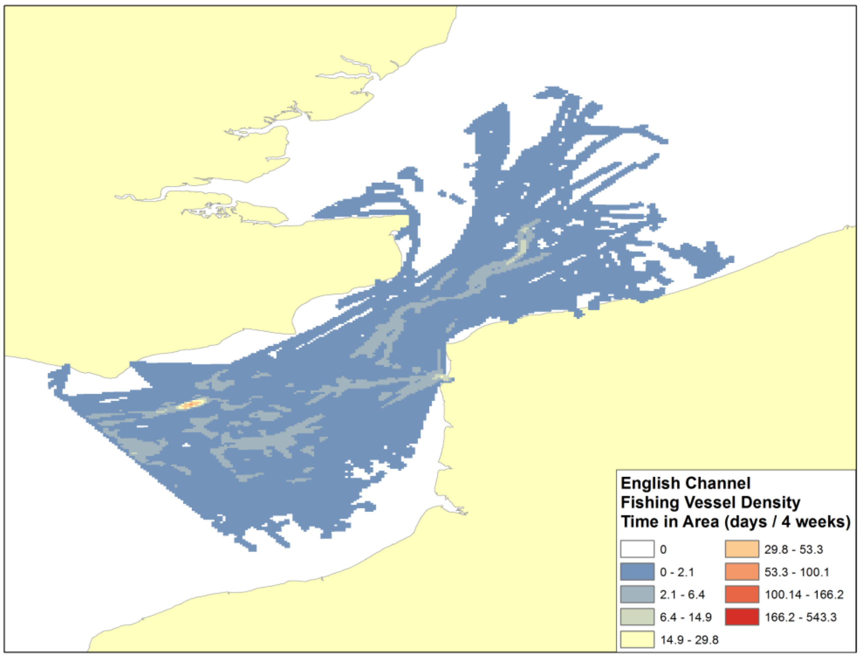


Figure 17 English Channel (2012) Fishing Vessel Density (Vessel - Days in area / 4 weeks)

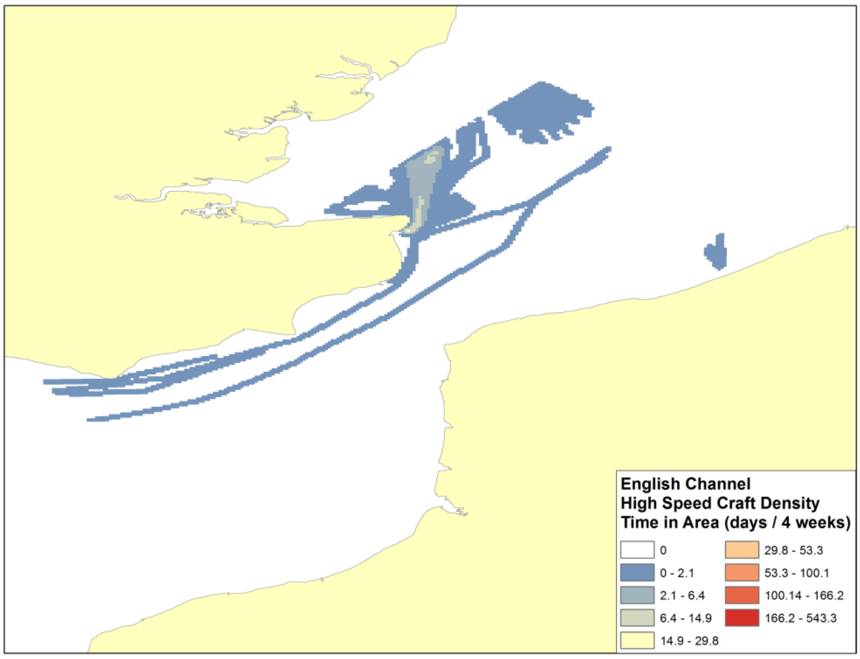


Figure 18 English Channel (2012) High Speed Craft Density (Vessel - Days in area / 4 weeks)

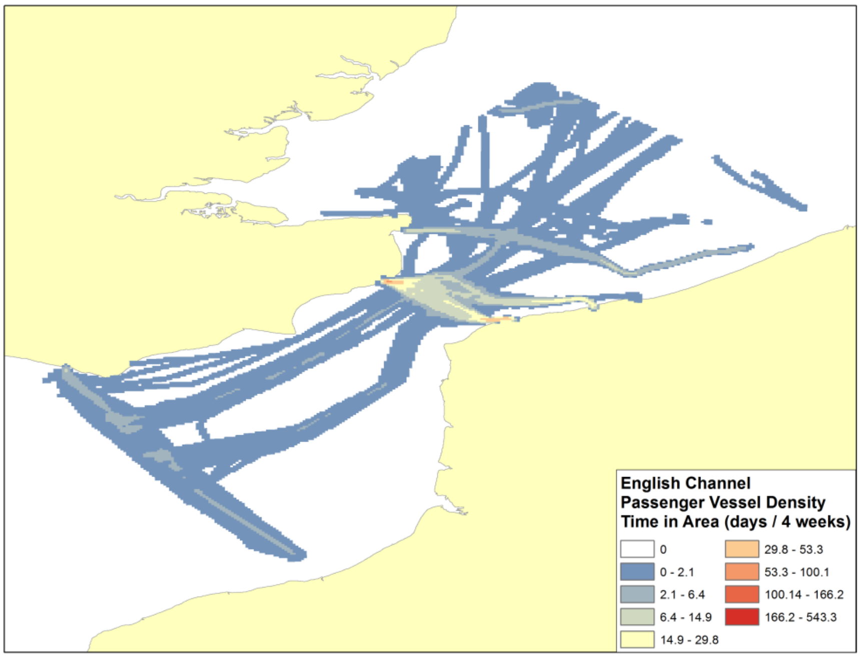


Figure 19 English Channel (2012) Passenger Vessel Density (Vessel - Days in area / 4 weeks)

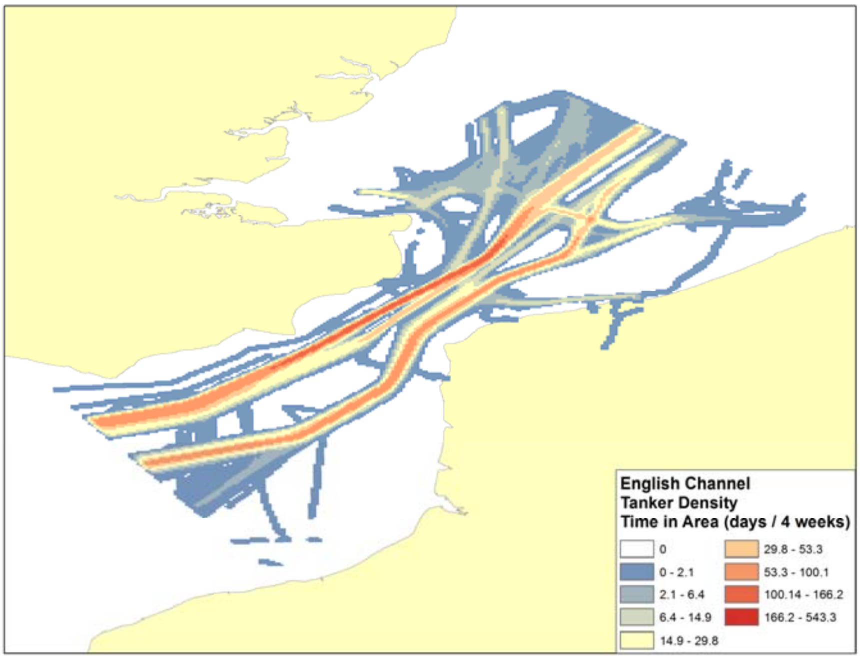


Figure 20 English Channel (2012) Tanker Density (Vessel - Days in area / 4 weeks)

<u>San Francisco Bay</u>

Figure 21 illustrates the overall traffic density in the San Francisco Bay area based on the 2013 subset of data. The figure clearly depicts a bottleneck in the Golden Gate Bridge area, at the entrance to the Bay. This high density area extends into the precautionary area and TSS to its west and to a variety of Bay Area destinations to its east, including San Francisco to the south, Oakland directly east, Richardson and San Rafael Bay to the north west, Richmond to the north, and through the San Pablo Bay and Carquinez Strait extending further north and east. Of the three traffic lanes to the west of the area, the centre of the three, southwest to northeast appears to contain the greatest share of the traffic. While there do not appear to be many crossings of the TSS lanes themselves, the closely clustered nature of the high density paths in the centre of the area suggest that most of the traffic travels through an area in which encounters occur between vessels at multiple orientations. Of relevant note to TSS crossings generally, the high density traffic confluence does extend to the inner bay precautionary area.

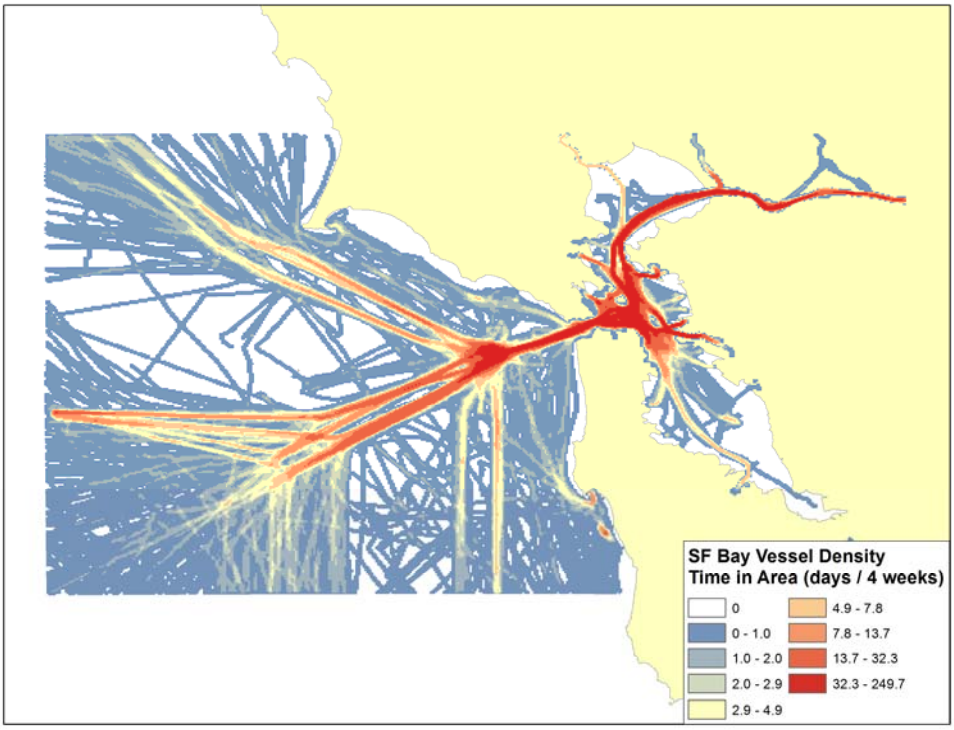


Figure 21 San Francisco Bay Area (2013) Vessel Density (Vessel - Days in area / 4 weeks)

Table 13 shows the main features of the traffic by vessel type. Figure 22 to Figure 26 show the traffic density plots for each of the following selected vessel categories – cargo; fishing vessels; high speed craft; passenger vessels; and tankers (see Part 3 for plots for all ten vessel categories).

Table 13: Observations in San Francisco Bay AOI Traffic Plots (2013) by Type

Vessel Type	Observations
Cargo Vessels	• Noted to observe TSS lanes • Generally destined to Oakland or north through San Pablo Bay and Carquinez Strait
Fishing Vessels	• Very low volume • Small hotspot at mouth of Bay
Tug / Harbour Svc.	• High volume noted • Primarily utilizing southwest-northeast traffic lane • Traffic between: mouth of Bay, SF port, Oakland, Richmond, Redwood and north through San Pablo Bay and Carquinez Strait
High Speed Craft	• Low volume noted • Noted running between SF port and Richardson bay, likely as ferry
Pleasure Craft	• Moderate volume noted • Patterns diffuse, running through centre of Bay
Unreferenced Vessels	• Single path only noted
Other Type Vessels	• Low volume noted • Patterns diffuse, running through centre of Bay
Passenger Vessels	• Moderate to high volume noted • Several ferry paths evident by density: o Golden Gate Ferry o Tiburon to San Francisco o Sausalito to San Francisco o Angel Island to San Francisco o Oakland to San Francisco

Vessel Type	Observations
	o Vallejo to San Francisco o Oyster Point to Oakland • Several ferry paths cross the in-Bay precautionary area
Tankers	• Moderate to low volume noted • Primarily utilizing southwest-northeast traffic lane • Generally destined to San Francisco, Richmond or north through San Pablo Bay and Carquinez Strait
Unknown Type Vessels	• Low volume noted • Similar in extent to passenger vessel traffic

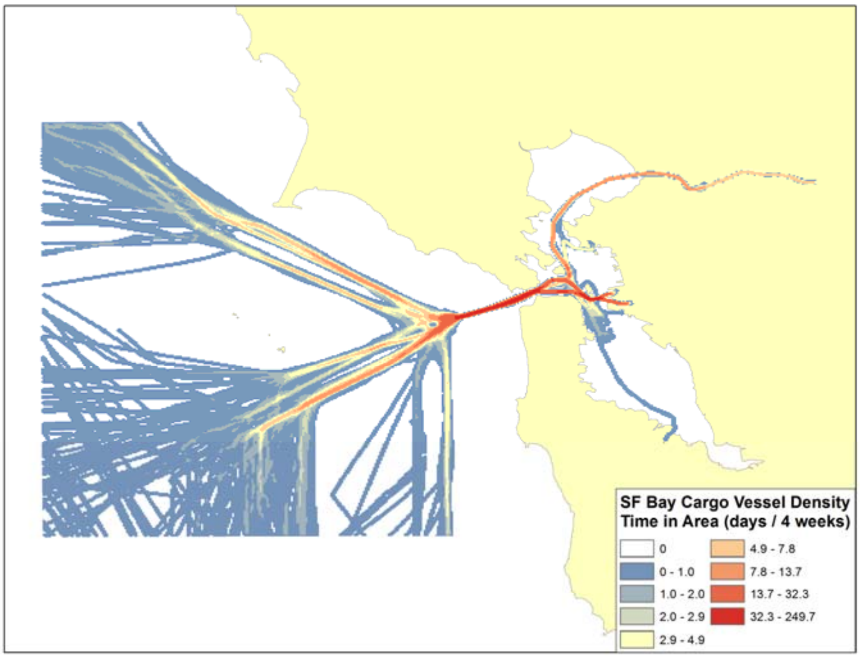


Figure 22 San Francisco Bay Area (2013) Cargo Vessel Density (Vessel - Days in area / 4 weeks)

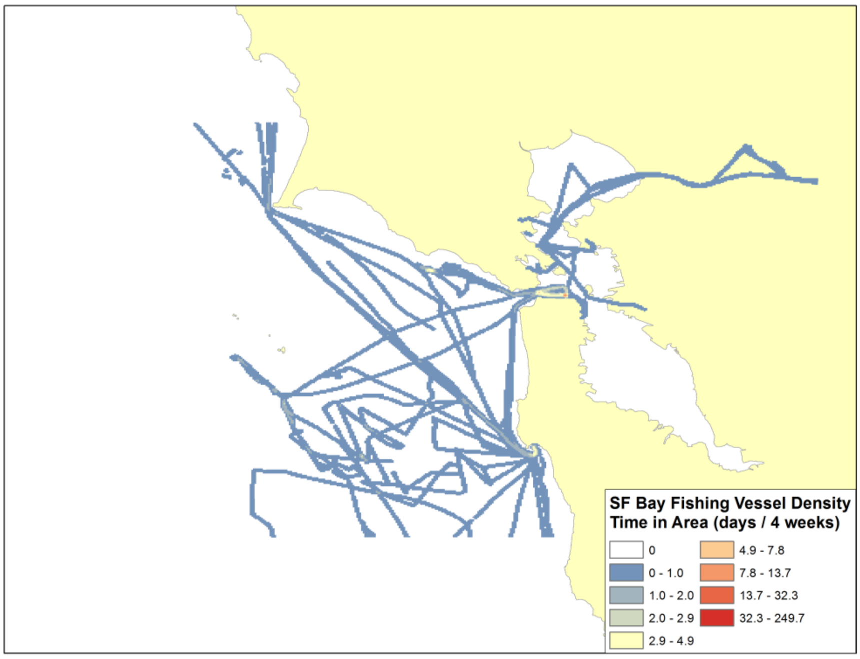


Figure 23 San Francisco Bay Area (2013) Fishing Vessel Density (Vessel - Days in area / 4 weeks)

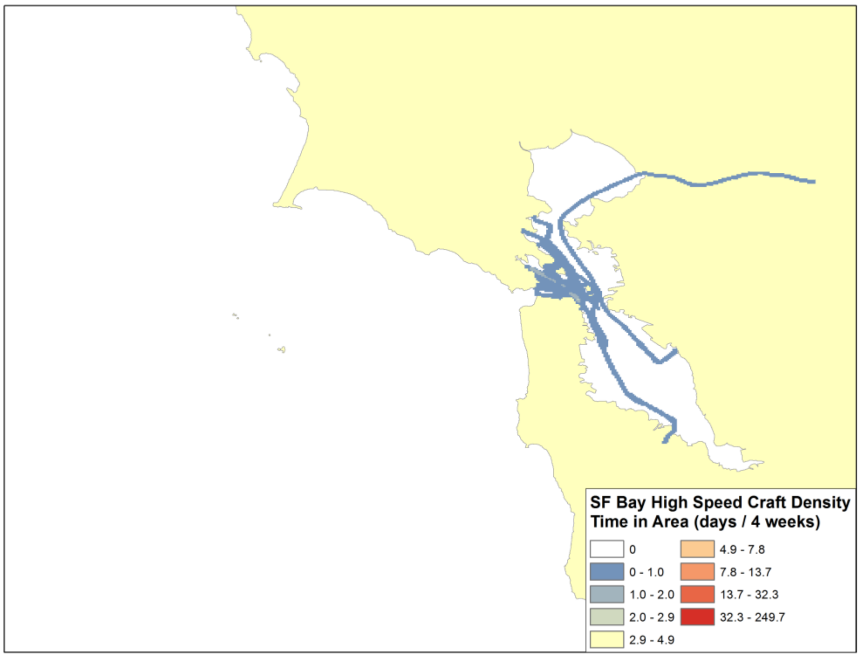


Figure 24 San Francisco Bay Area (2013) High Speed Craft Density (Vessel - Days in area / 4 weeks)

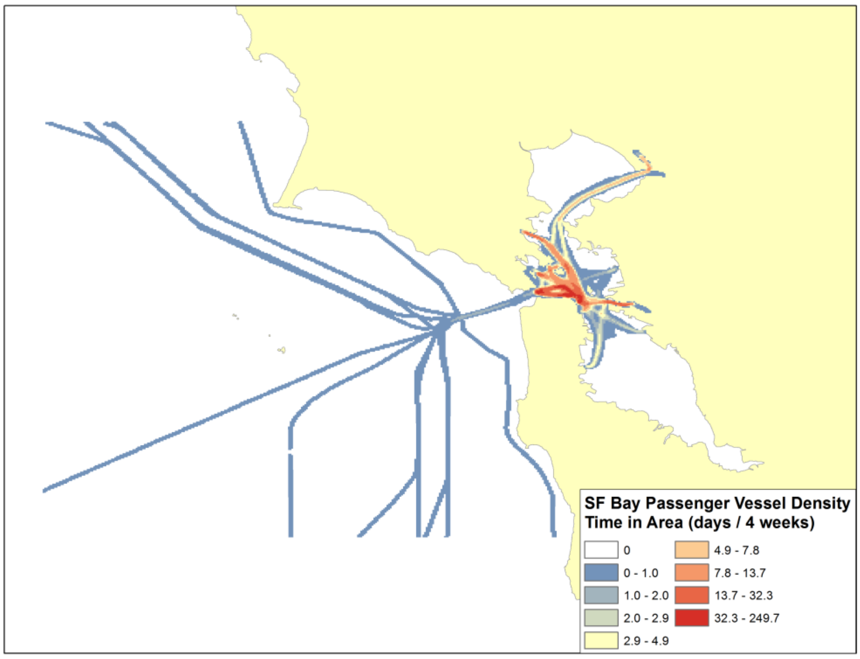


Figure 25 San Francisco Bay Area (2013) Passenger Vessel Density (Vessel - Days in area / 4 weeks)

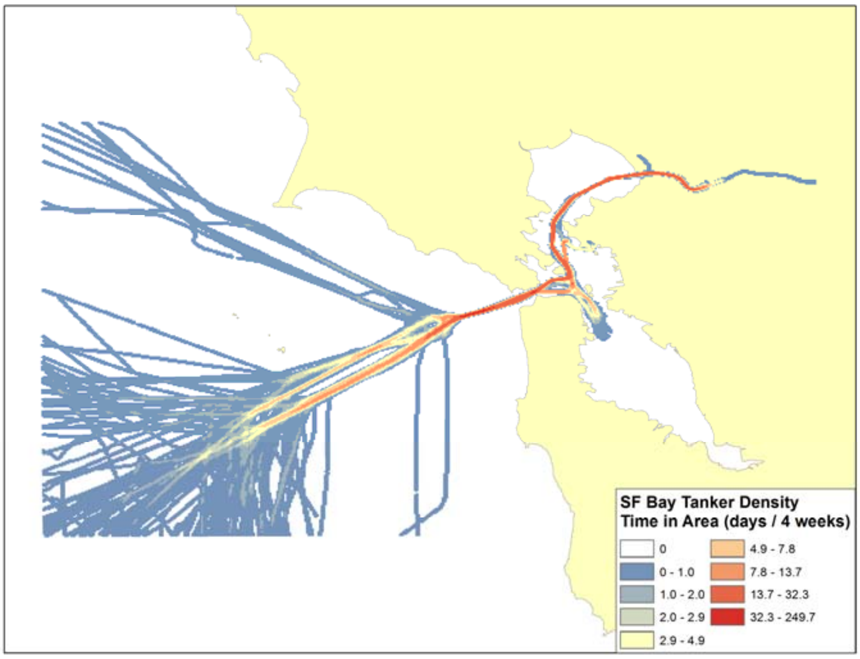


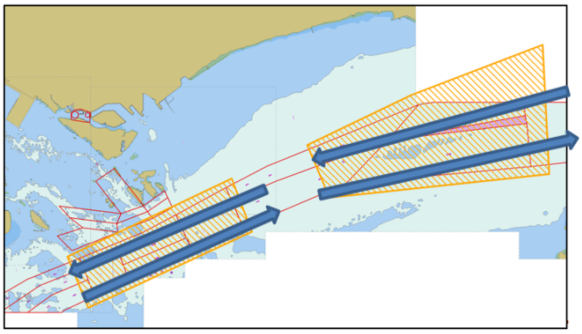
Figure 26 San Francisco Bay Area (2013) Tanker Density (Vessel - Days in area / 4 weeks)

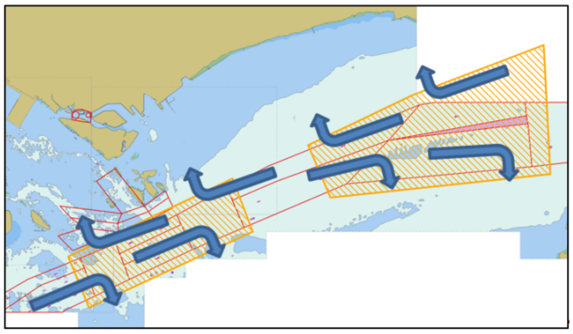
4.2.2 Crossing Rates

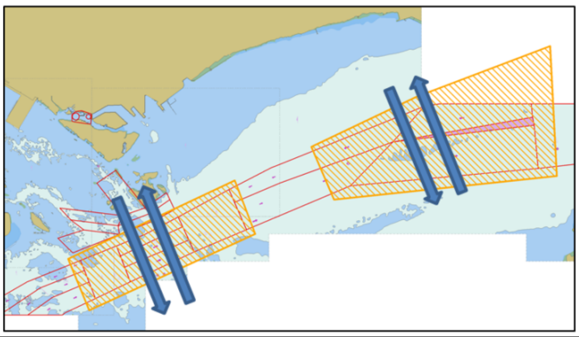
One goal of the traffic simulation effort was to provide information in support of both the HAZID and the bridge simulation exercise regarding the anticipated rates at which crossing vessels might be expected for each of the areas under review. More specifically, the questions to be answered could be phrased as:

1. "At what rate might a vessel, travelling along a TSS lane within the areas of interest, be expected to encounter vessels crossing a TSS lane?"
2. "What is the expected vessel traffic rate travelling along the TSS lanes in the areas of interest?"

Because of the overall complexity of the Singapore region, analysis of vessel rates was constrained to these two "High Risk" areas. Vessels travelling through the TSS in the vicinity of these "High Risk" Areas of Interest in the Singapore Strait area were found to take one of four broad classes of routes. Vessels which did not cross traffic lanes were found to be travelling straight along the prescribed lanes, or exiting / entering the lanes to their right, as in Figure 27.


Traffic Transiting Straight Through TSS


Traffic Leaving (or entering) TSS Without Crossing Lanes


Traffic Directly Crossing TSS

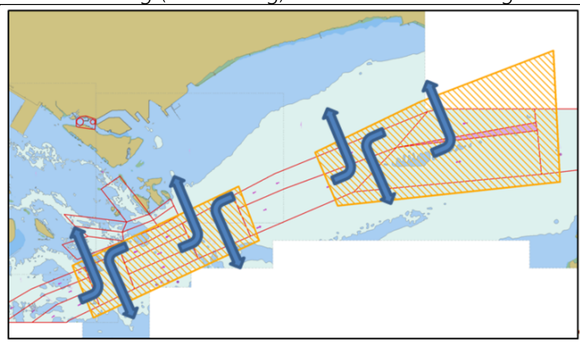

Traffic leaving (or entering) TSS, Crossing Lane

Figure 27 Traffic Lanes in Singapore Strait

These four cases roughly describe the spatial selections applied to the generated traffic segments in the Area of Interest using a GIS. By generating subsets of the overall data, sorted into these categorizations, it was possible to estimate rates of crossing and along-track traffic flow as summarized in Table 14 for the easternmost and westernmost sections of the Singapore AOI. Note that in the table, vessel segments are defined as sequences of AIS reporting points, having no greater temporal gap than 180s and speed consistently greater than 0.5 knot. The inferred rates were obtained by dividing the number of segments by the number of days (28 days).

Table 14: Singapore Strait TSS - Along Track and Crossing Rates (4 Week Sample)

	Easternmost Area		Westernmost Area	
Action	Vessel Segments	Inferred Rate	Vessel Segments	Inferred Rate
Vessels directly crossing TSS	498	~18/d; 0.74/hr	4814	~172/d; ~7.1/hr
Vessels departing lane and crossing TSS	1603	~57/d; 2.4/hr	1696	~60/d; ~2.5/hr
Crossings, Total	2101	~75/d; 3.12/hr	6510	~232.5/d; ~9.7/hr

Along-track movements within TSS (both directions combined)	7168	~256/d; ~10/hr	5040	~180/d; ~7.5/hr
Vessels departing lane, not crossing TSS	2752	~98/d; ~4/hr	1034	~37/d; ~1.5/hr
Outside TSS, but in area of interest (excluded from rates)	4337		4340	

The English Channel AOI is more easily compared to that of the Singapore Strait than is San Francisco Bay, owing to the greater similarity of the former two in terms of TSS and traffic configuration (i.e. as international shipping routes). However, the traffic in the English Channel AOI was found to adhere more rigidly to the TSS lanes therein, with little lane departure noted. Because of this, it was much simpler to separate the data crossing the TSS from that travelling along the track. The bulk of the crossings were noted to occur between Dover and Calais or Dunkirk. The crossing count (bi-directional) was established as 4849 track segments per 28 days, working out to ~173 per day or ~7.2 per hour.

Effectively, no crossing events were noted in the TSS lanes on the approach to the San Francisco Bay area within the data sample analysed. This is most likely due to the very low volumes of traffic in the area. Within the precautionary area inside the Bay, however, measureable traffic volumes were found to be travelling along perpendicular courses. For the purposes of informing the bridge simulation in this study, some spot measurements of traffic volume were also evaluated at the most extreme points as suggested by the earlier density maps (see Table 15).

Table 15: San Francisco Bay AOI - Measurements / Estimates of Traffic Rates (4 week sample)

Measurement / Estimate	Vessel Segments Noted	Inferred Rate
Spot Measurements:		
Mouth of Bay (East - West total)	1140	~40.7/day; ~1.7/hr
Alcatraz to Shore (East - West, South of Island)	2002	~72/day; ~3.0/hr
Alcatraz to Shore (East - West, North of Island)	2103	~75/day; ~3.1/hr
SF West to Treasure Island (East - West)	5163	~184/day; ~7.7/hr
Traffic Lane Measurements:		
Northwest Branch of TSS, North Lane	104	~3.7/day
Northwest Branch of TSS, South Lane	55	~2.0/day
Southwest Branch of TSS, North Lane	177	~6.3/day
Southwest Branch of TSS, South Lane	221	~7.9/day
South Branch of TSS, West Lane	30	~1.1/day
South Branch of TSS, East Lane	49	~1.8/day
Inner Precautionary Area:		
Tracks Running North - South	740	~26/day; ~1.1/hr
Tracks Approaching from East	1823	~65/day; ~2.7/hr

4.2.3 Future Trends in Singapore Strait

To supplement the simulated traffic results, some work was undertaken in surveying expected trends particular to the Singapore AOI. In addition to providing supplemental information to the project stakeholders in the area of particular interest, knowledge about potential changes to the traffic environment may aid in determining the necessity of implementing the “3 green lights” signal, among other risk control measures.

Predictions regarding traffic volumes in the Singapore Strait region universally suggest an increase in the coming years. Disparities between reviewed documentation only exist regarding the extent of growth.

Estimated rates of change range from 6.2% increase per year [9] to as high as 11.5% per year [10]. Of these estimates, the report based on the most current projections is that which suggests growth at 6.2% per year over a 10-year horizon.

It should be noted that traffic projections in the area are generally taken with an eye toward commerce and, as such, might be expected to influence some vessel types more so than others. In particular, tanker and cargo traffic might be expected to grow at the given rate, while passenger vessels might experience more modest growth. From among the vessel types considered in this study, tug and harbour service vessel traffic might be expected to increase to serve the additional commercial shipping traffic, however, constraints on port resources could moderate the growth to some degree. With these factors in mind, the effects of the most conservative (6.2% / year) growth estimate are applied to the traffic rates computed. Of these estimates, it is expected that increases in the along-track rate would be most accurate (along track traffic consisting primarily of commercial shipping vessels), while the increases in crossing rate are more likely to be overestimates (due to the greater proportion of non-commercial shipping traffic {i.e. ferries}).

Table 16 shows the impact of extrapolating out to 2023 from the current along-track and crossing rates for both of the “High Risk Areas”, assuming a yearly traffic increase of 6.2%. Given estimates on carrying capacity for the waterway ranging from 7 vessels per hour [11] (Straits of Malacca) to 29 - 51 vessels per hour [12] (Singapore Strait), the rates noted for along-track traffic flow appear to be approaching the capacity for the waterway over the next 10 years. With the primary lanes operating at or near capacity, the drive to avoid collisions between vessels in the lanes and those seeking to cross is magnified.

Table 16: Estimates of Traffic Rate Increases - Singapore High Risk Areas

	Eastern High Risk Area		Western High Risk Area	
Year	Along Track (includes turns)	Crossing	Along Track (includes turns)	Crossing
2013	14.00	3.12	9.00	9.70
2014	14.87	3.31	9.56	10.30
2015	15.79	3.52	10.15	10.94
2016	16.77	3.74	10.78	11.62
2017	17.81	3.97	11.45	12.34
2018	18.91	4.21	12.16	13.10
2019	20.09	4.48	12.91	13.92
2020	21.33	4.75	13.71	14.78
2021	22.65	5.05	14.56	15.70
2022	24.06	5.36	15.47	16.67
2023	25.55	5.69	16.42	17.70

The results of the traffic volume, traffic density and turning rates obtained from the traffic simulations as discussed above were taken into consideration in the risk workshop and RCO simulation exercise.

4.3 Risk Workshop

A qualitative risk rating/ranking of hazards was also undertaken at the risk workshop. Hazards were rated in terms of the likelihood of a collision event, given the hazard, using a scale of 0 (not likely) to 100 (very likely). Each participant provided a rating for each identified hazard and the scores were aggregated to give an overall risk rating for the hazard. A risk categorization scheme, such as the one shown in Table 17 was used to screen out less important hazards from the point of view of causing a collision event. Hazards rated as High or Extreme Risk were selected for risk reduction. This risk rating and ranking process was discussed and agreed upon by the participants.

Table 17: Risk Categorization Scheme

Risk Rank	Description
0 – 25	Low Risk
25 – 50	Medium Risk
50 – 75	High Risk
75 – 100	Extreme Risk

Table 18 summarizes the risk rating and ranking of the hazards. In the table, the hazards are ranked in descending order of the likelihood of the hazard resulting in a collision scenario, and the hazard descriptions include the type/category of the risk factor and descriptions of the hazardous scenarios presented in Table 9. As per the risk categorization scheme of Table 17, it is seen that two of the identified hazards were ranked as Extreme risk, 31 of the hazards were ranked as High risk and the remaining 17 were ranked as Medium risk. It is noted that the two hazards ranked as Extreme risk are human factors related issues involving lack of situational awareness or lack of competence.

Table 18: Hazards Ranked According to Likelihood to Result in a Collision Event

Hazard ID	Hazards	Risk Rating
15	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77
9	Human factors, Competence / capacity, Lack of competence (wrong rules or inaccurate assessment)	76
33	Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71
26	Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66
14	Human factors, Fatigue, Fatigue, leading to inappropriate analysis	65
17	Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64
30	Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64
47	Policies, SMS, including passage plans and contingency plans, Inadequate SMS, SMS not used properly	63
28	Physical surrounding, Density of marine traffic, Overloading, Inadequate reaction time	63
16	Human factors, Information overload, Too much information to process, Not paying attention to high priority tasks	63
1	Human factors, Visual, Failure of identification	62
32	Physical surrounding, Limited sea room (choke points), Potential reduced manoeuvring	61
2	Human factors, Visual, Absence / incomplete assessment	61
4	Human factors, Radar, Absence / incomplete assessment	60

Hazard ID	Hazards	Risk Rating
45	Policies, Speed limits, No speed limits for vessels other than VLCCs, Lack of adequate space for manoeuvres	60
6	Human factors, Competence / capacity, Inattention	59
34	Physical surrounding, TSS & precautionary area, Limitations of current TSS and precautionary areas	58
7	Human factors, Competence/ capacity, Divided attention	58
21	Environmental, Rain, Effect of visual detection and assessment	57
29	Physical surrounding, Mix of marine traffic, Increases assessment difficulty	56
44	Policies, COLREGs	55
48	Policies, Regulatory framework, Inadequate, misunderstood, Unenforced regulatory framework	55
42	Shipboard technology, Mechanical failure, Inability to execute manoeuvre	55
10	Human factors, Competence/ capacity, Inappropriate delegation (BRM)	54
18	Human factors, Commercial pressures, Pressures to make ETAs, others	54
8	Human factors, Competence / capacity, Numbers of targets	53
23	Environmental, Proximity of navigational hazards, Reduced safe manoeuvring room	53
50	Policies, Communications protocol, Congestion of communication, delays in getting information	53
3	Human factors, Radar, Failure of identification	53
13	Human factors, Language / communication, Language barriers, Personnel of different nationalities, Master-pilot exchange	53
20	Environmental, Rain, effect on radar detection and assessment	53
37	Physical surrounding, Traffic diversity, Complexity of application of rules and manoeuvres	52
49	Policies, VTS regime, Advisory vs control, Quality	52
24	Environmental, Haze, Effect on visual detection and assessment	49
25	Environmental, Squalls, Reduced visual and radar detection, and manoeuvrability of vessel	48
36	Physical surrounding, Non-reporting traffic, Cannot rely on VTS, Cannot rely on them to comply with rules	48
11	Human factors, Competence/ capacity, Unwillingness to speak up, Power distance gap	48
22	Environmental, Currents, High currents, affecting situational awareness and potential manoeuvring	48
41	Shipboard technology, Electronic charts, Interfaces, updates and overlays	45
38	Shipboard technology, Radar, Limitations of equipment	45
31	Physical surrounding, Shore line (reclamation), Ability to determine position independently, Changes to current	43

Hazard ID	Hazards	Risk Rating
40	Shipboard technology, Over reliance on GPS, Inadequate settings, no means to cross check	43
19	Human factors, Vessel early, lots of time on hand, Slowing, Loitering, Loss of manoeuvring, Loss of attention	43
43	Shipboard technology, Ship type and equipment, Manoeuvring capabilities and restrictions	43
27	Environmental, Tidal conditions/ variations, Similar to UKC	42
39	Shipboard technology, AIS, Limitations of equipment	40
12	Human factors, AIS, Inappropriate user input, Misuse	39
5	Human factors, Radar, Multiple users, different setting preferences	38
35	Physical surrounding, Marine safety information, Effect on passage plan	38
46	Policies, Under keel policy, Inadequate UKC, affecting manoeuvring	35

In order to provide meaningful discussion of risk control options and for judicious use of resources, it was decided to focus on the top 10 ranked hazards for risk control. The selected hazards are shown highlighted in cyan in Table 18, and include hazards with risk rating scores of 63 or higher.

5. FSA Step 3 – Risk Control Options (RCOs)

5.1 Risk Workshop

5.1.1 Identification and Ranking of RCOs

An assessment of RCOs for High and Extreme risk hazards was undertaken at the risk workshop. This was undertaken through a brainstorming exercise by the subject matter experts. Starting with a preliminary list provided by the facilitation team, the workshop participants identified and refined possible RCOs. The RCOs were then rated in accordance with (a) ease of implementation; and (b) effectiveness of controlling the High and Extreme Risk hazards.

The ease of implementation was assessed on a scale of 0 (easy to implement) to 100 (difficult to implement). Each participant provided a rating for each identified RCO and the scores were aggregated to give an average rating on the ease of implementation. The categorization scheme shown in Table 19 was used to rate the RCOs in terms of the ease of implementation.

Table 19: Ease of RCO Implementation Categorization Scheme

Ease of RCO Implementation Rating	Description
0 – 25	Easy to implement
25 – 50	Moderately difficult to implement
50 – 75	Difficult to implement
75 – 100	Very difficult to implement

It is noted that the ease of implementation alone is not sufficient to rank the RCO, as it is acknowledged that some RCOs that are difficult to implement may be more effective in reducing the risk of collision hazards. The ease of implementation has to be combined with the potential effectiveness of the RCOs in reducing the risks, especially those rated as High or Extreme Risk, in order to fully appreciate the value/ benefit of the RCO.

Table 20 provides a list and description of 31 RCOs identified by the workshop participants. In the table, the RCOs are listed in order of ease of implementation, from easiest to the most difficult. It is seen that the 3 green lights night signal RCO was ranked in the top seven RCOs that were considered easy to implement. The majority of the RCOs were considered to be moderately difficult to difficult in terms of implementation.

Table 20: RCO Ranked According to Ease of Implementation

RCOs	Description	RCO Rating
Day shapes	Day shapes associated with night signals	6
Anchors ready for use		7
New navigation lights	3 green lights for crossing vessels	9
Readiness of machinery, including thrusters, for immediate manoeuvring		10
Dedicated lookout		12
Passage planning guide (mandatory)	Specific passing guide compulsory for Singapore and Malacca Straits	22
Bridge resource management	Improved composition and interaction of bridge team	25

RCOs	Description	RCO Rating
AIS message	Special message to indicate crossing vessels	27
Penalty for non-compliance	Enforced through flag state	29
VTS procedures	Ship operational data, link to port operations for reduced communications (pilot boarding changes)	29
Aids to navigation	Review characteristics of navigation aids to facilitate identification	29
Pilotage non-compulsory (advisory service)	Make compulsory for certain vessel types	30
Silent VTS	Reduce amount of radio communications, potential to switch to aircraft mode	31
Pilot boarding ground	Reduce congestion at pilot boarding ground, improve pilot-master exchange, provide 1 mile separation zone	31
Duplex plus VTS	Duplex communication between ship and VTS	36
Proactive VTS control	Strong advice, not full control	36
Manning	Size and composition of bridge team, e.g. dedicated Lookout	37
Competent crews	Increasing quality of assessment and implementing the rules	40
Escort tugs	Escort tugs at critical areas	41
Other means of communications	Ship-to-ship communication, to reduce "noise", other radio channels or AIS messaging	41
Policies / Procedures		42
Separation distances between vessels	Set separation distances depending of ship types	42
Pilotage compulsory		44
Tether tugs	Tugs assist for critical areas, e.g. at blind sectors	44
Laser lights	Laser lights to get attention of other vessels	46
Radar transponder		47
Regulations		49
No overtaking zones	No overtaking at critical and precautionary areas	49
Speed limits for ships other than VLCC	Provide speed limits for critical and precautionary areas	52
Remove radar blind sector	Ships utilizing VTS to know what is in their blind sectors	58
Positive VTS control	VTS controls, and provides directions	65

For judicious use of resources and to provide meaningful discussion of the effectiveness of the RCOs, it was decided to focus on the top 11 ranked RCOs, which had a score of less than 30 on the RCO rating scheme. These RCOs are highlighted in cyan in **Table 20**.

In the risk workshop, the effectiveness of the identified RCOs was assessed in terms of the potential risk reduction achievable by potential implementation of the RCO. Due to the large numbers of combinations of RCOs and applicable Hazards, it was not possible to consider all of these combinations to obtain meaningful results within the available timeframe. Rather, it was decided to focus on the RCOs with Ease of RCO Implementation Rating of 30 or less (i.e. RCOs that are easy to implement and some moderately difficult to implement), and applicable hazards rated as High or Extreme risk. By this process, the focus is considered to be on those RCOs with high Benefit-to-Cost ratios. For the selected RCOs, the approach is to identify the applicable hazards and then have workshop participants rate the hazards after potential implementation of the RCO, using the risk rating scheme described in Table 17. The ratings from each of the participants were aggregated to obtain an overall risk rating of the hazard post-RCO implementation. The new risk rating, post-RCO implementation, was compared to the risk rating pre-RCO implementation to determine the potential percent risk reduction.

For instance, **Table 21** shows the case of the 3 green lights night signal RCO. The percent reduction in risk score for each applicable hazard is presented in the last column. Assuming, for purposes of this analysis, that we are interested in reducing/eliminating the top 10 ranked hazards, then the weighted percent risk reduction for the RCO can be obtained by multiplying each percent risk reduction by 0.1 and summing up for all applicable hazards. Thus, the weighted percent risk reduction for the 3 green lights night signal is obtained as 19%. The percent risk reduction for other RCOs are obtained similarly as shown in the detailed Part 2: Risk Workshop report.

Table 21: Effectiveness of 3 Green Lights Night Signal RCO to Control Selected High & Extreme Risk Hazards

RCO	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
New navigation lights	3 green lights for crossing vessels	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	48	37.3
		Human factors, Competence / capacity, Lack of competence (wrong rules or inaccurate assessment)	76	62	18.4
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	56	20.8
		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	48	28.1
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	42	33.4
		Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64	55	14.7
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	52	17.5
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	52	16.7

Table 22 shows the weighted percent risk reduction for the top RCOs, ranked according to percent risk reduction from highest to lowest. It is interesting to note that the 3 green lights night signal RCO provides the highest percent risk reduction. This is not surprising given, for example, the fact that the hazard posing the highest risk involves lack of situational awareness, and the use of the 3 green lights night signal is specifically intended to provide clarity on the intentions of crossing vessels.

Table 22: Top RCOs Ranked According to Effectiveness to Control Top Ten Ranked Hazards

RCOs	Percent Reduction of Top 10 Ranked Hazards
New navigation lights	19%
Day shapes	15%
Bridge resource management	13%
Dedicated lookout	11%
Passage planning guide (mandatory)	8%
Penalty for non-compliance	8%
VTS procedures	8%
Aids to navigation	7%
AIS message	6%
Readiness of machinery, including thrusters, for immediate manoeuvring	6%
Anchors ready for use	5%

It is important to note that although the analysis presented focuses on the top RCOs to control the top ranked hazards, these RCOs can also be applicable in controlling hazards other than the top 10 hazards. Furthermore it should also be noted that RCOs other than those considered in the analysis may also be applicable in controlling the top 10 or other hazards. In this sense, the overall list of RCOs presented in Table 20 can be regarded as a log of RCOs from which suitable ones can be selected to address any hazard of concern.

5.1.2 Need for Day Signal

The workshop brainstormed and discussed the need for day signals to correspond with the 3 green lights signal. The significant highlights of these discussions are presented below.

The participants noted that there is limited usefulness of existing day signals used under collision regulations. Day signals are difficult to see against mast or at a distance.

There is currently provision in the International Code of Signals, Chapter 2 Section 3 for a hoist of signal flag LZ1 indicating "I intend to pass through the channel/fairway".

For the use of such signal flags no regulatory change is required although mariners may require a reminder to use it regularly in such TSS circumstances.

Using a day signal, whether a normal day signal or flags, requires sending someone to physically raise, and shortly thereafter lower, it. This means depleting the bridge team at a critical navigational juncture or calling someone out for a very short duration assignment. In the case of vessels crossing a TSS the signal would only be used for a short time. Given the option, many bridge teams may choose to not utilize the signal.

Flags have limited utility. They may wrap around halyard or may be pushed by wind to a direction they can't be seen, and require resources from the bridge team at the critical time for raising and lowering them.

Sound signals have limited utility. If there are several vessels ahead and several behind, it will be difficult to determine who made a given sound signal. This would, in general, only give an indication that someone is crossing. However, generally knowing that someone is crossing TSS is not as useful as knowing who is crossing. Furthermore, manoeuvring sound signals tend to be used very close to the time of executing the manoeuvre so little advantage is gained with respect to signalling intent in advance.

Flashing high intensity green strobe light could be another type of day signal. They are easy to see, different from other signals and temporary in nature. They are easy to turn on/off with little distraction. Consensus was that a high intensity green strobe would suit the purpose.

This generated a discussion as to whether a high intensity green strobe would be a suitable signal for both day and night crossings. The general consensus was mixed:

- Some vessels can use existing navigation lights on their mast simply by changing lenses to meet the 3 green light configuration, but would require a new installation for the strobe.
- Some ships only show 2 lights now due to space limitations. Some will struggle to achieve the required vertical separation of lights.
- A strobe for daytime signalling may require some technical work to achieve an appropriate specification, which may delay implementation.
- A high intensity strobe was generally felt to be potentially too distracting at night with most favouring it for daylight use only.

Some barriers to implementation were identified:

- Strobe lights can be a challenge for cost and time implementation.
- COLREG Rule 36 does not allow use of strobe lights as means of signal to attract attention.
- Ships currently do not have it and no international specifications exist for the light being contemplated.

Following specifications may be considered for the flashing green light:

- High intensity flashing all-round green light. This could be similar to existing COLREG Rule 23 (c) which requires WIG craft to exhibit similar light but in red colour.
- Specification of all-round light and frequency of flashing may be considered in line with existing COLREG Rule 21 (e) and (f) – showing unbroken light over an arc of the horizon of 360 degrees and light flashing at regular intervals at a frequency of 120 flashes or more per minute. The High intensity light should be visible at least from a distance of 3 miles during day light.

In summary, although the risk workshop participants found great utility in the three green lights as a night signal they did not feel that a corresponding day signal, as per the collision regulations, was either appropriate or useful. The difficulty in identifying day signals, coupled with the necessity of detailing a person to hoist a signal for a limited time during a critical navigational juncture was deemed not to be a useful measure for risk reduction. The participants showed a strong preference for trying a high-intensity green strobe light as a day signal provided appropriate technical specifications could be developed. Such a light could be easily switched on and off by a member of the bridge team with a minimum of distraction and could serve as an indication of, or intent to, cross the traffic separation scheme. However, as COLREGs does not allow high intensity flashing light for attention, at present the most feasible option would be to enforce the use the signal flag LZ1 indicating "I intend to pass through the channel/fairway" as per International Code of Signals, if considered necessary.

5.1.3 Global Issues

Highlights of discussions regarding global implementation of the three green lights night signal include the following:

- In Japan large vessels (greater than 200 m long) exhibit a green flashing light.
- Having the three green light signals will be beneficial as all ships would be fitted. Therefore vessels not previously operating in Singapore Strait will not be faced with making a decision on whether to have the three green lights fitted should they decide to operate in the Singapore Strait at a later time.

- The use of the three green lights night signal may affect other jurisdictions with respect to local rules. For instance, Germany is currently using 3 green lights for purposes of identifying a vessel of the German Federal Customs Administration.
- There is potential for confusing the 3 green lights signal with that for a minesweeper (three green lights in triangular formation) in certain times or configurations.
- If a vessel is constrained by draught and is crossing it would have 3 red and 3 green which some may see as problematic particularly with regards to confusion with a dredge.
- Small craft may not have sufficient vertical separation for the three green lights.

5.1.4 Sound Signal

The question was asked of the participants whether vessels crossing a TSS should use a special sound signal. The consensuses was No. The vessels are executing a normal manoeuvre and should use the current manoeuvring signals from the collision regulations. The ship is not a priority ship and therefore should just be considered as executing a manoeuvre.

5.2 Ship Simulations

5.2.1 Objectives

The purpose of this simulation study was to evaluate if the three green lights night signal are beneficial to identifying vessels that are intending to cross or are currently crossing the traffic separation scheme. This was achieved by testing the ability of lookouts to identify crossing vessels in a traffic separation scheme (TSS) using a new combination of navigation lights as compared with those using only traditional navigation lights. The following provides a brief description of the methodology and the results of the simulation study. Details are provided in Part 4: Simulation of 3 Green Lights Night Signal.

5.2.2 Methodology

The simulation exercise was carried out at the facilities of the Centre for Marine Simulation (CMS) of the Marine Institute of Memorial University in St. John's, Newfoundland, on November 18-20, 2014. The team members participating in the study consisted of the instructor, the facilitator, two recorders, the designer of the simulation plan and SME in HF, and four Lookouts from CMS, Hammurabi Consulting and LRNA.

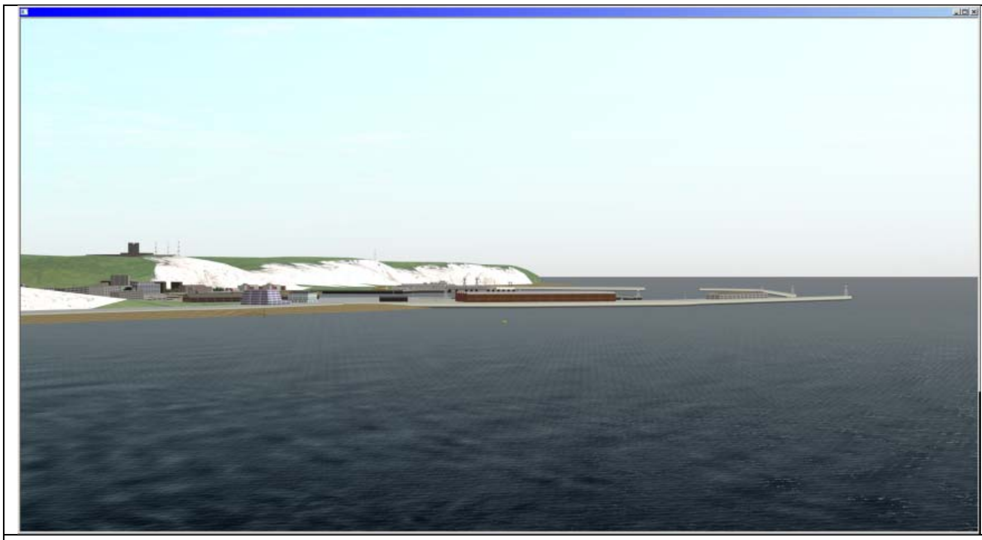
For this study, the CMS made available their full mission, full motion bridge simulator (shown in Figure 28) and a tug visual simulator. This made it possible to collect twice the amount of data that would have been collected with the use of only one simulator. The Full Motion Ships Bridge simulator utilizes Kongsberg Maritime's industry leading Polaris Ship Bridge simulator software. Using advanced numerical models for environmental forces, vessels, and sea states, this simulation engine, when combined with high fidelity visual graphics, can represent any marine transportation scenario including ship manoeuvring, voyage or route studies, emergency situations, or risk assessments.

Figure 28 Full-mission, full-motion bridge simulator

The CMS's tug simulator is capable of simulating a 6 DOF hydrodynamic math model and thus realistically interact with the vessel to which it is attached (e.g. hawser forces are exerted on both the vessel and the tug). The tug Instructor Station allows the instructor to monitor and control aspects of the simulator such as tug position, hawser angle/tension, and propulsion system settings.

The tug simulator has a much narrower field of view. The Lookout can stand in one spot and see all of the screens and easily scan the whole field. On the full mission bridge the candidate has more windows to deal with as well as a much larger physical space. They were more inclined to be walking around to see the full field. Also, as the tug has LCD screens the contrast is very good and picking out shadows against light is easier. Furthermore, the tug simulator had no course and speed indicator that the Lookout could use to assess if movement of lights may be due to the change in course or speed of own ship. The Lookouts only had visuals to make all assessments. This was not the case for the full mission bridge. Blind sectors in the full mission bridge can be seen around by the lookout moving around, whereas the blind sector in the tug simulator cannot be seen around by moving and remains truly a blind sector. In order to determine if the differences in the simulator environments affected the results in any significant way, the data obtained from the two simulators were assessed separately.

The simulation files required for the navigation simulators were generated using geographic databases, which are collections of various data sets. The simulation files interact in the form of visuals, motion, ship models, and navigation systems. Environmental effects are maintained through the instructor station by the instructor. These elements influence the ship motion and navigation systems appropriately. The geographical data bases for Singapore Strait, the English Channel and San Francisco Bay available in the CMS library were refined/modified to suit the requirements of this study. The views of the three areas as seen from the simulators are shown in Figure 29 to Figure 31. Note that only the night views were used in the study. The day views are shown for illustration purposes to demonstrate that the cultural objects in the simulation models were close to reality. In addition to the Singapore Strait, which had background lights, the English Channel and San Francisco Bay were studied. The English Channel provided scenarios with no background lights, and the San Francisco Bay area provided additional scenarios with very bright background lights.

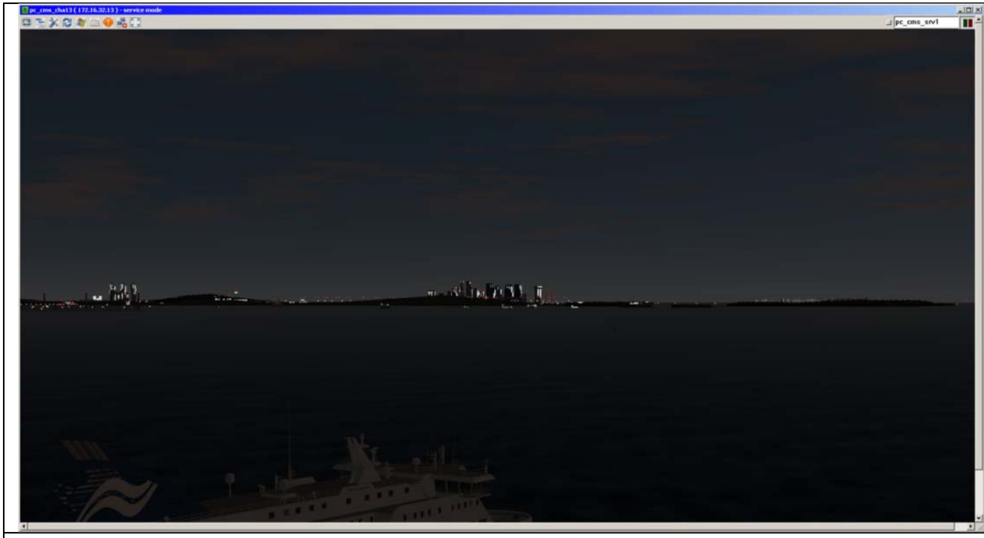


Day View

Night View

Figure 29 Day and Night Views of English Channel

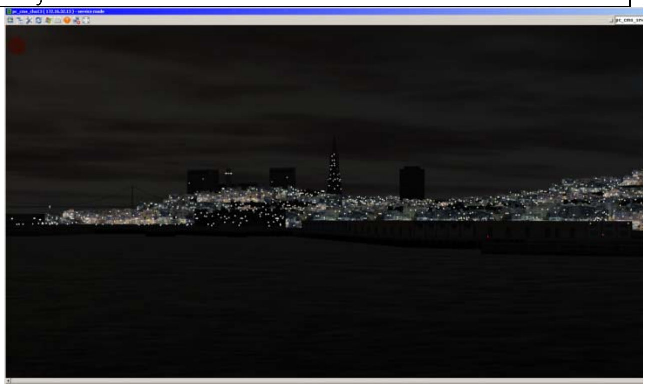
Day View



Night View

Figure 30 Day and Night Views of Singapore Strait

Day View | Day View



Night View | Night View

Figure 31 Day and Night Views of San Francisco Bay

The simulation plan was designed to determine, at a basic level, the benefits of the use of three green lights night signal. Simple sets of experiments were carried out to investigate any differences in the correct identification of crossing vessels by a set of Lookouts, if the vessels displayed the three green light night signal or not.

Using visual simulators four persons were assigned the task of being Lookouts at night. The Lookouts were presented with a number of crossing vessels, which were all of the same size, physical and visual characteristics in every run excepting that some exhibited normal navigation lights indicative of a power driven vessel and others additionally exhibited the three all-round green lights in a vertical line.

The Lookouts were given the task to identify crossing vessels, indicating whether the crossing vessel was displaying the 3 green lights night signal or normal navigation lights. The Lookouts were also required to record the time when they first noticed the navigation lights. The time recorded by the Lookout was compared to the control time (from the simulation program) to identify how long after initial presentation of the target the Lookout was able to observe the lights. The Lookouts also orally reported to the Observer what the vessel was doing. The report consisted of three elements:

1. Where they saw the ship (port, starboard, how many points off);
2. If the ship is a crossing vessel and whether crossing port to starboard or starboard to port; and
3. If the ship is exhibiting the normal navigation lights or the 3 green lights.

Five physical and environmental conditions, as listed in Table 23 were considered in the simulations. A total of 60 simulation runs were carried out over a three day period in the two simulators. The simulations seek to answer the following questions:

1. Are ships with the additional suite of navigation lights detected more often when compared to ships with just the normal navigation lights?
2. Does the new suite of navigation lights reduce the time taken to detect the ship, and assess the aspect/intent of the ship?

Table 23: List of Simulation Conditions

Condition No.	Description of Condition (Location, Physical and Environmental Conditions)
1	Clear Visibility / Multiple Ships / Background Lights – San Francisco
2	Clear Visibility / Single Ship / Background Lights – San Francisco
3	Clear Visibility / Multiple Ships / No Background Lights – English Channel
4	Clear Visibility / Single Ship / No Background Lights – English Channel
5	Degraded Visibility / Multiple Ships / Background Lights - Singapore

The intervals between the crossing vessels were randomized. Each run had 10 crossing vessels, which were randomly fitted with the new suite of lights so that 50% had each configuration. The Lookouts were not informed on the number of crossing vessels in each run, until after the whole exercise. A total of 600 targets were presented to the Lookouts of which 300 displayed the three green lights night signal, and 300 did not. This provides a reasonably large data size from which to derive statistically significant results, when assessing the overall results. Similarly, reasonably large data sets are available when assessing the influence of the individual simulation condition, simulator or Lookout, as shown in Table 24.

Table 24: No. of Targets in Simulations

Data Set	Number of Targets		
	With Green Lights	Without Green Lights	Total
Overall	300	300	600
Each Simulation Condition	60	60	120
Each Simulator	150	150	300
Each Lookout	75	75	150

Three main measures were used to assess benefit of using the three green lights versus not using them (those with only the normal lights), namely: (a) the percentage of targets that were correctly identified (correct lights and correct direction of the crossing vessel); (b) percentage of vessels with green or normal lights not detected; and (c) time it takes to identify the target.

5.2.3 Results of Analysis

Overall, 600 targets (300 with the three green lights night signal, and 300 without) were presented. Table 25 provides an overall summary of the extent to which the Lookouts were able to identify the targets that were presented to them. Overall, there was improvement in the rate of correctly identifying the crossing vessels and in the time it took the Lookout to correctly detect and identify the crossing vessels, if the vessels displayed the three green lights.

For vessels displaying the three green lights, the Lookouts were able to provide accurate information for 88% of the time, compared to 85% of the time for vessels not displaying the three green lights night signal, and 86% for all targets.

The percentages of targets for which the Lookouts correctly identified the type of lights displayed by the target, but incorrectly determined the crossing direction, were generally small: 3% for vessels with green lights; 2% for vessels without the green lights; and 3% overall. Note that in the experiment, for simplicity, all of the targets were crossing vessels, and the Lookouts were only required to identify the crossing direction and not the intention.

The percentages of targets for which the Lookouts incorrectly identified the type of lights displayed by the target were again generally small: 4% for vessels with green lights; 3% for vessels without the green lights; and 4% overall.

Only 5% of targets displaying the three green lights were not detected by the Lookouts, compared to 10% of targets not displaying the three green lights and 8% overall.

On average, for vessels displaying the three green lights night signal, it took the Lookouts 23 s to detect the vessel after the vessel first appeared, compared to 28 s for vessels not displaying the three green lights, and 26 s overall.

Finally, there were a number of non-crossing vessels that were identified as crossing vessels. Even though the experiment had been greatly simplified, there were still uncertainties as to the intents of vessels in the environment.

Table 25: Summary of Overall Results

Three Green Lights (1)	Vessel Detected			Vessel Not Detected (5)	Average Correct Detection Time (s) (6)	Non-Crossing Vessels Detected (7)
	Correct Lights Correct Directions (2)	Correct Lights Incorrect Directions (3)	Incorrect Lights (4)			
Y	88%	3%	4%	5%	23	18
N	85%	2%	3%	10%	28	
Overall	86%	3%	4%	8%	26	

For each simulation condition, a total of 120 targets (60 with the three green lights night signal, and 60 without) were presented. Table 26 presents the results for each of the five simulation conditions

Condition 1 (Multiple Ships in San Francisco, with Background Lights) had a much lower correct detection rate (78%) than the other conditions. The overall average rate of vessels not detected was also highest at 12% for Condition 1. The only difference was in the time it took to detect and identify the targets. The average time for identifying targets displaying the three green lights was 34 s compared to 40 s for targets not displaying the three green lights.

For Condition 2 (Single Ship in San Francisco, with Background Lights), the benefit of the three green lights in correctly detecting the targets was more pronounced: 95% detection rate for vessels displaying the three green lights versus 82% for vessels not displaying the green lights, and 3% non-detection rate for vessels displaying the three green lights versus 15% for vessels not displaying the green lights. However, the average time for detection was higher for targets with the three green lights by 17% for this condition only.

For Condition 3 (Multiple Ships in English Channel, no Background Lights), the detection rates for targets with and without the three green lights were very similar: 88% for vessels with the three green lights and

90% for vessels without the three green lights. The rates of vessels not detected were also very similar, at 3% and 5%, respectively for vessels displaying and not displaying the three green lights. The significant benefit of the three green lights was shown in the time it took the Lookouts to correctly identify the targets, with a 26% reduction in the detection time recorded for targets displaying the three green lights.

For Condition 4 (Single Ship in English Channel, no Background Lights), the detection rates for targets with and without the three green lights were 90% vs 85%; the corresponding rates of vessels not detected were 5% vs 12%; and the reduction in the time for identifying vessels with the green lights over those without was 27%.

For Condition 5 (Degraded visibility with background lights in the Singapore Strait), the detection rates for targets with and without the three green lights were 88% vs 90%; the rates of vessels not detected were 3% vs 5%; and the reduction in the time for identifying vessels with the green lights over those without was 23%.

Table 26: Simulation Results for Various Simulation Conditions

Condition (1)	Three Green Lights (2)	Vessel Detected			Vessel Not Detected (6)	Average Correct Detection Time (s) (7)	Non-Crossing Vessels Detected (8)
		Correct Lights Correct Directions (3)	Correct Lights Incorrect Directions (4)	Incorrect Lights (5)			
1	Y	77%	3%	8%	12%	34	2
	N	78%	2%	8%	12%	40	
	Overall	78%	3%	8%	12%	37	
2	Y	95%	0%	2%	3%	28	0
	N	82%	2%	2%	15%	24	
	Overall	88%	1%	2%	9%	26	
3	Y	88%	5%	3%	3%	20	10
	N	90%	5%	0%	5%	27	
	Overall	89%	5%	2%	4%	23	
4	Y	90%	5%	0%	5%	16	3
	N	85%	2%	2%	12%	22	
	Overall	88%	3%	1%	8%	19	
5	Y	88%	2%	7%	3%	20	3
	N	90%	2%	3%	5%	26	
	Overall	89%	2%	5%	4%	23	

Figure 32 to Figure 34 presents the results graphically for quick comparison of the various conditions.

Figure 32 compares the percentage of vessels detected correctly under the various conditions. It can be seen that the use of the three green lights night signal provided the highest percentage of vessel detection for Condition 2 (Single Ship in San Francisco Bay with Background lights), and least for Condition 1 (Multiple Ships in San Francisco Bay with Background lights). The level of detection for all other conditions (Conditions 3 to 5) appeared to be similar.

Figure 33 compares the percentage of vessels not detected under the various conditions. It is seen that the number of vessels not detected is generally lower with the use of the three green lights. Without the use of the three green lights, the highest percentage of vessels not detected was highest for the single ship scenarios (Conditions 2 and 4).

Figure 34 compares the average amounts of time it took the Lookouts to correctly detect the targets under various simulation conditions. The San Francisco scenarios with background lights (Conditions 1 and 2) required the most time to detect, with the multiple ship scenarios being the highest. The average detection times for Condition 3 (Multiple Ship in English Channel without background lights) and Condition 5 (Multiple Ships in Degraded Visibility in Singapore Straight) were very similar. Condition 4 (Single Ship in with no background lights in English Channel) required the least amount of time for correct detection and identification. In all cases, the corresponding time for vessels displaying the three green lights was lower than that for vessels without the three green lights, except for Condition 2 where a slightly higher detection time was noticed.

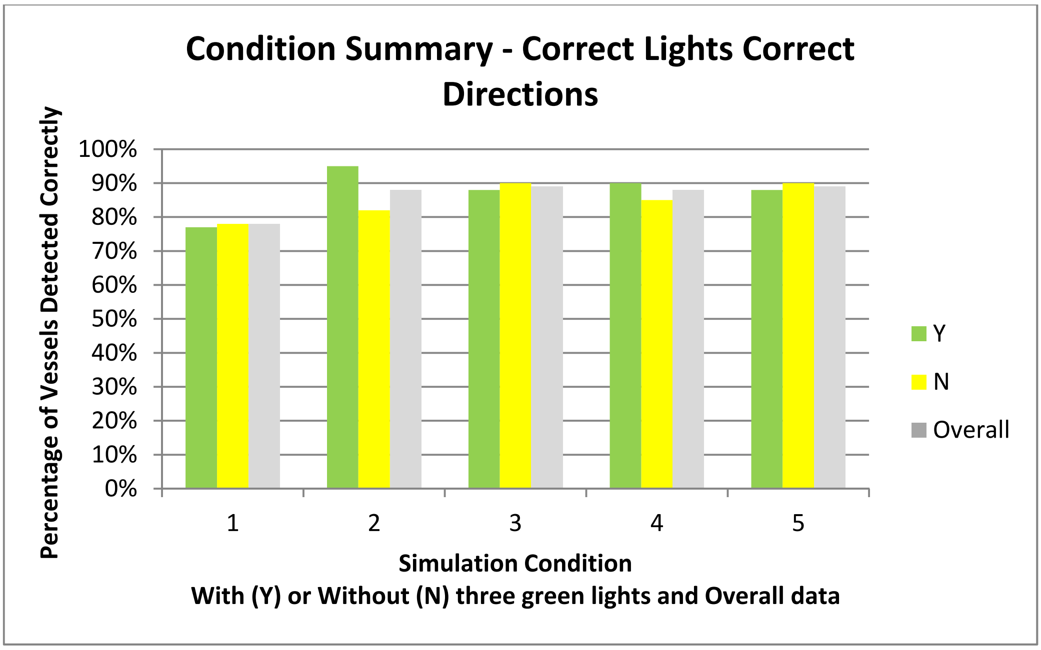


Figure 32 Percentage of Vessels Detected Correctly Under Various Simulation Conditions

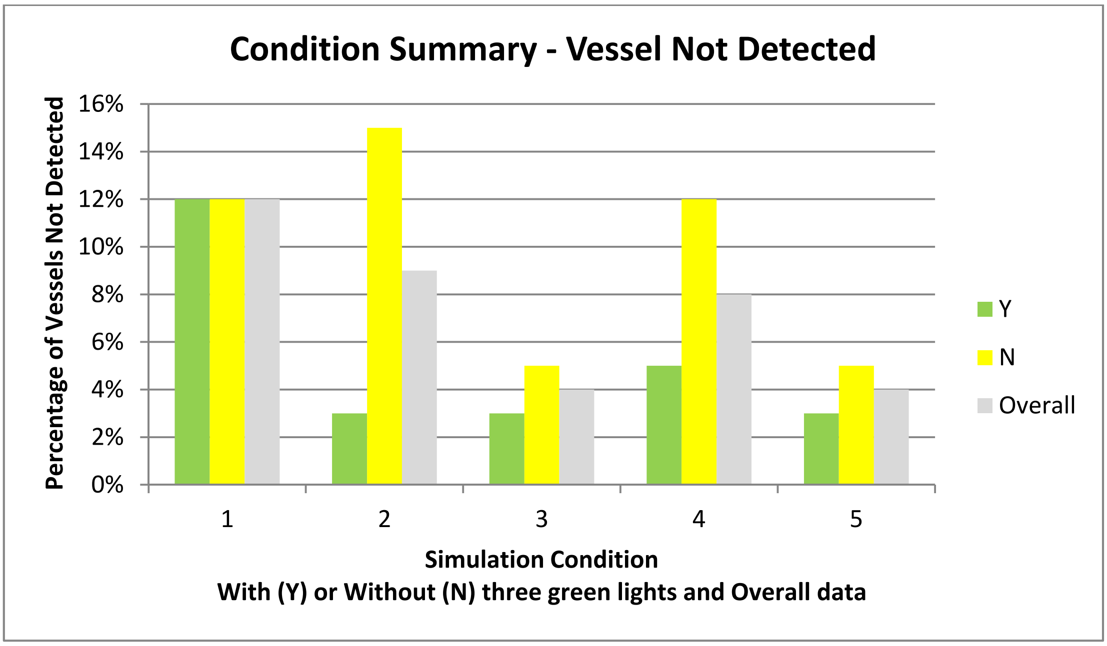


Figure 33 Percentage of Vessels Not Detected Under Various Simulation Conditions

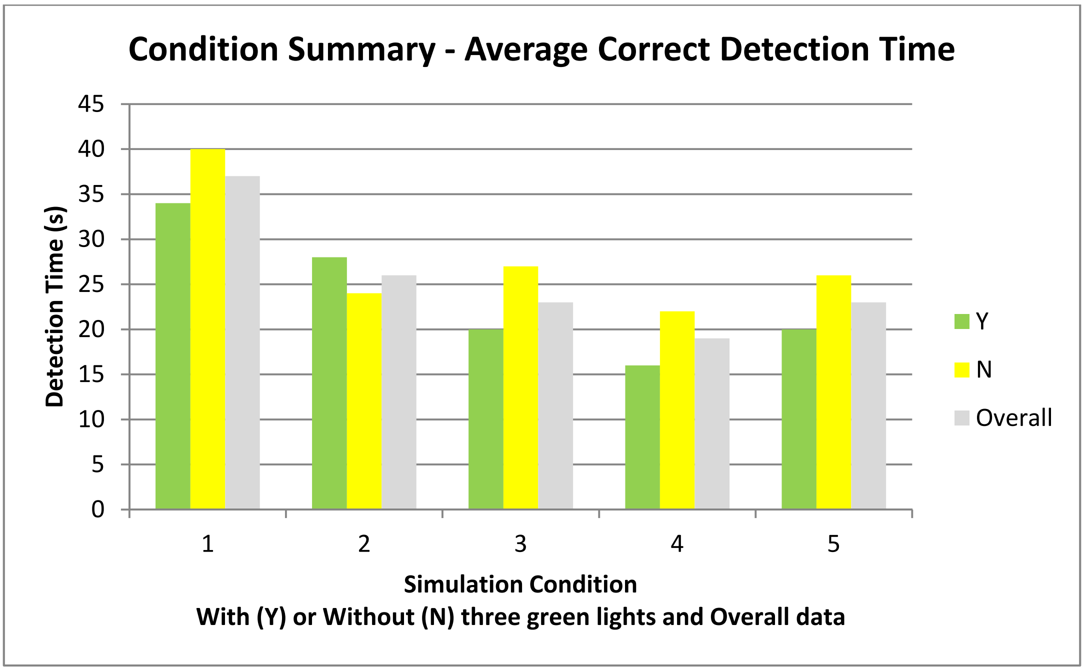


Figure 34: Average Time for Correct Identification of Vessels Under Various Simulation Conditions

The influence of the simulator, Lookout and time spent on simulator on the simulation results are discussed in details in Part 4: Simulation of 3 Green Lights Night Signal.

5.2.4 Limitations and Uncertainty Analysis

Limitations and issues that arose during the exercise were discussed in the debrief session and summarized in Part 4: Simulation of 3 Green Lights Night Signal.

All targets are moving at speeds of 15 to 20 knots which makes a good relative motion. It was pointed out that picking out against background lights with lower vessels speeds could still be very difficult.

The influence of variability (standard deviations) of the test results was studied by performing simple t-statistics on the overall results and data sets for each of the five conditions. The goal was to determine the confidence levels for which the following hypotheses were valid:

1. Time to detect vessels with green lights is less than without green lights night signal
2. Vessels with three green lights could be correctly detected at greater rate than without three green lights

Table 27 summarizes the results. Overall, there is 98% confidence that the time to detect vessels with the three green lights is less that the time to detect vessels without the three green lights. The confidence levels for the individual simulation conditions, except Condition 2, were lower, and at least 80%. Recall that the sample sizes for the overall data sets were approximately five times larger than those for the individual simulation conditions. This could account for why the confidence levels for the individual simulation conditions were lower than overall. Unfortunately, the hypothesis was violated for Condition 2 (Single Ship / Background Lights – San Francisco). On the question of correct detection (correct lights and correct crossing direction) only the overall case was investigated and the level of confidence for acceptance of the hypothesis was 79%. Overall, the results of the study provide reasonable confidence on the utility of the three green light night signal. Additional support on the utility of the new navigation light was obtained through questionnaires administered by the MPA on vessels operating live within the vicinity of crossing vessels on an ongoing basis in the Singapore Strait, as described in Part 1: Main Report.

Table 27: Confidence Levels for Acceptance of Hypotheses

Hypothesis	Condition	Confidence Level for Acceptance of Hypothesis
Time to detect vessels with green lights is less than without green lights night signal	Overall	98%
	Condition 1	80%
	Condition 2	Violated
	Condition 3	95%
	Condition 4	90%
	Condition 5	90%
Vessels with three green lights could be correctly detected at greater rate than without three green lights	Overall	79%

5.3 Questionnaire

The study was also informed by the results of questionnaires administer live on mariners within visual range of crossing vessels in the Singapore Strait. The questionnaire is administered by the MPA on a continuous basis to study the level of compliance with the 3 green lights night signal requirement, and to study the utility of the signals. From the VTS centre, when vessels crossing vessels are in view, VTS personnel will contact vessels in the vicinity of the crossing vessel and administer the question, which essentially inquires if the vessel was displaying the 3 green lights night signal, and if the signal was considered effective. Data for years 2012, 2013, and 2014 (January to September) were provided to the study team. The main highlights of the results are summarized below:

- Approximately 91% of crossing vessels displayed the three green lights night signal; and
- Approximately 94% of the vessels surveyed felt the three green lights night signal was effective.

5.4 Three Green Lights Duration

The current guidance regarding the use of three green lights does not give direction as to when they should be illuminated or extinguished. During the risk workshop the participants commented that one of the factors increasing the utility of the lights is that they are on "early" and they remain on for some time. This contrasts to normal manoeuvring signals that are given when executing an alteration of course and are only given once. It was remarked that the manoeuvring signals do not give advanced notice of intention and can be missed by an officer of the watch or lookout if distracted during the short period of time they are displayed.

It would be prudent to give considerations as in Collision Regulations Rule 6 on Safe Speed rather than a definitive time period. Such considerations could include:

- Speed and characteristics of own ship
- Proximity of other ships
- Whether ships are in the process of overtaking own ship
- Visibility
- Particular characteristics of waterway.

In any case mariners should be guided to turn on the lights in ample time to allow other traffic in the area to make an adequate assessment of the intent of the vessel and assess their intended track and actions relative to all traffic in the vicinity.

6. FSA Step 4 Cost-Benefit Analysis

6.1 Introduction

A cost-benefit analysis was undertaken in this study to provide broad orders of magnitude of the cost of implementing the 3 green light night signal RCO in relation to the potential risk reduction. In this context, risk reduction was considered in the form of (a) fatalities averted, using the Gross Cost of Averting a Fatality (GCAF) index; and (b) tonnages of oil spills averted, using the Cost of Averting a Tonne of oil spilt (CATS) index. In order to determine these cost effectiveness measures, it was necessary to estimate the following three costs:

- Cost of the RCO, including material, installation, and maintenance costs;
- Cost of fatalities averted as a result of implementation of the RCO; and
- Cost of tonnes of oil spill averted as a result of implementation of the RCO

Details of how these costs were estimated and used to calculate the cost effectiveness indices are provided in the following sub-sections.

6.2 Cost of 3 Green Lights RCO

In order to obtain meaningful information on the cost of installing the 3 green lights night signal, several shipyards worldwide were contacted to provide cost estimates for labour and material. Responses were received from five shipyards in three countries, namely Singapore, China and Dubai. Table 28 provides a summary of the cost estimates obtained. The average cost from all shipyards is $7,650 USD, and this value was used in the CBA estimation for the installation onboard existing ships. However, due to the significant variation in the costs, it was decided to also estimate the CBA at the lower and upper bound values (one standard deviation down or up from the mean value), in order to account for uncertainty in the RCO cost.

For new build ships, there will only be marginal cost for fitting the 3 green lamps as the most of the associated activities - plan appraisal, inspection, fabrication, installation and installation, would have to be done in any case for the traditional navigation lights. Therefore, for new build, only the material and operating costs were considered. These costs were obtained from four of the shipyards that provided detailed breakdown of the costs. Unfortunately, one of the shipyards only provided lump sum for materials and labour, and it was not possible to deduce the material costs. The costs from the various shipyards are shown in the last column of Table 28. The average cost was 1,656 USD, and this value was used in the CBA estimation for new builds. Again, due to the significant variation in the costs, it was decided to also estimate the CBA at the lower and upper bound values (one standard deviation down or up from the mean value), in order to account for uncertainty in the RCO cost.

Table 28: Cost Estimates for Installation of 3 Green Lights Night Signal RCO

Location of Shipyard	Installation Cost (Material & Labour) (USD) for Existing Ships	Installation Cost (Material) (USD) for New Builds
Singapore	11,400	-
China	4,700	525
China	4,050	750
Dubai	9,500	3,250
Dubai	8,600	2,100
Average	7,650	1,656
Standard Deviation	3,164	1,270
Lower Bound Value	4,486	386
Upper Bound Value	10,814	2,926

6.3 Cost of Fatalities Averted

Of the 13 historical collision incidents identified in the Singapore Strait (see **Table 2**), only one incident resulted in a loss of one life. This shows that the probability of loss of life resulting from a collision incident in the Singapore Strait is very low. However, this does not give us enough data to estimate potential number of fatalities that could be averted from implementation of the 3 green lights night signal RCO. To this end, it was decided to look at incidents in other areas to see if meaningful inferences could be made. Therefore, recent incidents, from 2000 to 2014, in the English Channel were reviewed as the channel had similar traffic characteristics, as discussed in Section 4.2. Of ten collision incidents that were reviewed, only one resulted in a fatality. This again did not provide sufficient information to estimate fatalities that could be averted as a result of implementation of the new navigation lights. However, it is common knowledge that collisions have resulted in larger numbers of fatalities, even in the English Channel, prior to 2000, and more recently in other parts of the world. For example, the following collision incidents in Hong Kong waters resulted in large numbers of fatalities [13]:

- In 2002, collision between high speed boat and pleasure boat resulted in 39 fatalities;
- In November 2013, collision involving a high speed craft resulted in 87 people injured; and
- In May 2014, 11 fatalities occurred when container ship MOL Motivator collided with cargo ship Zhong Xing 2.

Such information was used in conjunction with the traffic structure in the Singapore Strait, and expert opinion to estimate credible worst case, moderate and low fatality collision scenarios. **Table 29** presents these scenarios and possible fatality outcomes. The table provides justification for categorization, as well as estimates of potential likelihood for the fatality categories, given that an accident occurs.

Table 29: Collision Scenarios Involving Fatalities

Collision Scenario	Description	Fatalities	Reasoning	Estimated Likelihood of Occurrence
Collision of cargo or tanker vessel with similar vessel	Low	2	Based on historical review of recent incidents in Singapore Strait and English Channel	70%
Collision of fishing vessel or pleasure craft with large cargo or tanker	Moderate	6	Potential for loss of all personnel on board fishing vessel	20%
Collision of ferry or high-speed craft with large cargo or tanker vessel	Worst Case	30	Conservative estimate comparable to outcome of 2002 incident in Hong Kong	10%

The above information was used to estimate the cost of averting fatalities per incident per year as shown in **Table 30**. The fatality frequency computed in **Table 10** was used to estimate the implied probability for each of the fatality categories. Cost for averting a fatality value used in the estimates was 3 m USD as per IMO guidelines [2]. The total cost of averting a fatality per year per incident was estimated as 18,171 USD.

Table 30: Estimates of Cost of Averting Fatality Per Year Per Incident

Fatality Frequency			1.082E-03		
Cost of averting fatality (USD)				3,000,000	
Fatality Category	Fatalities	Likelihood	Implied Probability	Cost (USD) Per Incident	Cost (USD) Per Year Per Incident
Low Fatality	2	0.7	7.571E-04	6,000,000	4,543
Moderate Fatality	6	0.2	2.163E-04	18,000,000	3,894
Worst Case Fatality	30	0.1	1.082E-04	90,000,000	9,734
TOTAL					18,171

6.4 Cost of Oil Spill Averted

As with fatalities, using the historical incident information in conjunction with the traffic structure in the Singapore Strait, and expert opinion estimates of credible worst case, moderate and low oil spill collision scenarios were developed. **Table 31** presents these scenarios and possible oil spill volumes. The table also provides some reasoning, as well as estimates of potential likelihood for the oil spill categories. This information was used to estimate the cost of averting a tonne of oil spill per incident per year as shown in **Table 32**. The oil spill frequency computed in **Table 10** was used to estimate the implied probability for each of the oil spill categories. The cost for averting a tonne of oil spill value used in the estimates was 60,000 USD as suggested in [14]. The total cost of averting a tonne of oil spill per year per incident was estimated as 494,511 USD.

Table 31: Collision Scenarios Involving Oil Spills

Collision Scenario	Description	Spill Volume (tonnes)	Reasoning	Estimated Likelihood of Occurrence
Collision of smaller tanker or bunker spill	Low	100	Based on historical review of recent incidents in Singapore Strait and English Channel	70%
Collision of smaller tanker and large tanker/ bunker spill	Moderate	1,000	Possible moderate sized spill	20%
Major collision involving large tanker	Worst Case	10,000	Conservative estimate compared to worldwide average of 126,000 t [14]	10%

Table 32: Estimates of Cost of Averting Oil Spill Per Year Per Incident

Oil Spill Frequency			6.490E-03		
Cost of Averting tonne of spill (USD)				60,000	
Oil Spill Category	Spill Volume (tonnes)	Likelihood	Implied Probability	Cost (USD) Per Incident	Cost (USD) Per Year Per Incident
Low Spill	100	0.7	4.543E-03	6,000,000	27,257
Moderate Spill	1,000	0.2	1.298E-03	60,000,000	77,876
Worst Case Spill	10,000	0.1	6.490E-04	600,000,000	389,379
TOTAL					494,511

6.5 Cost/Benefit Assessment Estimates

The gross cost of averting a fatality (GCAF) and cost of averting a tonne spilt (CATS) costs discussed above are used to estimate the cost-benefit ratios for the new navigation lights RCO. The calculations are summarized in **Table 33** for existing ships and for new builds. The cost-benefit ratios were computed for a 20 year time period.

For existing ships, the costs-benefit ratios obtained were 0.77% and 127%, respectively for CATS and GCAF based assessments. This shows that the new navigational lights are very cost effective for controlling collision resulting in oil spills (cost of the RCO is only 0.77% of the savings in CATS). On the other hand, the new navigational light is not cost effective for collisions resulting in fatalities (cost of the

RCO is greater than the savings in GCAF), the reason being the very low frequency of collision incidents causing fatalities.

For new builds, the costs-benefit ratios obtained were 0.25% and 42%, respectively for CATS and GCAF based assessments. This shows that the new navigational lights are very cost effective for controlling collision resulting in oil spills (cost of the RCO is only 0.25% of the savings in CATS). Additionally, the new navigation lights are also moderately cost effective for collisions resulting in fatalities (cost of the RCO is 42% of the savings in GCAF).

Table 33: Cost-Benefit Ratios

Cost-Benefit Analysis - Baseline	Existing Ships	New Build
	Average	Average
Time period (yrs)	20	20
Costs		
Cost of Installation (USD)	7,650	1,656
Plan approval and Inspection Cost (USD)	3,500	0
Yearly Costs (USD/yr)	150	150
Total Cost of RCO over Selected Time Period (USD)	14,150	4,656
Benefits		
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15
GCAF Based Cost-Benefit Ratio		
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	18,171	18,171
Number of Fatality Incidents over Time Period	4	4
GCAF over Selected Time period (USD)	72,684	72,684
Potential GCAF Savings (USD)	11,182	11,182
Cost-Benefit Ratio (based on GCAF)	127%	42%
CATS Based Cost-Benefit Ratio		
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	494,511	494,511
Number of Oil Spill Incidents Over Time Period	24	24
CATS Over time period (USD)	11,868,269	11,868,269
Potential CATS Savings (USD)	1,825,888	1,825,888
Cost-Benefit Ratio (based on CATS)	0.77%	0.25%

The above cost-benefit ratios are considered to be baseline estimates based on the data used in this study. Sensitivity analyses were undertaken to investigate the influence of uncertainties in the data on the cost-benefit ratios. First, the influence of uncertainty of the RCO cost was studied by computing the baseline cost-benefit ratios at the lower and upper bound RCO cost estimate, i.e. average RCO minus or plus the standard deviation of RCO estimated costs. This provides the lower and upper bound cost-benefit ratios. The results are summarized in Table 34 for existing ships and in Table 35 for new builds.

For existing ships, it is seen that the lower bound cost-benefit ratio based on GCAF was 98%, which is still considered to be high; and the upper bound cost-benefit ratio based on CATS was 1.14%, which is still very low and demonstrates the effectiveness of the RCO for spill collisions. For new builds, the lower bound cost-benefit ratio based on GCAF was 30%, which demonstrates effectiveness for fatality collisions;

and the upper bound cost-benefit ratio based on CATS was 0.39%, which is still very low and demonstrates the effectiveness of the RCO for spill collisions.

Table 34: Sensitivity Analysis for Cost-Benefit Ratios (Existing Ships)

Scenarios	Cost-Benefit Rations for Various RCO Costs (%)		
	RCO Cost		
	Average	Lower Bound	Upper Bound
Baseline GCAF-Based Cost-Benefit Ratio	127	98	155
Likelihood of 60-20-20% for Low, Moderate and Worst Case Fatality Collision Scenarios	84	65	103
CAF for Passengers Increased from 3m to 6m USD (CAF for crew remain at 3 m USD)	82	**64**	101
Baseline CATS-Based Cost-Benefit Ratio	0.77	0.72	1.14
Likelihood of 80-15-5% for Low, Moderate and Worst Case Oil Spill Collision Scenarios	1.35	1.26	1.98
CATS Reduced to 30,000 USD	1.55	1.44	**2.28**

Table 35: Sensitivity Analysis for Cost-Benefit Ratios (New Builds)

Scenarios	Cost-Benefit Rations for Various RCO Costs (%)		
	RCO Cost		
	Average	Lower Bound	Upper Bound
Baseline GCAF-Based Cost-Benefit Ratio	42	30	53
Likelihood of 60-20-20% for Low, Moderate and Worst Case Fatality Collision Scenarios	28	**20**	35
CAF for Passengers Increased from 3m to 6m USD (CAF for crew remain at 3 m USD)	27	**20**	35
Baseline CATS-Based Cost-Benefit Ratio	0.25	0.22	0.39
Likelihood of 80-15-5% for Low, Moderate and Worst Case Oil Spill Collision Scenarios	0.44	0.39	0.68
CATS Reduced to 30,000 USD	0.51	0.45	**0.78**

Next, the cost-benefit ratios were computed for the following four scenarios:

(a) The likelihoods for the collision scenarios were changed from 70%-20%-10% used in the baseline case for low, moderate and worst case scenarios to 60%-20%-20%. That is, the likelihoods were 60% for low, 20% for moderate, and 20% for worst case collision scenarios.
(b) The CAF for passengers was increased from 3m USD to 6m USD. This would affect the worst-case collision scenario involving passenger vessels and high speed craft. The CAF for crew remained the same as 3m USD.
(c) The likelihoods for the collision scenarios were changed from 70%-20%-10% used in the baseline case for low, moderate and worst case scenarios to 80%-15%-5%.
(d) The CATS value was reduced from 60,000 USD to 30,000 USD.

The first two scenarios were designed to improve the cost-benefit ratios for fatality collisions; and the latter two scenarios were designed to provide pessimistic CATS based cost-benefit ratios. The results of the sensitivity analyses are provided in Table 34 for existing ships and in Table 35 for new builds, and details of the calculations are provided in Appendix 1B.

For existing ships, considering the estimates based on average RCO costs, it is seen that the cost-benefit ratio for fatality collisions could potentially be reduced from 127% to 82%. This number is still high, but demonstrates that RCO could be potentially beneficial if the scenarios and costs assumed in the sensitivity study are realized. In fact, if the lower bound RCO cost estimate is used, the cost-benefit ratio could be further reduced to 64%, which could be considered as a reasonable benefit.

For new builds, considering the estimates based on average RCO costs, it is seen that the cost-benefit ratio for fatality collisions could potentially be reduced from 42% to 27%, or to 20% if based on lower bound RCO cost. This demonstrates that the RCO could be potentially very cost beneficial if the scenarios and costs assumed in the sensitivity study are realized.

For CATS based estimates, the worst case cost-benefit ratio increased to 2.28% and 0.78%, for existing ships and new builds, respectively, (based on upper bound RCO cost and half of the CATS cost), which are still very low and demonstrates the effectiveness of the RCO for spill collision scenarios is very robust.

In summary, the study has shown that the three green lights night signal RCO is very cost effective for collision incident resulting in oil spills, for both existing ships and new builds. Since oil spills are the most commonly observed consequences of collision in the Singapore Strait, the RCO is considered to be quite beneficial. For collisions resulting in fatalities, the RCO was found to be cost effective for new builds, but not for existing ships for the baseline scenarios and cost data used in the study. However, for existing ships, the RCO was found to be moderately cost effective, if catastrophic events involving large passenger vessels and high speed crafts, resulting in large numbers of fatalities or situations where passenger costs are higher than IMO suggested CAF values of 3m USD, were to happen.

7. FSA Step 5 Decision Making

The utility of the 3 green light night signal RCO has been extensively investigated in this study, using a variety of methods as summarized below:

- HAZID Workshop, where SMEs with knowledge and experience navigating in the Singapore Strait and other areas with TSS worldwide ranked the three green lights night signal as the RCO with the highest weighted percent risk reduction;
- Administration of live questionnaires to mariners in the vicinity of crossing vessels in the Singapore Strait. It was noticed that 91% of crossing vessels complied with the 3 green light night signal, and 97% of mariners in the vicinity of the crossing vessels, who were interviewed stated that the RCO was effective.
- Ship simulation exercises that showed that the time to detect a vessel displaying the three green lights was shorter than if the vessel was not displaying the three green lights.
- Cost-benefit analysis demonstrated that the 3 green lights night signal RCO was very cost effective for collision incidents resulting in oil spills, for both existing ships and new builds. The RCO was also found to be cost effective for collisions resulting in fatalities for new builds. It was also shown that, for existing ships, the RCO could be moderately cost effective, if catastrophic events involving large passenger vessels or high speed crafts, resulting in large numbers of fatalities or situations where passenger costs are higher than IMO suggested CAF values of 3m USD, were to happen.

In light of these demonstrated benefits of the utility/ effectiveness of the 3 green lights night signal in Singapore Strait, it is concluded that this RCO will be beneficial to navigation in similar straits and bodies of water in other parts of the world, and it is recommended that efforts be made to introduce the RCO worldwide.

Although the mariners, both in the risk workshop and in the Singapore user surveys, found great utility in the three green lights they did not feel that a corresponding day signal, as per the collision regulations, was either appropriate or useful. The difficulty in identifying day signals, coupled with the necessity of detailing a person to hoist a signal for a limited time during a critical navigational juncture was deemed not to be a useful measure for risk reduction.

The risk workshop participants showed a strong preference for trying a high-intensity green strobe light as a day signal provided appropriate technical specifications could be developed. Such a light could be easily switched on and off by a member of the bridge team with a minimum of distraction and could serve as an indication of, or intent to, cross the traffic separation scheme. However, as COLREGs does not allow high intensity flashing light for attention, at present the most feasible option would be to enforce the use the signal flag LZ1 indicating “I intend to pass through the channel/fairway” as per International Code of Signals, if considered necessary.

8. Uncertainty Analysis

As with any risk study, there are a number of uncertainties and limitations inherent in this study. These have been discussed in detail where appropriate in this report and in Parts 2, 3 and 4 of report. Highlights of these are summarized below:

- Historical incident data was extensively used in the study. Uncertainties exist as to the completeness and accuracy of the information, as some of the sources did not provide all of the required information. Engineering judgment and inferences from literature and other related sources were used to augment available data.
- A number of assumptions were made in the use the AIS data for traffic simulation. Due to the volume of the data, only a limited sample of data was used in the analysis, with assumptions made that the sample data was representative of the overall data. Simple tests were performed to ensure reasonable validity of such assumptions (See Part 3: Traffic Simulation Report). Furthermore, it was reported in Part 3 report that the AIS data contained a number of unreferenceable vessel, which could have an impact on the actual structure of the vessel traffic in the respective areas. Detailed descriptions of how these and obvious errors in the data were handled were discussed as well in the Part 3 report.
- A number of assumptions were made in assessing frequencies, consequences (fatalities and oil spill volumes), and costs, using the best available data and engineering judgement.
- In the ship simulation studies, variability in the test results were noticed, and attempts were made to determine confidence levels at which the intents of the test could be accepted, using statistical measures, such as t-test.
- SMEs were frequently used to provide opinion on various aspects of the work. To reduce influence of subjectivity of the SMEs on the project outcomes, multiple SMEs would generally be consulted to enhance the results.
- A number of assumptions were made on the collision scenarios, their frequencies and corresponding consequence costs. A sensitivity study was undertaken to investigate the influence of uncertainties associated with these assumptions on the cost-benefit ratios.

9. Summary and Conclusions

This study was undertaken to perform a formal safety assessment (FSA) for the use of three green lights night signal for vessels crossing the traffic separation scheme (TSS) and precautionary areas in the Singapore Strait. In order to demonstrate the applicability of the study results to other areas worldwide with TSS, investigations of the traffic and navigational risks in two other selected areas with TSS, namely, the English Channel and San Francisco Bay were also undertaken. The study was carried out in accordance with IMO's FSA guidelines. FSA is a rational and systematic process for assessing the risks relating to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks, and involves the following five stages: (1) Identification of hazards; (2) Risk analysis; (3) Risk control options; (4) Cost-benefit assessment; and (5) Recommendation for decision-making. These FSA steps were addressed through a number of studies and activities, including a review of historical incidents/ data, expert opinion during a HAZID work, traffic and ship simulation exercises, and cost-benefit analysis.

Six types/categories of causal factors were identified, namely (a) human factors; (b) environment; (c) physical surrounding; (d) shipboard technology; (e) policies; and (f) method (of identification and assessment), and were used to develop a hazards list. A number of hazards were identified, assessed and ranked. High risk hazards were subjected to risk control. A total of 31 Risk Control Options (RCOs) were identified in the study. These were rated and ranked in accordance with their ease of implementation and effectiveness in terms risk reduction. The 3 green lights night signal RCO had the highest weighted percent risk reduction of 19.

This effectiveness of the three green lights was further studied in a ship simulator. The main objective was to evaluate if the three green lights night signal are beneficial to identifying vessels that are intending to cross or are currently crossing the traffic separation scheme. This was achieved by testing the ability of lookouts to identify crossing vessels in a traffic separation scheme (TSS) using the new combination of navigation lights as compared with those using only traditional navigation lights. It was observed that for vessels displaying the three green lights, the Lookouts were able to provide accurate information for 88% of the time, compared to 85% of the time for vessels not displaying the three green lights night signal, and 86% for all targets. There was thus a some improvement in the correct identification of targets when the vessels displayed the three green lights.

On average, for vessels displaying the three green lights night signal, it took the Lookouts 23 s to detect the vessel after the vessel first appeared, compared to 28 s for vessels not displaying the three green lights, and 26 s overall. In addition, the simple tests conducted in the simulation exercise have demonstrated an approximately 18% improvement in the time it took the Lookout to correctly detect and identify the crossing vessels, if the vessels displayed the three green lights night signal. Additional support on the utility of the new navigation light was obtained through questionnaires administered by the MPA on vessels operating live within the vicinity of crossing vessels on an ongoing basis in the Singapore Strait. It was noticed that 91% of crossing vessels complied with the 3 green light night signal, and 97% of mariners in the vicinity of the crossing vessels, who were interviewed stated that the RCO was effective.

Cost-benefit analysis demonstrated that the 3 green lights night signal RCO was very cost effective for collision incidents resulting in oil spills, for both existing ships and new builds. The RCO was also found to be cost effective for collisions resulting in fatalities for new builds. It was also shown that, for existing ships, the RCO could be moderately cost effective, if catastrophic events involving large passenger vessels or high speed crafts, resulting in large numbers of fatalities or situations where passenger costs are higher than IMO suggested CAF values of 3m USD, were to happen.

In light of these demonstrated benefits of the utility/effectiveness of the 3 green lights night signal in Singapore Strait, it is concluded that this RCO will be beneficial to navigation in similar straits and bodies of water in other parts of the world, and it is recommended that efforts be made to introduce the RCO worldwide.

Although the mariners, both in the risk workshop and in the Singapore user surveys, found great utility in the three green lights they did not feel that a corresponding day signal, as per the collision regulations, was either appropriate or useful. The difficulty in identifying day signals, coupled with the necessity of detailing a person to hoist a signal for a limited time during a critical navigational juncture was deemed not to be a useful measure for risk reduction. The risk workshop participants showed a strong preference for trying a high-intensity green strobe light as a day signal provided appropriate technical specifications could be developed. Such a light could be easily switched on and off by a member of the bridge team with a minimum of distraction and could serve as an indication of, or intent to, cross the traffic separation scheme. However, as COLREGs does not allow high intensity flashing light for attention, at present the most feasible option would be to enforce the use the signal flag LZ1 indicating "I intend to pass through the channel/fairway" as per International Code of Signals, if considered necessary.

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All Lookouts in Ship simulation Exercise (Part 4)

APPENDIX 1A: COLLISION INCIDENTS LOGS SINGAPORE STRAIT

		SINGAPORE STRAIT COLLISION INCIDENTS LOG (2010-2014)								
								Consequences		
Vessels	**Year**	**Incident**	**Encounter**	**Description/ Details**	**Geographical Location**	**Vessel Type**	**Day/ Night**	**injuries/ Fatalities**	**Oil Spill**	**Damage**
Laptev Sea; MV PWP	2010	Collision	Overtaking	Overtaking vessel alters course	Precautionary area, south of Eastern Buoy	tanker, general cargo	Day	None	None	vessel
Voge Prestige; RHL Fidelitas	2011	Collision	Crossing		Precautionary area, 2 nm SW of Eastern Buoy	container, bulk carrier	Night	None	None	vessel
Kota Tenaga; SEEB	2012	collision	Joining traffic lane	Vessel alters course into deep water route	1.5 nm S of Sebarok Beacon	Container; VLCC	Night	None	54 MT HFO	vessel, containers
Sunny Horizon; DL Salvia	2012	collision		Fairway collision	Temasek Fairway, 700 metres east of Sultan Shoal	Bulk carrier, LPG carrier	early morning	None	60 MT bunker fuel	bunker tank breached
BOSUN; SC3566	2013	Collision		Fairway collision	Sinki Fairway about 7km southwest of Pasir Panjang Terminal	container, habour craft	Day	1 fatality, 1 injured	None	sinking of harbourcraft
Oriental Pioneer; Atlantic Hero	2013	Collision			6.6km south-west of Tanah Merah Ferry Terminal	bulk carrier, bulk carrier	early morning		100 MT	tank damage
Beks Halil; Tuan My	2013	Collision	overtaking	Bulk carrier overtaking at close quarter; ssmall tanker suddenly turned to left	3.4 kilometres south of Sisters Islands	bulk carrier; small tanker	Day	None	None	hatch of cargo damaged
Lime Galaxy; Feihe	2014	Collision		ineffective bridge resource management	about 2.7 km, south of Jurong Island	chemical tanker; container	evening	None	Yes, amount not known	container scrapped
NYK Themis; AZ Fuzhou	2014	Collision		Fairway collision	East Keppel Fairway, 4 kilometers south of Marina South	container; barge in tow	Day	None	Yes, amount not known	serious damage to vessels
Hammonia Thracium; Zoey	2014	Collision	crossing		off Sebarok Island (about 10km south of mainland Singapore) at 01° 11.40'N 103° 49.99'E	container; chemical tanker	Day	None	80 MT	tank breached, bow damage
Lord Vishnu; Skua	2014	Collision	Crossing		at position 01° 11.39' N 103° 50.06' E, in the Precautionary Area of the TSS.	car carrier; bulk carrier; bulk carrier	Night	none	None	damage to all three ships
Best Unity; Southern Explorer	2014	Collision	collision at anchorage		eastern bunkering anchorage	Bulk carrier; bulk carrier	Day	none	None	significant damage to both ships
Hisui; Ye Chi	2014	Collision	Crossing		1.3nm east southeast of Eatern Borading Ground B at 01° 15.18'N 103° 58.65'E,	LPG, Tanker	Day	None	None	minor vessel damage

ENGLISH CHANNEL

Year	Vessels	Study-Relevant Collision Details	Injuries / Fatalities	Oil Spill	Damage
2000	Pasadena Universal; Nordheim	Dover Strait; Congestion in overtaking; Lack of proper intention assessment	0	0	Vessel superstructure damage (x2)
2000	East Fern; Kinsale	Collision SW of Dover; Poor BRM attention for conditions	0	0	Vessel damage (x2)
2001	Gudermes; Saint Jacques II	TSS crossing; Night visibility conditions; Bad crossing bearing	0	71 T "Oil"	Tank holed; vessel damage
2001	Hampoel; Atlantic Mermaid	TSS overtaking; Night visibility conditions	1 minor injury	0	Cargo shift, vessel damage
2001	MV Sand Heron; FV Celtit	TSS crossing; Fishing vessel, w/ unclear intentions	0	0	Superficial vessel damage; bow damage
2001	MV Ash; Dutch Aquamarine	Close overtaking in TSS under good visibility	1 fatality	0	Vessel loss; superficial vessel damage
2002	Diamant; Northern Merchant	Ro - pax and HSC collision; Poor visibility	0	0	Substantial bow damage (x2)
2008	Scot Isles; Wadi Halfa	TSS crossing; Early morning light conditions; Watchkeeping failure	0	60 T Marine gas oil	Extensive damage to hull plating; extensive damage to bridge wing
2013	Paula C; Barya Gayatri	Night conditions; In TSS	0	0	Significant damage to bridge, lifesaving equipment, hull holed; port bow holed
2014	Rickmers Dubai; Walcon Wizard	Overtaking in TSS; Morning light conditions	0	0	Damage to on deck machinery (x2)

APPENDIX 1B: SENSITIVITY ANALYSES FOR COST-BENEFIT RATIOS

Cost-Benefit Analysis – Baseline (Existing Ships)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	7,650	4486	10,814
Plan approval and Inspection Cost (USD)	3,500	3,500	3,500
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	14,150	10,986	17,314
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	18,171	18,171	18,171
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	72,684	72,684	72,684
Potential GCAF Savings (USD)	11,182	11,182	11,182
Cost-Benefit Ratio (based on GCAF)	127%	98%	155%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	494,511	494,511	494,511
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	11,868,269	9,890,224	9,890,224
Potential CATS Savings (USD)	1,825,888	1,521,573	1,521,573
Cost-Benefit Ratio (based on CATS)	0.77%	0.72%	1.14%

Cost-Benefit Analysis - Likelihood of 60-20-20 for Low, Moderate & Worst Case Scenarios (Existing Ships)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	7,650	4486	10,814
Plan approval and Inspection Cost (USD)	3,500	3,500	3,500
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	14,150	10,986	17,314
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	27,257	27,257	27,257
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	109,026	109,026	109,026
Potential GCAF Savings (USD)	16,773	16,773	16,773
Cost-Benefit Ratio (based on GCAF)	84%	65%	103%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	879,996	879,996	879,996
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	21,119,912	17,599,927	17,599,927
Potential CATS Savings (USD)	3,249,217	2,707,681	2,707,681
Cost-Benefit Ratio (based on CATS)	0.44%	0.41%	0.64%

Cost-Benefit Analysis - CAF for Passengers Increased to 6m USD (Existing Ships)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	7,650	4486	10,814
Plan approval and Inspection Cost (USD)	3,500	3,500	3,500
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	14,150	10,986	17,314
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	27,905	27,905	27,905
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	111,622	111,622	111,622
Potential GCAF Savings (USD)	17,173	17,173	17,173
Cost-Benefit Ratio (based on GCAF)	82%	64%	101%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	494,511	494,511	494,511
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	11,868,269	9,890,224	9,890,224
Potential CATS Savings (USD)	1,825,888	1,521,573	1,521,573
Cost-Benefit Ratio (based on CATS)	0.77%	0.72%	1.14%

Cost-Benefit Analysis - Likelihood of 80-15-5, for Low, Moderate & Worst Case Scenarios (Existing Ships)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	7,650	4486	10,814
Plan approval and Inspection Cost (USD)	3,500	3,500	3,500
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	14,150	10,986	17,314
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	12,979	12,979	12,979
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	51,917	51,917	51,917
Potential GCAF Savings (USD)	7,987	7,987	7,987
Cost-Benefit Ratio (based on GCAF)	177%	138%	217%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	284,247	284,247	284,247
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	6,821,918	5,684,932	5,684,932
Potential CATS Savings (USD)	1,049,526	874,605	874,605
Cost-Benefit Ratio (based on CATS)	1.35%	1.26%	1.98%

Cost-Benefit Analysis - CATS Reduced to 30,000 USD (Existing Ships)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	7,650	4486	10,814
Plan approval and Inspection Cost (USD)	3,500	3,500	3,500
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	14,150	10,986	17,314
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	18,171	18,171	18,171
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	72,684	72,684	72,684
Potential GCAF Savings (USD)	11,182	11,182	11,182
Cost-Benefit Ratio (based on GCAF)	127%	98%	155%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	247,256	247,256	247,256
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	5,934,135	4,945,112	4,945,112
Potential CATS Savings (USD)	912,944	760,786	760,786
Cost-Benefit Ratio (based on CATS)	1.55%	1.44%	2.28%

Cost-Benefit Analysis - Baseline (New Build)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	1,656	386	2,926
Plan approval and Inspection Cost (USD)			
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	4,656	3,386	5,926
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	18,171	18,171	18,171
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	72,684	72,684	72,684
Potential GCAF Savings (USD)	11,182	11,182	11,182
Cost-Benefit Ratio (based on GCAF)	42%	30%	53%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	494,511	494,511	494,511
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	11,868,269	9,890,224	9,890,224
Potential CATS Savings (USD)	1,825,888	1,521,573	1,521,573
Cost-Benefit Ratio (based on CATS)	0.25%	0.22%	0.39%

Cost-Benefit Analysis - Likelihood of 60-20-20 for Low, Moderate & Worst Case Scenarios (New Build)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	1,656	386	2,926
Plan approval and Inspection Cost (USD)			
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	4,656	3,386	5,926
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	27,257	27,257	27,257
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	109,026	109,026	109,026
Potential GCAF Savings (USD)	16,773	16,773	16,773
Cost-Benefit Ratio (based on GCAF)	28%	20%	35%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	879,996	879,996	879,996
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	21,119,912	17,599,927	17,599,927
Potential CATS Savings (USD)	3,249,217	2,707,681	2,707,681
Cost-Benefit Ratio (based on CATS)	0.14%	0.13%	0.22%

Cost-Benefit Analysis - CAF for Passengers Increased to 6m USD (New Build)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	1,656	386	2,926
Plan approval and Inspection Cost (USD)			
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	4,656	3,386	5,926
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	27,905	27,905	27,905
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	111,622	111,622	111,622
Potential GCAF Savings (USD)	17,173	17,173	17,173
Cost-Benefit Ratio (based on GCAF)	27%	20%	35%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	494,511	494,511	494,511
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	11,868,269	9,890,224	9,890,224
Potential CATS Savings (USD)	1,825,888	1,521,573	1,521,573
Cost-Benefit Ratio (based on CATS)	0.25%	0.22%	0.39%

Cost-Benefit Analysis - Likelihood of 80-15-5, for Low, Moderate & Worst Case Scenarios (New Build)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	1,656	386	2,926
Plan approval and Inspection Cost (USD)			
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	4,656	3,386	5,926
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	12,979	12,979	12,979
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	51,917	51,917	51,917
Potential GCAF Savings (USD)	7,987	7,987	7,987
Cost-Benefit Ratio (based on GCAF)	58%	42%	74%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	284,247	284,247	284,247
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	6,821,918	5,684,932	5,684,932
Potential CATS Savings (USD)	1,049,526	874,605	874,605
Cost-Benefit Ratio (based on CATS)	0.44%	0.39%	0.68%

Cost-Benefit Analysis - CATS Reduced to 30,000 USD (New Build)			
	Average	Low	High
Time period (yrs)	20	20	20
Costs			
Cost of Installation (USD)	1,656	386	2,926
Plan approval and Inspection Cost (USD)			
Yearly Costs (USD/ yr)	150	150	150
Total Cost of RCO over Selected Time Period (USD)	4,656	3,386	5,926
Benefits			
Crossing Collision Incidents as fraction of all collision Incidents (based on incident data)	0.31	0.31	0.31
Assume 50% of crossing incidents reduced	0.15	0.15	0.15
GCAF Based Cost-Benefit Ratio			
Gross Cost of Averting a Fatality (GCAF) per Incident per Year (USD)	18,171	18,171	18,171
Number of Fatality Incidents over Time Period	4	4	4
GCAF over Selected Time period (USD)	72,684	72,684	72,684
Potential GCAF Savings (USD)	11,182	11,182	11,182
Cost-Benefit Ratio (based on GCAF)	42%	30%	53%
CATS Based Cost-Benefit Ratio			
Cost of Averting a Tonnage Spilt (CATS) per Incident per Year (USD)	247,256	247,256	247,256
Number of Oil Spill Incidents Over Time Period	24	24	24
CATS Over time period (USD)	5,934,135	4,945,112	4,945,112
Potential CATS Savings (USD)	912,944	760,786	760,786
Cost-Benefit Ratio (based on CATS)	0.51%	0.45%	0.78%

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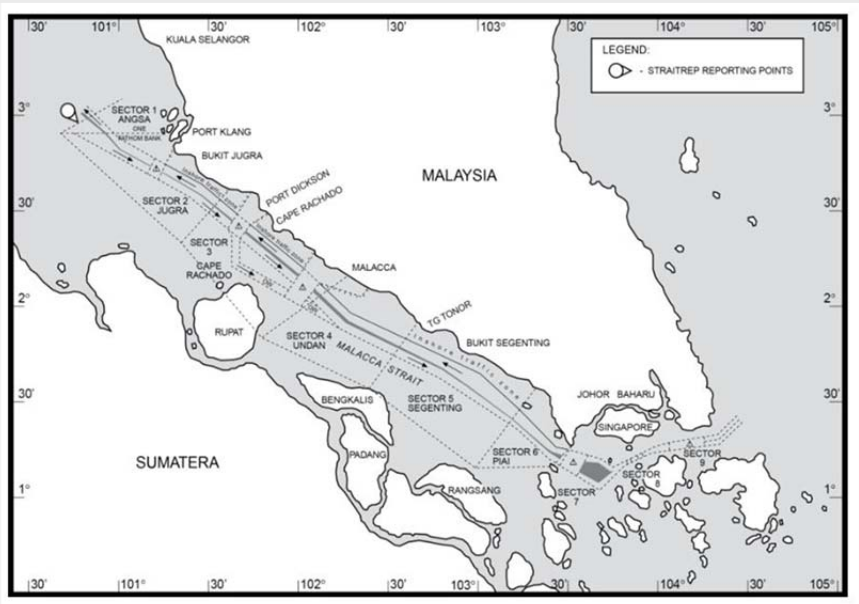
FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait

Part 2: Risk Workshop

February 20, 2015



Summary

FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait

Part 2 - Risk Workshop

Technical Report No.:	Revision:	Date:
TR- SNG 1404102/02	1	20 February, 2015
Prepared by:	Reviewed by:	Approved by:
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Executive Summary

This study was undertaken as part of the formal safety assessment (FSA) for the use of three green lights night signal for vessels crossing the traffic separation scheme (TSS) and precautionary areas in the Singapore Strait. The main objective of the study was to elicit expert opinion on the hazards that are causes of, or contributing factors to, collisions in the Singapore Strait TSS and to examine risk control options. This report informs FSA Step 1 - Identification of hazards; Step 2 - Risk analysis; Step 3 - Risk control options.

A systematic hazard identification (HAZID) exercise of hazards leading to collisions in the Singapore Strait was undertaken using the collective knowledge and experience of various stakeholders, including MPA, APL Co. Ltd, BWFM Singapore, Eastern Pacific Shipping Pte Ltd, AET Ship Management Singapore PTE Ltd, Singapore VTIS, PSA Marine, Pacific International Lines PTE Ltd, and LRA. The workshop was conducted at the facilities of Lloyd's Register Asia, Singapore offices at 460 Alexandra Road, #28-01/02 PSA Building, Singapore 119963, on October 20-21, 2014.

Six types /categories of causal factors were identified, namely (a) human factors; (b) environment; (c) physical surrounding; (d) shipboard technology; (e) policies; and (f) method (of identification and assessment), and were used to develop a hazards list. A total of 50 hazards were identified, each being a unique combination of type / category, risk factor and hazardous scenario. The identified hazards were rated (on a scale of 0-100) and ranked in decreasing order in terms of the likelihood of the hazards resulting in a collision scenario. As per the risk categorization scheme used in the study, two of the hazards were ranked as Extreme risk, 31 of the hazards were ranked as High risk and the remaining 17 were ranked as Medium risk. It is noted that the two hazards ranked as Extreme risk are human factors related issues involving lack of situational awareness or lack of competence. The top ranked hazards, with risk rating scores of 63 or higher were selected for risk control (see table below).

Hazard ID	Hazards	Risk Rating
15	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77
9	Human factors, Competence / capacity, Lack of competence (wrong rules or inaccurate assessment)	76
33	Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71
26	Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66
14	Human factors, Fatigue, Fatigue, leading to inappropriate analysis	65
17	Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64
30	Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64
47	Policies, SMS, including passage plans and contingency plans, Inadequate SMS, SMS not used properly	63
28	Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63

Hazard ID	Hazards	Risk Rating
16	Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63

A total of 31 Risk Control Options (RCOs) were identified in the study, and first rated in terms of their ease of implementation, on a scale of 0-100 (100 indicating highest difficulty in implementation). The 3 green lights night signal RCO was ranked in the top seven RCOs that were considered easy to implement. The majority of the RCOs were considered to be at least moderately difficult to implement. The effectiveness of RCOs, which had a score of less than 30 on the RCO rating scheme, were assessed. This involved comparing the risk levels of applicable hazards pre- and post-RCO implementation, and computing the percent reduction in the risk rating. For each RCO, a weighted percent risk reduction, which accounts for the fraction of applicable High and Extreme Risk hazards with respect to the total number of High and Extreme Risk hazards considered in the study, was computed. The 3 green lights night signal RCO had the highest weighted percent risk reduction of 19% as shown in the table below. This is not surprising given the fact that the hazard posing the highest risk involves lack of situational awareness, and the use of the 3 green lights night signal is specifically intended to provide clarity on the intentions of crossing vessels.

RCOs	Percent Reduction of Top 10 Ranked Hazards
New navigation lights	19%
Day shapes	15%
Bridge resource management	13%
Dedicated lookout	11%
Passage planning guide (mandatory)	8%
Penalty for non-compliance	8%
VTS procedures	8%
Aids to navigation	7%
AIS message	6%
Readiness of machinery, including thrusters, for immediate manoeuvring	6%
Anchors ready for use	5%

The workshop discussed the need for corresponding day signals. It was noted that there is limited usefulness of existing day signals used under collision regulations. Day signals are difficult to see against mast or at a distance. In the case of vessels crossing a TSS the signal would only be used for a short time, and would require sending someone to raise it, and shortly thereafter to lower it. This means depleting the bridge team at a critical navigational juncture or calling someone out for a very short duration assignment. Given the option, many bridge teams may choose to not utilize the signal.

The use of flags was also discussed and considered to have limited utility, as they may wrap around halyard or may be pushed by wind to a direction they can't be seen, and require resources from the bridge team at critical time for raising and lowering.

Sound signals were also considered to have limited utility. If there are several vessels ahead and several behind, it will be difficult to determine who made a particular sound signal. This would, in general, only give an indication that a vessel is crossing, without identifying which.

The risk workshop participants showed a strong preference for trying a high-intensity green strobe light as a day signal provided appropriate technical specifications could be developed. Such a light could be easily switched on and off by a member of the bridge team with a minimum of distraction and could serve as an indication of, or intent to, cross the traffic separation scheme. However, as COLREGs does not allow high intensity flashing light for attention, at present the most feasible option would be to enforce the use the signal flag LZ1 indicating “I intend to pass through the channel/fairway” as per International Code of Signals, if considered necessary.

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GLOSSARY AND ACRONYMS

AIS	Automatic Identification System
BIMCO	Baltic and International Maritime Council
COLREGS	Collision Regulations
FSA	Formal Safety Assessment
GPS	Global Positioning System
HAZID	Hazard Identification
IMO	International Maritime Organization
LRA	Lloyd's Register Asia
MPA	Maritime and Port Authority of Singapore
RCO	Risk Control Option
SME	Subject Matter Expert
SMS	Ship Management System
TSS	Traffic Separation Scheme
UKC	Under Keel Clearance
VHF	Very High Frequency
VLCC	Very Large Crude Carrier
VTS	Vessel Traffic System

1. Introduction

1.1 Background

This document is Part 2 of the overall report on the formal safety assessment (FSA) for the use of three green lights night signal for vessels crossing the traffic separation scheme (TSS) and precautionary areas in the Singapore Strait. The document provides details of the risk workshop undertaken as part of the FSA. The FSA methodology [1] comprises a five step process involving:

(1) Identification of hazards;
(2) Risk analysis;
(3) Risk control options;
(4) Cost benefit assessment; and
(5) Recommendations for decision making.

This report addresses Steps 1, 2 and 3.

1.2 Objectives and Scope

The main objective of the risk workshop was to elicit expert opinion on the hazards that are causes or contributing factors to collisions in the Singapore Strait TSS and to examine risk control options. The scope of the workshop included the following:

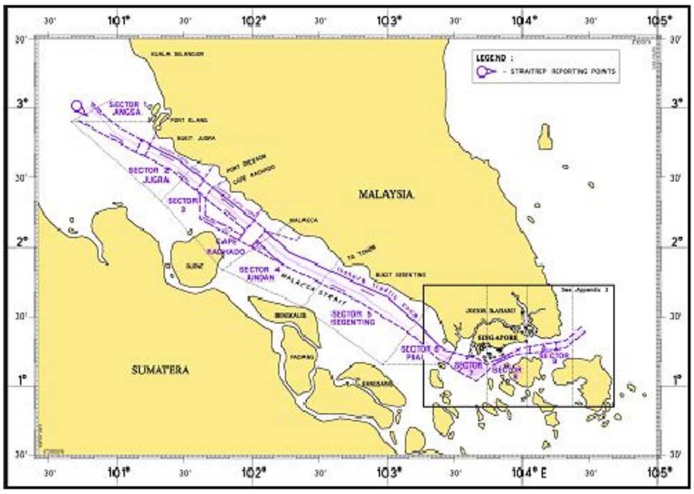
- Identification of hazards / scenarios that could lead to a collision scenario in the TSS
- Rating and ranking of the hazards
- Identification of risk control options (RCOs) for reducing likelihood of the identified hazards resulting in a collision scenario
- Rating and ranking of the effectiveness of the RCOs
- Evaluation of the need for a Day Signal.

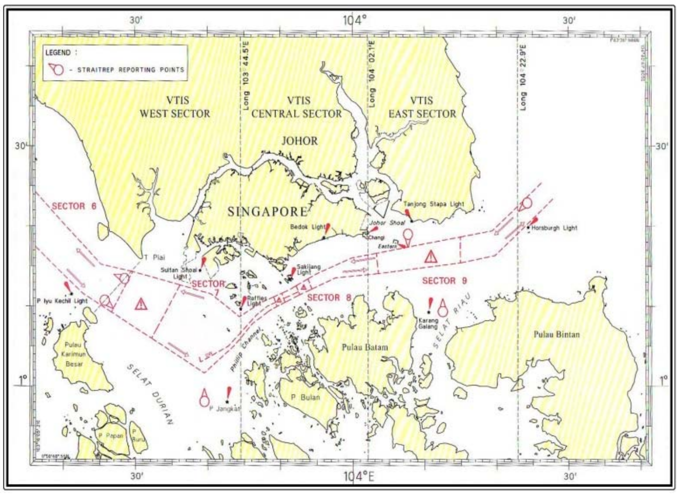
2. Description of the Use Of 3 Green Lights in TSS and Precautionary Areas in Singapore Strait

The Maritime and Port Authority (MPA) of Singapore introduced the three green lights night signal for crossing vessels in the Singapore Strait as a recommendatory measure in July 2011 [2]. The night signals identify vessels crossing the TSS during hours of darkness, thus allowing other vessels in the appropriate lanes to take actions if required, thereby enhancing navigational safety. Vessels are recommended to display the night signals consisting of three all-round green lights in a vertical line in the following situations:

- Vessels departing from ports or anchorages when crossing the westbound or eastbound lane of the TSS or precautionary areas in the Singapore Strait to join the eastbound traffic lane or to continue to routes or destinations south of the TSS;
- Eastbound vessels in the TSS or precautionary areas in the Singapore Strait crossing to proceed to ports or anchorages in the Singapore Strait;
- Vessels transiting from ports or routes south of the TSS when crossing either the eastbound lane to join the westbound lane or when crossing both lanes to proceed to port or anchorages of Singapore;
- The night signals are recommended to be displayed by vessels of length equal to or greater than 50m; vessels of 300 gross tonnage and above; and vessels engaged in towing or pushing with a combined 300 gross tonnage and above, or with a combined length of 50 metres or more.

Figure 1 shows a map of the study area.





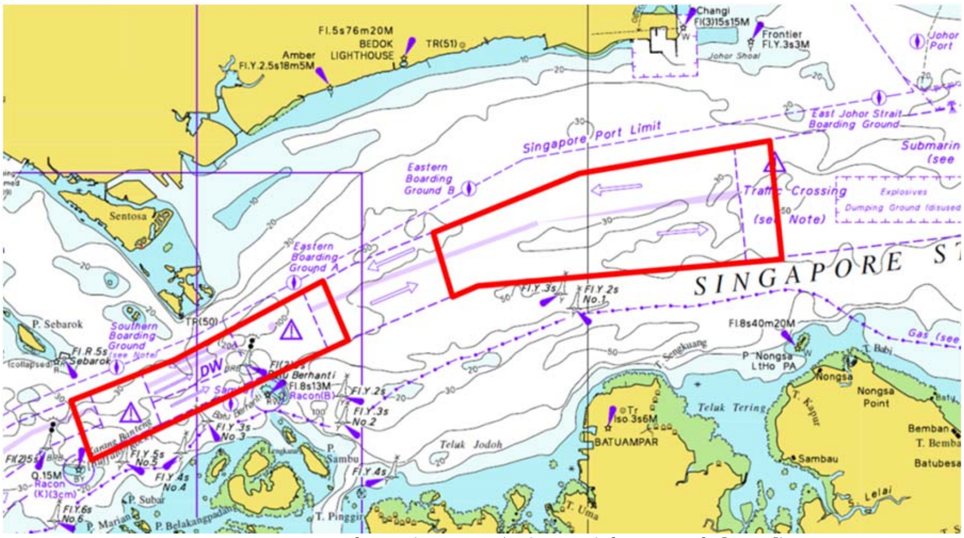


Figure 1 Map of Study Area (adapted from Ref. [3, 4])

3. Methodology

A systematic hazard identification (HAZID) exercise was undertaken, exploring hazards which may lead to collisions in the Singapore Strait. The purpose of the HAZID is to apply a rigorous format of examination in order to demonstrate that all credible scenarios and incidents have been considered for vessels operating in the TSS and Precautionary Areas of the Singapore Strait. The HAZID was conducted at the facilities of Lloyd's Register Asia, Singapore offices at 460 Alexandra Road, #28-01/02 PSA Building, Singapore 119963, on October 20-21, 2014. A standard HAZID approach was modified for specific use within this study.

3.1 Study Team and Attendance

The Risk Workshop team members and experts participating in the study are listed in Table 1.

Table 1: Study Team Members

Name	Organization	Role/ Position	E-mail Address	Attendance	
				Day 1	Day 2
Capt. Jia C. Chong	MPA	Observer, Navigation Expert, Regulatory Framework	CHONG_Jia_Chyuan@ mpa.gov.sg	Yes	Yes
Henry Heng	MPA	Observer, Navigation Expert, Regulatory Framework	Henry_HENG@ mpa.gov.sg	No	Yes
Irinjalakuda G Sangameswar	MPA	Observer, Navigation Expert, Regulatory Framework	Irinjalakuda_G_SANGAMESWAR@mpa.gov.sg	Yes	No
Brijesh Tewari	LRA	Project Lead	Brijesh.tewari@Lr.org	Yes	Yes
Samshul Huda	LRA	Risk Assessment	Shamsul.Huda@lr.org	Yes	Yes
Capt. David Cheong	LRA	SME, Navigation in Singapore Strait	David.cheong@lr.org	Yes	No
Tamunoiyala Koko	LRA	Facilitator & Scribe; Risk Assessment	Tamunoiyala.koko@lr.org	Yes	Yes
Capt. Jack Gallagher	Hammurabi Consulting	Facilitator, SME Navigation Risk	jack@hammurabi.ca	Yes	Yes
Mr. Peng ChuXing	APL Co. Ltd	SME, Navigation in Singapore Strait	Chuxing_peng@apl.com	Yes	No
Capt. Franz G Klassen	APL Co. Ltd	SME, Navigation in Singapore Strait	Klassen_franz_gerard@ apl.com	Yes	Yes
Amit Nandrajog	BWFM Singapore	SME, Navigation in Singapore Strait	amit.nandrajog@ bwfm.com	Yes	Yes
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Mohammad Jamal	Singapore VTIS	SME, Navigation in Singapore Strait	Md_Jamal_MD_JANBARI@ mpa.gov.sg	Yes	Yes
Capt. Wong Yoong Siong	PSA Marine	SME, Navigation in Singapore Strait	yswong@psa.com.sg	Yes	Yes
Capt. Benedict Tan Hung Ching	PSA Marine	SME, Navigation in Singapore Strait	benedict@psa.com.sg	Yes	Yes

Name	Organization	Role/ Position	E-mail Address	Attendance	
Capt. Edward Abban	Pacific International Lines PTE Ltd	SME, Navigation in Singapore Strait	abban@sgp.pilship.com	Yes	Yes

3.2 Pre-Study Preparations

Prior to the study workshop, participants were given a Terms of Reference document [5], to enable participants to familiarize themselves with the workshop plan and methodology for the study.

In addition, the LRA Navigation SME / Facilitator had a tour of the Singapore Strait TSS at night to have a first hand view of navigating at night within the Singapore TSS.

3.3 Workshop Study Steps

The steps followed in the workshop are shown below:

- Identify the hazards/ factors that influence the risk of collision
- Rate and rank the factors that influence collisions
- Identify the possible risk control options (RCOs)
- Rate and rank the RCOs in terms of their effectiveness
- Discuss possibilities of day signal to correspond to crossing lights
- Discuss barriers to implementation and effectiveness/ benefits of risk control options

Workshop participants were guided through the processes and the proceedings, and results were displayed on a projector. This enabled participants to know the results of the study during the workshop and allowed for opportunity to validate and discuss the results to ensure they remain valid once collated.

The focus of the workshop was the Singapore TSS. Towards the end of the workshop, once all hazards and risk control measures had been ranked and rated, a discussion about applicability globally to all TSSs was undertaken.

Participants were encouraged not to focus only on recent occurrences, but to also consider the events that happen less often but which may have significant consequences.

When considering risk, one assesses a combination of the exposure (probability) and the consequence (outcome). In this study, due to the nature of the issue being addressed, the focus is entirely on probability. The intent is to reduce the number of collisions. Discussions of measures that would affect the consequences of collisions that do occur were not the focus of this study.

3.4 Hazards and Factors Influencing Risk of Collision

Using the collective knowledge and experience of the workshop participants, a brainstorming exercise was undertaken to identify hazards and factors that could influence the risk of collision in the Singapore Strait. A fishbone diagram was used to develop the hazards and factors that could lead to collision. Starting with a partially completed fishbone diagram (see Figure 2) the workshop participants refined and populated the diagram to identify the collision causal factors. There was no intent to develop relationships between causes or rate them at this time, but simply to enumerate and categorize the factors. The purpose of the exercise is twofold. Firstly it develops a large list of factors that could contribute to a collision. Secondly it functions to get the group to think broadly about issues and not be narrowly looking at the problem or the solution.

Once the causal factors were identified, the group then brainstormed and identified the associated potential hazards.

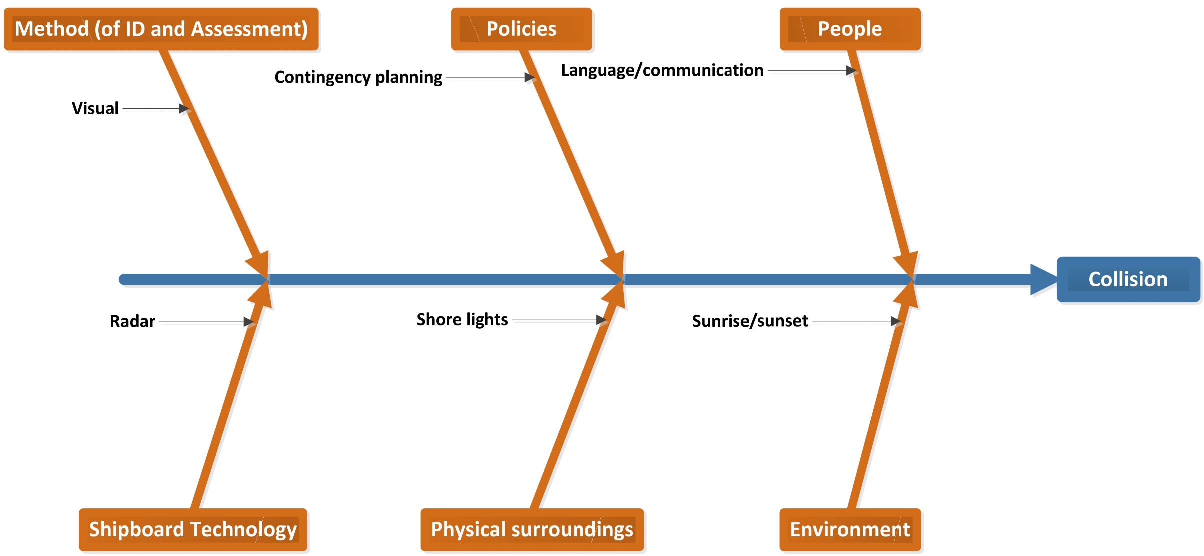

Figure 2 Partially Completed Fishbone Diagram

3.5 Risk Rating and Ranking Criteria

The next step in the process involved the rating and ranking of the identified hazards. Hazards were rated in terms of the likelihood of a collision event, given the hazard, using a scale of 0 (not likely) to 100 (very likely). Each participant provided a rating for each identified hazard and the scores were aggregated to give an overall risk rating for the hazard. A risk categorization scheme, such as the one shown in Table 2 was used to screen out less important hazards from the point of view of causing a collision event. Hazards rated as High or Extreme Risk were selected for risk reduction. This risk rating and ranking process was discussed and agreed upon by the participants.

Table 2: Risk Categorization Scheme

Risk Rank	Description
0 – 25	Low Risk
25 – 50	Medium Risk
50 – 75	High Risk
75 – 100	Extreme Risk

3.6 Identification and Rating of Risk Control Options (RCOs)

This step involves assessment of risk control options (RCO) for the High and Extreme risk hazards/ scenarios. This was undertaken through a brainstorming exercise by the subject matter experts. Starting with a preliminary list provided by the facilitation team, the workshop participants identified and refined possible RCOs.

The RCOs were then rated in accordance with (a) ease of implementation; and (b) effectiveness of controlling the High and Extreme Risk hazards.

The ease of implementation was assessed on a scale of 0 (easy to implement) to 100 (difficult to implement). Each participant provided a rating for each identified RCO and the scores were aggregated to give an average rating on the ease of implementation. The categorization scheme shown in Table 3 was used to rate the RCOs in terms of the ease of implementation.

Table 3: Ease of RCO Implementation Categorization Scheme

Ease of RCO Implementation Rating	Description
0 – 25	Easy to implement
25 – 50	Moderately difficult to implement
50 – 75	Difficult to implement
75 – 100	Very difficult to implement

It is noted that the ease of implementation alone is not sufficient to rank the RCO, as it is acknowledged that some RCOs that are difficult to implement may be more effective in reducing the risk of collision hazards. The ease of implementation has to be combined with the potential effectiveness of the RCOs in reducing the risks, especially those rated as High or Extreme Risk, in order to fully appreciate the value/ benefit of the RCO.

In the risk workshop, the effectiveness of the identified RCOs was assessed in terms of the potential risk reduction achievable by potential implementation of the RCO. Due to the large numbers of combinations of RCOs and applicable Hazards, it was not possible to consider all of these combinations to obtain meaningful results within the available timeframe. Rather, it was decided to focus on the RCOs with Ease of RCO Implementation Rating of 30 or less (i.e. RCOs that are easy to implement and some moderately difficult to implement), and applicable hazards rated as High or Extreme risk. By this process, the focus is considered to be on those RCOs with high Benefit-to-Cost ratios. For the selected RCOs, the approach is to identify the applicable hazards and then have workshop participants rate the hazards after potential implementation of the RCO, using the risk rating scheme described in section 3.5. The ratings from each of the participants were aggregated to obtain an overall risk rating of the hazard post RCO implementation. The new risk rating, post RCO implementation, was compared to the risk rating pre RCO implementation to determine the potential percent risk reduction, as illustrated in Table 4.

Table 4: Illustration of Computation of RCO Effectiveness

Option	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
New navigation lights	3 green lights for crossing vessels	Human Factors, Situational awareness, Lack or inadequate situational awareness, Master-Pilot-Master exchanges	77	48	37.3
		Human Factors, Competence/Capacity, lack of competence (wrong rules or inaccurate assessment)	76	62	18.4

3.7 Discussions on Need for Day Signals and Applicability of RCOs Globally

The workshop brainstormed and discussed the need for corresponding day signals, as well as issues related to implementation of the RCOs worldwide. The significant highlights of these discussions are presented in the Results and Discussions (Section 4).

4. Results and Discussion

4.1 Hazards and Risk Ranking

Figure 3 shows the detailed fishbone diagram developed to identify the factors influencing risk of collision through the brainstorming exercise. Six types or categories of causal factors were identified, namely: (a) human factors; (b) environment; (c) physical surrounding; (d) shipboard technology; (e) policies; and (f) method (of identification and assessment). An effort was made to identify all possible factors for each category, followed by identification of the hazards associated with each risk factor.

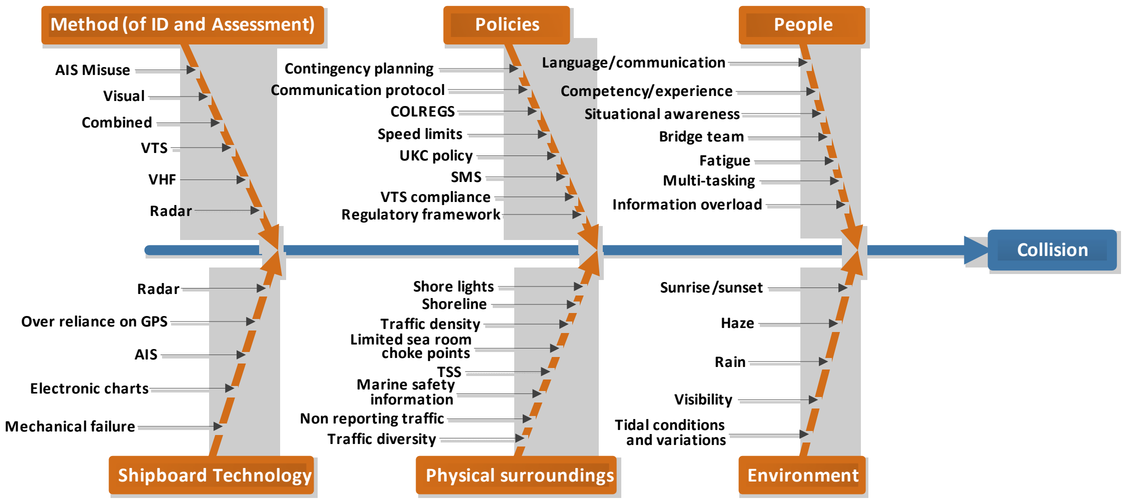

Figure 3 Fully Developed Fishbone Diagram

The complete list of hazards is presented in Table 5. A total of 55 hazards were identified, each being a unique combination of type/ category, risk factor and hazard.

Table 5: List of Risk Factors and Associated Hazards

Hazard ID	Type/ Category	Factor	Hazard
1	Human Factors	Visual	Failure of identification
2			Absence / incomplete assessment
3		Radar	Failure of identification
4			Absence / incomplete assessment
5			Multiple users, different setting preferences
6		Competence/ Capacity	Inattention
7			Divided attention
8			Numbers of targets
9			Lack of competence (wrong rules or inaccurate assessment)
10			Inappropriate delegation (BRM)
11			Unwillingness to speak up, power distance gap
12		AIS	Inappropriate user input, misuse
13		Language / Communication	Language barriers, personnel of different nationalities, Master-pilot exchange
14		Fatigue	Fatigue, leading to inappropriate analysis

Hazard ID	Type/ Category	Factor	Hazard
15		Situational awareness	Lack or inadequate situational awareness, Master-Pilot-Master exchanges
16		Information overload	Too much information to process, not paying attention to high priority tasks
17		Multi-tasking	Too many activities, leading to loss of focus on high priority tasks
18		Commercial pressures	Pressures to make ETAs, others
19		Vessel early, lots of time on hand	Slowing, loitering, loss of manoeuvring, loss of attention
20	Environmental	Rain	Effect on radar detection and assessment
21			Effect of visual detection and assessment
22		Currents	High currents, affecting situational awareness and potential manoeuvring
23		Proximity of navigational hazards	Reduced safe manoeuvring room
24		Haze	Effect on visual detection and assessment
25		Squalls	Reduced visual and radar detection, and manoeuvrability of vessel
26		Close proximity of anchorages and harbour areas	Short time to detect and assess
27		Tidal conditions/ variations	Similar to UKC
28	Physical surrounding	Density of marine traffic	Overloading, inadequate reaction time
29		Mix of marine traffic	Increases assessment difficulty
30		Background lighting (shore and anchorage)	Identification & assessment
31		Shore line (reclamation)	Ability to determine position independently, and changes to current
32		Limited sea room (choke points)	Potential reduced manoeuvring
33		Congestion (pilot boarding grounds)	Potential reduced manoeuvring, complicated interactions with other vessels
34		TSS & Precautionary area	Limitations of current TSS and precautionary areas
35		Marine safety information	Effect on passage plan
36		Non-reporting traffic	Cannot rely on VTS, cannot rely on them to comply with rules
37		Traffic diversity	Complexity of application of rules and manoeuvres
38	Shipboard Technology	Radar	Limitations of equipment
39		AIS	Limitations of equipment
40		Over reliance on GPS	Inadequate settings, no means to cross check
41		Electronic charts	Interfaces, updates and overlays
42		Mechanical failure	Inability to execute manoeuvre
43		Ship type and equipment	Manoeuvring capabilities and restrictions
44	Policies	COLREGs	
45		Speed limits	No speed limits for vessels other than VLCCs; lack of adequate space for manoeuvres
46		Under keel policy	Inadequate UKC, affecting manoeuvring

Hazard ID	Type/ Category	Factor	Hazard
47		SMS, including passage plans and contingency plans	Inadequate SMS, SMS not used properly
48		Regulatory framework	Inadequate, misunderstood, unforced regulatory framework
49		VTS regime	Advisory vs control, quality
50		Communications protocol	Congestion of communication, delays in getting information

The identified hazards were rated and ranked in accordance with the methodology described in Section 3.5.

Table 6 summarizes the risk rating and ranking of the hazards. In the table, the hazards are ranked in descending order of the likelihood of the hazard resulting in a collision scenariot, and the hazard descriptions include the type/category of the risk factor and descriptions of the hazardous scenarios presented in Table 5. As per the risk categorization scheme of Table 2, it is seen that two of the identified hazards were ranked as Extreme risk, 31 of the hazards were ranked as High risk and the remaining 17 were ranked as Medium risk. It is noted that the two hazards ranked as Extreme risk are human factors related issues involving lack of situational awareness or lack of competence.

Table 6: Hazards Ranked According to Likelihood to Result in a Collision Event

Hazard ID	Hazards	Risk Rating
15	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77
9	Human factors, Competence / capacity, Lack of competence (wrong rules or inaccurate assessment)	76
33	Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71
26	Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66
14	Human factors, Fatigue, Fatigue, leading to inappropriate analysis	65
17	Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64
30	Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64
47	Policies, SMS, including passage plans and contingency plans, Inadequate SMS, SMS not used properly	63
28	Physical surrounding, Density of marine traffic, Overloading, Inadequate reaction time	63
16	Human factors, Information overload, Too much information to process, Not paying attention to high priority tasks	63
1	Human factors, Visual, Failure of identification	62
32	Physical surrounding, Limited sea room (choke points), Potential reduced manoeuvring	61

Hazard ID	Hazards	Risk Rating
2	Human factors, Visual, Absence / incomplete assessment	61
4	Human factors, Radar, Absence / incomplete assessment	60
45	Policies, Speed limits, No speed limits for vessels other than VLCCs, Lack of adequate space for manoeuvres	60
6	Human factors, Competence / capacity, Inattention	59
34	Physical surrounding, TSS & precautionary area, Limitations of current TSS and precautionary areas	58
7	Human factors, Competence/ capacity, Divided attention	58
21	Environmental, Rain, Effect of visual detection and assessment	57
29	Physical surrounding, Mix of marine traffic, Increases assessment difficulty	56
44	Policies, COLREGs	55
48	Policies, Regulatory framework, Inadequate, misunderstood, Unenforced regulatory framework	55
42	Shipboard technology, Mechanical failure, Inability to execute manoeuvre	55
10	Human factors, Competence/ capacity, Inappropriate delegation (BRM)	54
18	Human factors, Commercial pressures, Pressures to make ETAs, others	54
8	Human factors, Competence / capacity, Numbers of targets	53
23	Environmental, Proximity of navigational hazards, Reduced safe manoeuvring room	53
50	Policies, Communications protocol, Congestion of communication, delays in getting information	53
3	Human factors, Radar, Failure of identification	53
13	Human factors, Language / communication, Language barriers, Personnel of different nationalities, Master-pilot exchange	53
20	Environmental, Rain, effect on radar detection and assessment	53
37	Physical surrounding, Traffic diversity, Complexity of application of rules and manoeuvres	52
49	Policies, VTS regime, Advisory vs control, Quality	52
24	Environmental, Haze, Effect on visual detection and assessment	49
25	Environmental, Squalls, Reduced visual and radar detection, and manoeuvrability of vessel	48
36	Physical surrounding, Non-reporting traffic, Cannot rely on VTS, Cannot rely on them to comply with rules	48
11	Human factors, Competence/ capacity, Unwillingness to speak up, Power distance gap	48
22	Environmental, Currents, High currents, affecting situational awareness and potential manoeuvring	48
41	Shipboard technology, Electronic charts, Interfaces, updates and overlays	45
38	Shipboard technology, Radar, Limitations of equipment	45

Hazard ID	Hazards	Risk Rating
31	Physical surrounding, Shore line (reclamation), Ability to determine position independently, Changes to current	43
40	Shipboard technology, Over reliance on GPS, Inadequate settings, no means to cross check	43
19	Human factors, Vessel early, lots of time on hand, Slowing, Loitering, Loss of manoeuvring, Loss of attention	43
43	Shipboard technology, Ship type and equipment, Manoeuvring capabilities and restrictions	43
27	Environmental, Tidal conditions/ variations, Similar to UKC	42
39	Shipboard technology, AIS, Limitations of equipment	40
12	Human factors, AIS, Inappropriate user input, Misuse	39
5	Human factors, Radar, Multiple users, different setting preferences	38
35	Physical surrounding, Marine safety information, Effect on passage plan	38
46	Policies, Under keel policy, Inadequate UKC, affecting manoeuvring	35

In order to provide meaningful discussion of risk control options and for judicious use of resources, it was decided to focus on the top 10 ranked hazards for risk control. The selected hazards are shown highlighted in cyan in **Table 6** , and include hazards with risk rating scores of 63 or higher.

4.2 RCOs

Table 7 provides a list and description of 31 RCOs identified by the workshop participants. In the table, the RCOs are listed in order of ease of implementation, from easiest to the most difficult, in accordance with the methodology described in Section 3.6. It is seen that the 3 green lights night signal RCO was ranked in the top seven RCOs that were considered easy to implement. The majority of the RCOs were considered to be moderately difficult to difficult in terms of implementation.

Table 7: RCO Ranked According to Ease of Implementation

RCOs	Description	RCO Rating
Day shapes	Day shapes associated with night signals	6
Anchors ready for use		7
New navigation lights	3 green lights for crossing vessels	9
Readiness of machinery, including thrusters, for immediate manoeuvring		10
Dedicated lookout		12
Passage planning guide (mandatory)	Specific passing guide compulsory for Singapore and Malacca Straits	22
Bridge resource management	Improved composition and interaction of bridge team	25
AIS message	Special message to indicate crossing vessels	27
Penalty for non-compliance	Enforced through flag state	29
VTS procedures	Ship operational data, link to port operations for reduced communications (pilot boarding changes)	29

RCOs	Description	RCO Rating
Aids to navigation	Review characteristics of navigation aids to facilitate identification	29
Pilotage non-compulsory (advisory service)	Make compulsory for certain vessel types	30
Silent VTS	Reduce amount of radio communications, potential to switch to aircraft mode	31
Pilot boarding ground	Reduce congestion at pilot boarding ground, improve pilot-master exchange, provide 1 mile separation zone	31
Duplex plus VTS	Duplex communication between ship and VTS	36
Proactive VTS control	Strong advice, not full control	36
Manning	Size and composition of bridge team, e.g. dedicated Lookout	37
Competent crews	Increasing quality of assessment and implementing the rules	40
Escort tugs	Escort tugs at critical areas	41
Other means of communications	Ship-to-ship communication, to reduce "noise", other radio channels or AIS messaging	41
Policies / Procedures		42
Separation distances between vessels	Set separation distances depending of ship types	42
Pilotage compulsory		44
Tether tugs	Tugs assist for critical areas, e.g. at blind sectors	44
Laser lights	Laser lights to get attention of other vessels	46
Radar transponder		47
Regulations		49
No overtaking zones	No overtaking at critical and precautionary areas	49
Speed limits for ships other than VLCC	Provide speed limits for critical and precautionary areas	52
Remove radar blind sector	Ships utilizing VTS to know what is in their blind sectors	58
Positive VTS control	VTS controls, and provides directions	65

Again, for judicious use resources and to provide meaningful discussion of the effectiveness of the RCOs, it was decided to focus on the top 11 ranked RCOs, which had a score of less than 30 on the RCO rating scheme. These RCOs are highlighted in cyan in Table 7.

The effectiveness of the selected RCOs was determined by comparing the risk levels of applicable hazards pre- and post-RCO implementation. For instance,

Table 8 shows the case of the 3 green lights night signal RCO. The aggregated risk scores following potential implementation of the RCO are compared with the originally obtained risk scores and the percent reduction in risk score for each applicable hazard is presented in the last column. Assuming, for purposes of this analysis, that we are interested in reducing / eliminating the top 10 ranked hazards, then the weighted percent risk reduction for the RCO can be obtained by multiplying each percent risk reduction by 0.1 and summing up for all applicable hazards. Thus, the weighted percent risk reduction for the 3 green lights night signal is obtained as 19%. The percent risk reduction for other RCOs are obtained similarly as shown in the detailed HAZID worksheet tables in Appendix 2B.

Table 8: Effectiveness of 3 Green Lights Night Signal RCO to Control Selected High & Extreme Risk Hazards

RCO	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
New navigation lights	3 green lights for crossing vessels	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	48	37.3
		Human factors, Competence / capacity, Lack of competence (wrong rules or inaccurate assessment)	76	62	18.4
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	56	20.8
		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	48	28.1
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	42	33.4
		Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64	55	14.7
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	52	17.5
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	52	16.7

Table 9 shows the weighted percent risk reduction for the top RCOs, ranked according to percent risk reduction from highest to lowest. It is interesting to note that the 3 green lights night signal RCO provides the highest percent risk reduction. This is not surprising given, for example, the fact that the hazard posing the highest risk involves lack of situational awareness, and the use of the 3 green lights night signal is specifically intended to provide clarity on the intentions of crossing vessels.

Table 9: Top RCOs Ranked According to Effectiveness to Control Top Ten Ranked Hazards

RCOs	Percent Reduction of Top 10 Ranked Hazards
New navigation lights	19%
Day shapes	15%
Bridge resource management	13%
Dedicated lookout	11%
Passage planning guide (mandatory)	8%
Penalty for non-compliance	8%
VTS procedures	8%
Aids to navigation	7%
AIS message	6%
Readiness of machinery, including thrusters, for immediate manoeuvring	6%

RCOs	Percent Reduction of Top 10 Ranked Hazards
Anchors ready for use	5%

It is important to note that although the analysis presented focuses on the top RCOs to control the top ranked hazards, these RCOs can also be applicable in controlling hazards other than the top 10 hazards. Furthermore it should also be noted that RCOs other than those considered in the analysis may also be applicable in controlling the top 10 or other hazards. In this sense, the overall list of RCOs presented in Table 7 can be regarded as a log of RCOs from which suitable ones can be selected to address any hazard of concern.

4.3 Need for Day Signals

The workshop brainstormed and discussed the need for day signals to correspond with the 3 green lights signal. The significant highlights of these discussions are presented below.

The participants noted that there is limited usefulness of existing day signals used under collision regulations. Day signals are difficult to see against mast or at a distance.

There is currently provision in the International Code of Signals, Chapter 2 Section 3 for a hoist of signal flag LZ1 indicating “I intend to pass through the channel/fairway”.

For the use of such signal flags no regulatory change is required although mariners may require a reminder to use it regularly in such TSS circumstances.

Using a day signal, whether a normal day signal or flags, requires sending someone to physically raise, and shortly thereafter lower, it. This means depleting the bridge team at a critical navigational juncture or calling someone out for a very short duration assignment. In the case of vessels crossing a TSS the signal would only be used for a short time. Given the option, many bridge teams may choose to not utilize the signal.

Flags have limited utility. They may wrap around halyard or may be pushed by wind to a direction they can’t be seen, and require resources from the bridge team at the critical time for raising and lowering them.

Sound signals have limited utility. If there are several vessels ahead and several behind, it will be difficult to determine who made a given sound signal. This would, in general, only give an indication that someone is crossing. However, generally knowing that someone is crossing TSS is not as useful as knowing who is crossing. Furthermore, manoeuvring sound signals tend to be used very close to the time of executing the manoeuvre so little advantage is gained with respect to signalling intent in advance.

Flashing high intensity green strobe light could be another type of day signal. They are easy to see, different from other signals and temporary in nature. They are easy to turn on/off with little distraction. Consensus was that a high intensity green strobe would suit the purpose.

This generated a discussion as to whether a high intensity green strobe would be a suitable signal for both day and night crossings. The general consensus was mixed:

- Some vessels can use existing navigation lights on their mast simply by changing lenses to meet the 3 green light configuration, but would require a new installation for the strobe.
- Some ships only show 2 lights now due to space limitations. Some will struggle to achieve the required vertical separation of lights.
- A strobe for daytime signalling may require some technical work to achieve an appropriate specification, which may delay implementation.

- A high intensity strobe was generally felt to be potentially too distracting at night with most favouring it for daylight use only.

Some barriers to implementation were identified:

- Strobe lights can be a challenge for cost and time implementation.
- COLREG Rule 36 does not allow use of strobe lights as means of signal to attract attention.
- Ships currently do not have it and no international specifications exist for the light being contemplated.

Following specifications may be considered for the flashing green light:

- High intensity flashing all-round green light. This could be similar to existing COLREG Rule 23 (c) which requires WIG craft to exhibit similar light but in red colour.
- Specification of all-round light and frequency of flashing may be considered in line with existing COLREG Rule 21 (e) and (f) – showing unbroken light over an arc of the horizon of 360 degrees and light flashing at regular intervals at a frequency of 120 flashes or more per minute. The High intensity light should be visible at least from a distance of 3 miles during day light.

In summary, although the risk workshop participants found great utility in the three green lights as a night signal they did not feel that a corresponding day signal, as per the collision regulations, was either appropriate or useful. The difficulty in identifying day signals, coupled with the necessity of detailing a person to hoist a signal for a limited time during a critical navigational juncture was deemed not to be a useful measure for risk reduction. The participants showed a strong preference for trying a high-intensity green strobe light as a day signal provided appropriate technical specifications could be developed. Such a light could be easily switched on and off by a member of the bridge team with a minimum of distraction and could serve as an indication of, or intent to, cross the traffic separation scheme. However, as COLREGs does not allow high intensity flashing light for attention, at present the most feasible option would be to enforce the use the signal flag LZ1 indicating "I intend to pass through the channel/fairway" as per International Code of Signals, if considered necessary.

4.4 Other Issues

The workshop discussed other issues, including global implementation of the RCO measures. The significant highlights of these discussions are presented below.

4.4.1 Global Issues

Highlights of discussions regarding global implementation of the three green lights night signal include the following:

- In Japan large vessels (greater than 200 m long) exhibit a green flashing light.
- Having the three green light signals will be beneficial as all ships would be fitted. Therefore vessels not previously operating in Singapore Strait will not be faced with making a decision on whether to have the three green lights fitted should they decide to operate in the Singapore Strait at a later time.
- The use of the three green lights night signal may affect other jurisdictions with respect to local rules. For instance, Germany may already be using 3 green lights for other purposes.
- There is potential for confusing the 3 green lights signal with that for a minesweeper (three green lights in triangular formation) in certain times or configurations.
- If a vessel is constrained by draught and is crossing it would have 3 red and 3 green which some may see as problematic particularly with regards to confusion with a dredge.
- Small craft may not have sufficient vertical separation for the three green lights.

4.4.2 Sound Signal

The question was asked of the participants whether vessels crossing a TSS should use a special sound signal. The consensuses was No. The vessels are executing a normal manoeuvre and should use the current manoeuvring signals from the collision regulations. The ship is not a priority ship and therefore should just be considered as executing a manoeuvre.

4.4.3 Other RCOs from List

The following RCOs: anchors, readiness of machinery, and dedicated lookouts, all fold into mandatory carriage and usage of Malacca and Singapore passage planning guide and rules. Participants see this as a document that advises on deep water routes, choke points, cautionary areas, places where overtaking is problematic, special advice for towing etc. It is seen as a combination of coastal pilot and guidance. Ideally it would provide templates for users for passage planning. It could be modelled on or included as a minimum the information in the BIMCO guide. Participants were in favour of a regulatory change requiring the mandatory carriage of the guide as it could then be enforced under the Port State Control inspection regime.

The RCO AIS message was considered to be not effective in Singapore Strait, given the high traffic volume and the fact that navigation officers already heavy workload.

Messaging to VTS via AIS could be useful to reduce radio traffic by removing the need to call in and confirm arrival at check in points or sector changes.

It may be useful to provide manoeuvring lights more than once during a manoeuver. Perhaps have the requirement to make the signal prior to executing a manoeuvre and again when executing the manoeuvre or some method of extending the time over which the signalling is carried out to improve the probability of detection.

5. Summary and Conclusions

This study was undertaken as part of the formal safety assessment (FSA) for the use of three green lights night signal for vessels crossing the traffic separation scheme (TSS) and precautionary areas in the Singapore Strait. The main objective of the study was to elicit expert opinion on the hazards that are causes of, or contributing factors to, collisions in the Singapore Strait TSS and to examine risk control options. This report informs FSA Step 1 - Identification of hazards; Step 2 - Risk analysis; Step 3 - Risk control options.

A systematic hazard identification (HAZID) exercise of hazards leading to collisions in the Singapore Strait was undertaken using the collective knowledge and experience of various stakeholders, including MPA, APL Co. Ltd, BWFM Singapore, Eastern Pacific Shipping Pte Ltd, AET Ship Management Singapore PTE Ltd, Singapore VTIS, PSA Marine, Pacific International Lines PTE Ltd, and LRA. The workshop was conducted at the facilities of Lloyd's Register Asia, Singapore offices at 460 Alexandra Road, #28-01/02 PSA Building, Singapore 119963, on October 20-21, 2014.

Six types /categories of causal factors were identified, namely (a) human factors; (b) environment; (c) physical surrounding; (d) shipboard technology; (e) policies; and (f) method (of identification and assessment), and were used to develop a hazards list. A total of 50 hazards were identified, each being a unique combination of type / category, risk factor and hazardous scenario. The identified hazards were rated (on a scale of 0-100) and ranked in decreasing order in terms of the likelihood of the hazards resulting in a collision scenario. As per the risk categorization scheme used in the study, two of the hazards were ranked as Extreme risk, 31 of the hazards were ranked as High risk and the remaining 17 were ranked as Medium risk. It is noted that the two hazards ranked as Extreme risk are human factors related issues involving lack of situational awareness or lack of competence. The top ranked hazards, with risk rating scores of 63 or higher were selected for risk control.

A total of 31 RCOs were identified in the study, and first rated in terms of their ease of implementation, on a scale of 0-100 (100 indicating highest difficulty in implementation). The 3 green lights night signal RCO was ranked in the top seven RCOs that were considered easy to implement. The majority of the RCOs were considered to be at least moderately difficult to implement. The effectiveness of RCOs which had a score of 30 or less on the RCO rating scheme was assessed. This involved comparing the risk levels of applicable hazards pre- and post-RCO implementation, and computing the percent reduction in the risk rating. For each RCO, a weighted percent risk reduction, which accounts for the fraction of applicable High and Extreme Risk hazards with respect to the total number of High and Extreme Risk hazards considered in the study, was computed. The 3 green lights night signal RCO had the highest weighted percent risk reduction of 19%. This is not surprising given the fact that the hazard posing the highest risk involves lack of situational awareness, and the use of the 3 green lights night signal is specifically intended to provide clarity on the intentions of crossing vessels.

The workshop participants discussed the need for corresponding day signals to the three green lights for nighttime. It was noted that there is limited usefulness of existing day signals used under collision regulations. Day signals are difficult to see against mast or at a distance. In the case of vessels crossing a TSS the signal would only be used for a short time, and would require sending someone to raise it, and shortly thereafter to lower it. This means depleting the bridge team at a critical navigational juncture or calling someone out for a very short duration assignment. Given the option, many bridge teams may choose to not utilize the signal.

The use of flags was also discussed and considered to have limited utility, as they may wrap around halyard or may be pushed by wind to a direction they can't be seen, and it requires resources from the bridge team at critical time for raising and lowering.

Sound signals were also considered to have limited utility. If there are several vessels ahead and several behind, it would be difficult to determine who made sound signal. This would, in general, only give an indication that a vessel is crossing, but not necessarily which vessel is crossing.

The workshop participants showed a strong preference for trying a high-intensity green strobe light as a day signal provided appropriate technical specifications could be developed. Such a light could be easily switched on and off by a member of the bridge team with a minimum of distraction and could serve as an indication of, or intent to, cross the traffic separation scheme. However, as COLREGs does not allow high intensity flashing light for attention, at present the most feasible option would be to enforce the use the signal flag LZ1 indicating "I intend to pass through the channel/fairway" as per International Code of Signals, if considered necessary.

6. References

1. Revised Guidelines for the Formal Safety Assessment, MSC-MEPC.2/Circ.12, IMO, 2013
2. MPA Port Marine Circular, Circular No. 4, 2013
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4. http://www.news.gov.sg/public/sgpc/en/media_releases/agencies/mpa/press_release/P-20091028-2/ImagePar/0/image/Figure%201.JPG
5. FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait – Terms of Reference for Risk Workshop, LRA Technical Report No. TR-SNG-1404102/01, October 2014.

7. Appendix 2A: Brief Resumes of Participants

Name	Organization	Present Position	Brief Resume
Capt. Jia C. Chong	MPA	Senior Marine Officer	Currently in charge of operations in Singapore Port Operations Control Centre to ensure monitoring of shipping traffic for the purpose of enhancing navigation safety. Previous experience includes Senior Officer onboard cargo ships; and Fleet Manager.
Henry Heng	MPA	Assistant Director	Head of Vessel Traffic Management Department. 4 years of command experience and a total 17 years sailing on board merchant vessels with A P Moller(S) Pte Ltd. 19 years with MPA – 16 years with Port Master's Dept and 3 years with Port Policy Dept.
Irinjalakuda G Sangameswar	MPA	Senior Marine Officer	Training of VTS personnel in line with international and national standards. Senior officer on board merchant cargo vessels, responsibilities include safe navigation, cargo operations as well as personnel management.
Brijesh Tewari	LRA	Marine Consultancy Services Manager	B.E. Marine; and MBA. 27 years marine experience. Currently leading the consultancy team and managing, delivery of marine consultancy services. Served at sea as a Marine Engineer progressing to the rank of Chief Engineer.
Samshul Huda	LRA	Risk Specialist	Class One Certificate of Competency from Maritime and Coast Guard Agency, UK. Over 20 year's marine experience. Worked onboard various types of ocean going vessels as watch keeping engineer, and later promoted to Chief Engineer.
Capt. David Cheong	LRA	Manager, Marine Management Systems	Served with Neptune Shipmanagement Services Pte Ltd (NSSPL) from 1983 till 2006. At various levels of rank up to Chief Officer, served on worldwide bulk carrier and container trade. As Master, served on various classes of containerships (feeders to post-panamax class), trading worldwide. Was posted on shore attachment to NSSPL's Safety, Quality and Environmental Dept as Marine Superintendent.
Tamunoiyala Koko	LRA		PhD structural mechanics. 25 years' engineering experience. Expert in risk assessment methodologies. Technical lead and facilitation of risk assessments for marine vessel designs and operations
Capt. Jack Gallagher	Hammurabi Consulting	Owner & Principal	Master Marine Certificate of Competence, over 35 years marine experience. Previously worked for Canadian Coast Guard rising to Director of Operations Maritime Provinces. Current Owner and Principal of Hammurabi Consulting, focusing on navigation and other marine risks.
Mr. Peng ChuXing	APL Co. Ltd	Head, Marine Safety Department / DPA (NSSPL	Currently, Head, Marine Safety Department, DPA, NSSPL Previous experience include: Ship Master; Port State Control officer (MPA); Marine Safety Investigator (MPA); Loss Prevention Executive (Ship Owners' P&I Club).
Capt. Franz G Klassen	APL Co. Ltd	Manager, Fuel Strategy	Master Mariner, Class 1 (Unlimited) with almost 40 years sailing experience and 26 years as a Captain on Bulk Carriers, Container and Offshore vessels. As a marine superintendent, he is familiar with contractual agreements, between shippers / charterers and owners, as well as ship-management.
Amit Nandrajog	BWFM Singapore	Head of Marine, BWFM Singapore	Marine Manager and Superintendent at BWFM; Master Mariner, sailed on VLCCs and product carriers.
Navneet Singh	BWFM Singapore	Head of Marine, BWFM Singapore	Master Mariner, sailed on VLCCs and product carriers.
Mircea Ionut Comanici	Eastern Pacific Shipping Pte. Ltd	Captain	Sailing Master on Chemical Tankers, Operations Superintendent, Marine Superintendent, Vetting Coordinator.

Name	Organization	Present Position	Brief Resume
Capt. Nabo Kumar Ghosh	Eastern Pacific Shipping Pte. Ltd	Manager, Navigation & Training	Training Manager, NYKSM Master Mariner, NYKSM.
Capt.Sivasubramaniam Ganesan	AET Ship Management Singapore PTE LTD	Senior Manager HSSE operations	DPA , CSO , Marine Superintendent , Audit and Training Superintendent , Regional Manager – AET UK Master on STS and product tankers.
Capt. P.U. Sarma	AET Ship Management Singapore PTE LTD	Navigation & DP Superintendent	Focal point on navigation and DP related matters; ensuring SMS procedures with respect to DP and conventional navigation are consistent with the best practices within the industry. 7 years of Command, 5 years as company's internal auditor.
Capt. Ramakrishnan Aravazhi	Singapore VTIS	Training of VTS personnel	Senior officer on board merchant cargo vessels, responsibilities include safe navigation, cargo operations as well as personnel management
Mohammad Jamal	Singapore VTIS	Senior VTS officer in Singapore VTIS	Joined Singapore VTIS since 2008.
Capt. Wong Yoong Siong	PSA Marine	Master Pilot (Pilotage)	Master Mariner
Capt. Benedict Tan Hung Ching	PSA Marine	Senior Manager (Pilotage)	Master Mariner
Capt. Edward Abban	Pacific International Lines PTE Ltd	DPA/CSO for PIL, Assistant Gen Manager & HoD, Quality, Safety & Security Dept.	Fleet Training Manager; Shipboard Training Supt. and Auditor; Master Mariner; years of command experience on container vessels

8. Appendix 2B: Effectiveness of RCOs to Control Selected High and Extreme Hazards

Option	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
New navigation lights	3 green lights for crossing vessels	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	48	37.3
		Human factors, Competence/ capacity, Lack of competence (wrong rules or inaccurate assessment)	76	62	18.4
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	56	20.8
		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	48	28.1
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	42	33.4
		Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64	55	14.7
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	52	17.5
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	52	16.7
Day shapes	Day shapes associated with night signals	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	55	28.1

Option	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
		Human factors, Competence/ capacity, Lack of competence (wrong rules or inaccurate assessment)	76	64	15.3
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	57	19.9
		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	56	14.8
		Human factors, Fatigue, Fatigue, leading to inappropriate analysis	65	56	13.8
		Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64	57	10.9
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	50	21.7
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	53	16.3
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	57	9.2
VTS procedures	Ship operational data, link to port operations for reduced communications (pilot boarding changes)	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	65	15.3
		Human factors, Competence/ capacity, Lack of competence (wrong rules or inaccurate assessment)	76	67	11.2
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	56	21.6

Option	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	60	9.2
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	59	6.9
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	53	15.0
Passage planning guide (mandatory)	Specific passing guide compulsory for Singapore and Malacca Straits	Human factors, Competence/ capacity, Lack of competence (wrong rules or inaccurate assessment)	76	57	24.0
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	59	17.4
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	62	2.8
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	56	10.8
		Policies, SMS, including passage plans and contingency plans, Inadequate SMS, SMS not used properly	63	49	22.5
Anchors ready for use		Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	69	10.0
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	64	9.6
		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	56	14.8

Option	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	53	15.8
Aids to navigation	Review characteristics of navigation aids to facilitate identification	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	66	14.4
		Human factors, Competence/ capacity, Lack of competence (wrong rules or inaccurate assessment)	76	71	6.3
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	65	8.2
		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	57	13.8
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	54	15.0
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	60	4.4
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	58	7.8
AIS message	Special message to indicate crossing vessels	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	65	15.6
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	63	11.1
		Human factors, Fatigue, Fatigue, leading to inappropriate analysis	65	57	11.4

Option	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
		Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64	59	8.5
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	58	8.8
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	57	9.0
Dedicated lookout		Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	60	22.2
		Physical surrounding, Congestion (pilot boarding grounds), Potential reduced manoeuvring, complicated interactions with other vessels	71	64	10.5
		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	57	13.5
		Human factors, Fatigue, Fatigue, leading to inappropriate analysis	65	56	13.2
		Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64	55	14.6
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	54	15.5
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	56	11.9
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	54	13.5

Option	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
Bridge resource management	Improved composition and interaction of bridge team	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	54	30.1
		Human factors, Competence/ capacity, Lack of competence (wrong rules or inaccurate assessment)	76	52	31.6
		Human factors, Multi-tasking, Too many activities, leading to loss of focus on high priority tasks	64	49	23.5
		Policies, SMS, including passage plans and contingency plans, Inadequate SMS, SMS not used properly	63	50	21.2
		Human factors, Information overload, Too much information to process, not paying attention to high priority tasks	63	50	20.6
Readiness of machinery, including thrusters, for immediate manoeuvring		Environmental, Close proximity of anchorages and harbour areas, Short time to detect and assess	66	43	34.7
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	44	30.1
Penalty for non-compliance	Enforced through flag state	Human factors, Situational awareness, Lack or inadequate situational awareness, master-pilot-master exchanges	77	62	19.1
		Human factors, Competence/ capacity, Lack of competence (wrong rules or inaccurate assessment)	76	56	26.2
		Human factors, Fatigue, Fatigue, leading to inappropriate analysis	65	56	12.7
		Physical surrounding, Background lighting (shore and anchorage), Identification & assessment	64	59	6.8

Option	Description	Applicable High/Extreme Risk Hazards	Risk Rating (w/o RCO)	Risk Rating (w/ RCO)	Risk Reduction (%)
		Physical surrounding, Density of marine traffic, Overloading, inadequate reaction time	63	55	12.3

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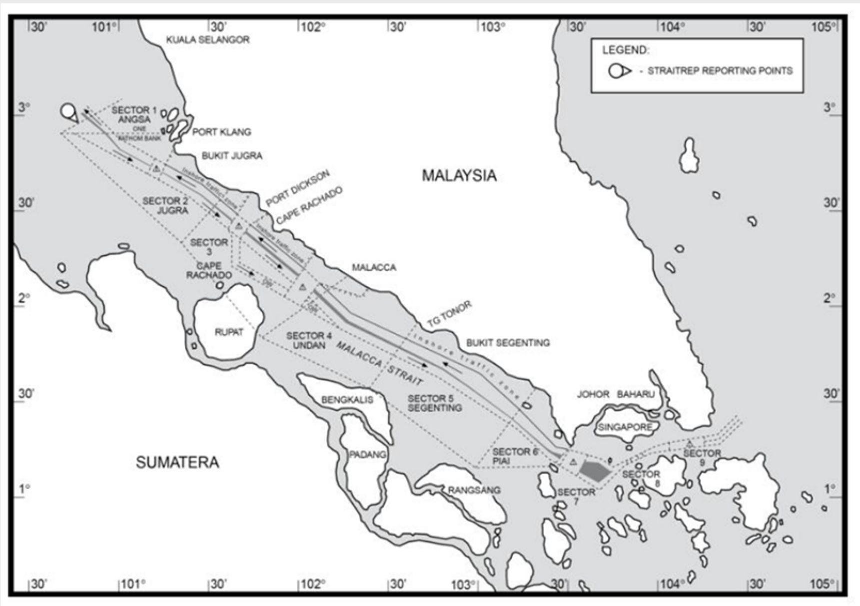
FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait

Part 3: Traffic Simulation / Analysis

February 20, 2015



Summary

FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait

Part 3 - Traffic Simulation / Analysis

Technical Report No.:	Revision:	Date:
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Executive Summary

In support of the Singapore MPA initiated "FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait", traffic and incident data have been surveyed and presented here for three international areas of interest. In addition to the Singapore Strait area, the San Francisco Bay area and the English Channel between Dover and Calais were considered.

This report documents the processing measures applied to the traffic data to generate an historical simulation of vessel transits, and an analysis of the outputs is presented. In general terms, the traffic simulation has indicated the relative traffic volumes between the three regions, with the Singapore Strait indicated as the highest trafficked, followed by the English Channel area and finally the San Francisco Bay area. Results are presented in the document detailing the relative contributions of various traffic types to the totals for each area, and also illustrating their densities within the area. Rates of travel within the Traffic Separation Schemes of each area are computed to determine the extent to which crossings may be expected to be an issue. For the Singapore area, extrapolations on these rates have been developed using predictions from literature, which suggest that the waterway might be reaching the upper bounds of its effective capacity within the near (10 year) term. This observation underlines the need to ensure the safety of all vessels given that there are vessels crossing this extremely busy area.

As a supplement to the simulation and review of vessel traffic in the areas under consideration, a survey was made of collision incidents in each of the three areas considered, and the results presented. Notable numbers of collisions occurred in all areas, several of which under conditions which match those intended to be mitigated by a measure such as the "three green lights" signal.

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Glossary and Acronyms

AIS	Automatic Identification System
AOI	Area of Interest
ENC	Electronic Nautical Chart
FSA	Formal Safety Assessment
GIS	Geographic Information System
GPS	Global Positioning System
HAZID	Hazard Identification
IMO	International Maritime Organization
km	Kilometre
LRA	Lloyd's Register Asia
MISLE	Marine Information for Safety and Law Enforcement
MMSI	Maritime Mobile Service Identity
MPA	Maritime and Port Authority of Singapore
RCO	Risk Control Option
TSS	Traffic Separation Scheme
UK MAIB	United Kingdom Marine Accident Investigation Branch
UK MCA	United Kingdom Maritime and Coastguard Agency
UKCG	United Kingdom Coastguard
USCG	United States Coastguard

1 Introduction

1.1 Background

This report has been prepared to describe the simulation and analysis of marine traffic data in support of the Hazard Identification (HAZID) process being conducted by LR Martec for the Singapore Maritime and Port Authority (MPA). This HAZID process is one component of a broader Formal Safety Assessment (FSA) - "FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait". This FSA, at its core, examines the utility and feasibility of more broadly applying the Singapore MPA "3 green lights" signal [1] (on its own and versus other measures) to mitigate collision risk between vessels within Traffic Separation Schemes (TSS) and those vessels seeking to cross such TSS. The FSA methodology [2] comprises five steps:

1. Identification of hazards;
2. Risk analysis;
3. Risk control options;
4. Cost benefit assessment ; and
5. Recommendations for decision making

This report is primarily concerned with step 1, but also serves to inform step 2.

In conducting the traffic simulation component of the HAZID, three geographic areas were chosen for analysis. The primary area was the Singapore Strait, being of direct interest to the project owners, as well as being an extraordinarily high volume TSS with frequent crossing situations and impediments to visibility noted. The other two areas, the English Channel between Dover and Calais and San Francisco Bay, were chosen based on a number of factors, including: traffic volume (along- and cross-track), lighting conditions, and availability for simulation within the proposed bridge simulation environment for watch keeper assessment.

The goal of this simulation and analysis is to inform the HAZID as to the extent of the crossing issue within the areas under consideration, particularly for along and across TSS traffic density, as well as areas of concern. Historic collision incidents in the three areas of interest are reviewed, where available, in the context of the traffic data to determine if any conclusions can be drawn from comparing the two data sources.

1.2 Areas of Interest

The three areas of interest to this work include the Singapore Strait, the San Francisco Bay area and approach, and the English Channel, particularly between Dover and Calais.

With respect to this traffic simulation effort, the Singapore Strait AOI has been defined more specifically as bounded by meridians 103.71 and 104.08 east longitude and parallels 1.12 and 1.32 north latitude. These boundaries, as well as two areas denoted by Singapore MPA as being of particular concern, are shown in Figure 1 included here. Of the three areas under study, the Singapore Strait AOI is the smallest in extent, but also the most complex in terms of traffic features and the highest in traffic volume. The AOI (as depicted in Figure 1) is roughly 40 kilometres from east to west, and just over 20 kilometres from north to south. A TSS with two major traffic lanes runs east-west through the centre of the AOI, with the East to West lane north and the West to East lane to the south. To the northwest of the AOI lies the port of Singapore, with a number of traffic lanes leading away from the primary TSS to serve the port. Additionally, outside the port area proper and to its east lies a large anchorage area, which is also to the north of the TSS. Within this configuration of the area, the primary traffic features are the east-west running traffic along the identified traffic lanes, traffic turning between these lanes and areas north of the lanes to head to or from the Port of Singapore / anchorages, and ferry traffic crossing the lanes north-south directly between ports on either side.

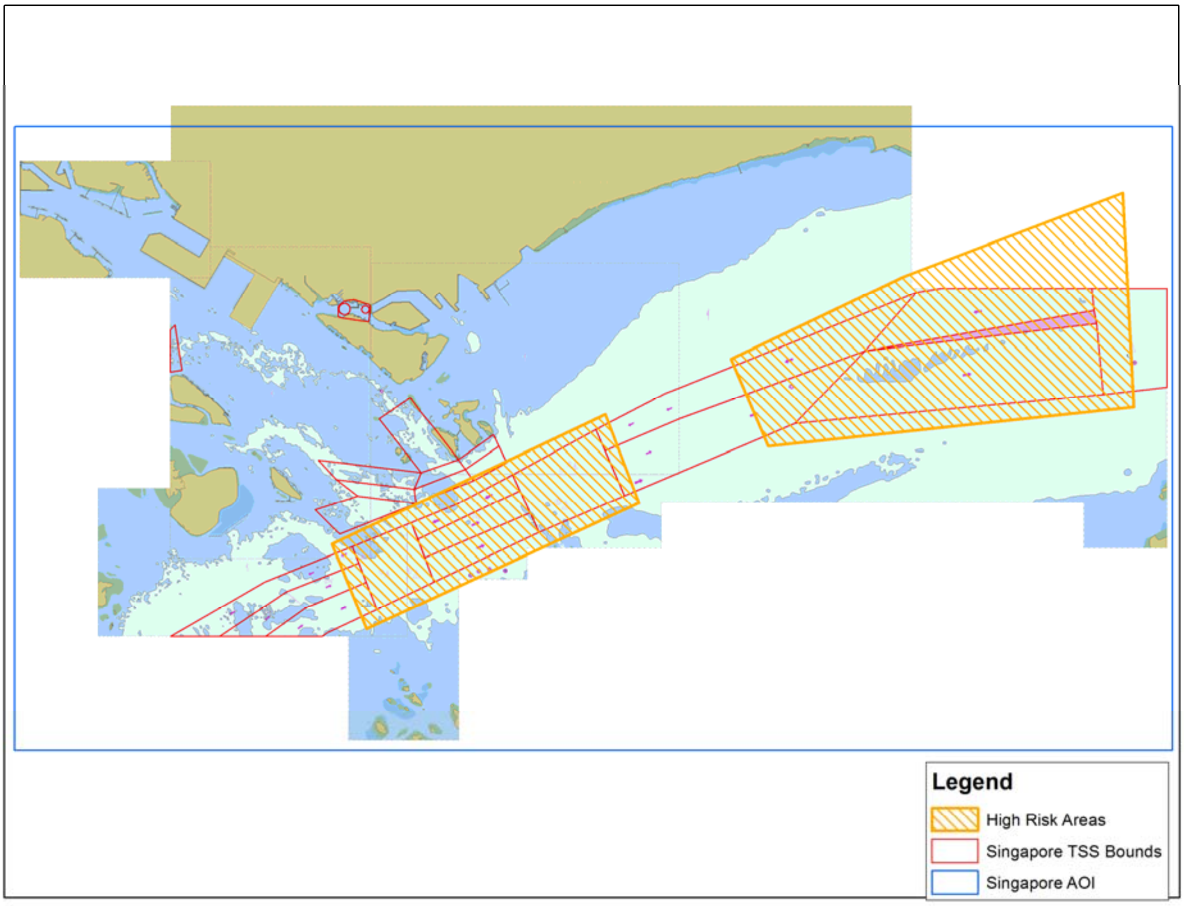

Figure 1 - Singapore Strait AOI

The AOI in the vicinity of the San Francisco Bay area includes the region bounded by the meridians 121.9 and 123.5 west longitude, and the parallels 37.311833 and 38.169 north latitude. This region is depicted in Figure 2. In the San Francisco Bay area, an AOI was defined to include both the Inner Bay area, and the approach to the Bay, including the established TSS (see Figure 2), extending approximately 140 kilometres east to west and 95 kilometres north to south. This area was the least trafficked of the three studied, possibly because, unlike the other areas, it served more as a destination (port) rather than a route between destinations. At the west of the AOI, a TSS directs traffic into and out of the Bay Area. The TSS is composed of three sets of traffic lanes heading northwest-southeast, southwest-northeast, and south-north, into a central precautionary area hub, before extending east-west into the Bay under the Golden Gate Bridge. In addition to this TSS outside the Bay a smaller, roughly square, precautionary area exists along the San Francisco waterfront, alongside the San Francisco - Oakland Bay Bridge. Traffic approaching the area is generally constrained to the TSS, and then bottlenecked in the Golden Gate Bridge area. From this point, traffic then fans out to destinations in San Francisco, Oakland, Richmond, San Rafael and points north through the Carquinez Strait.

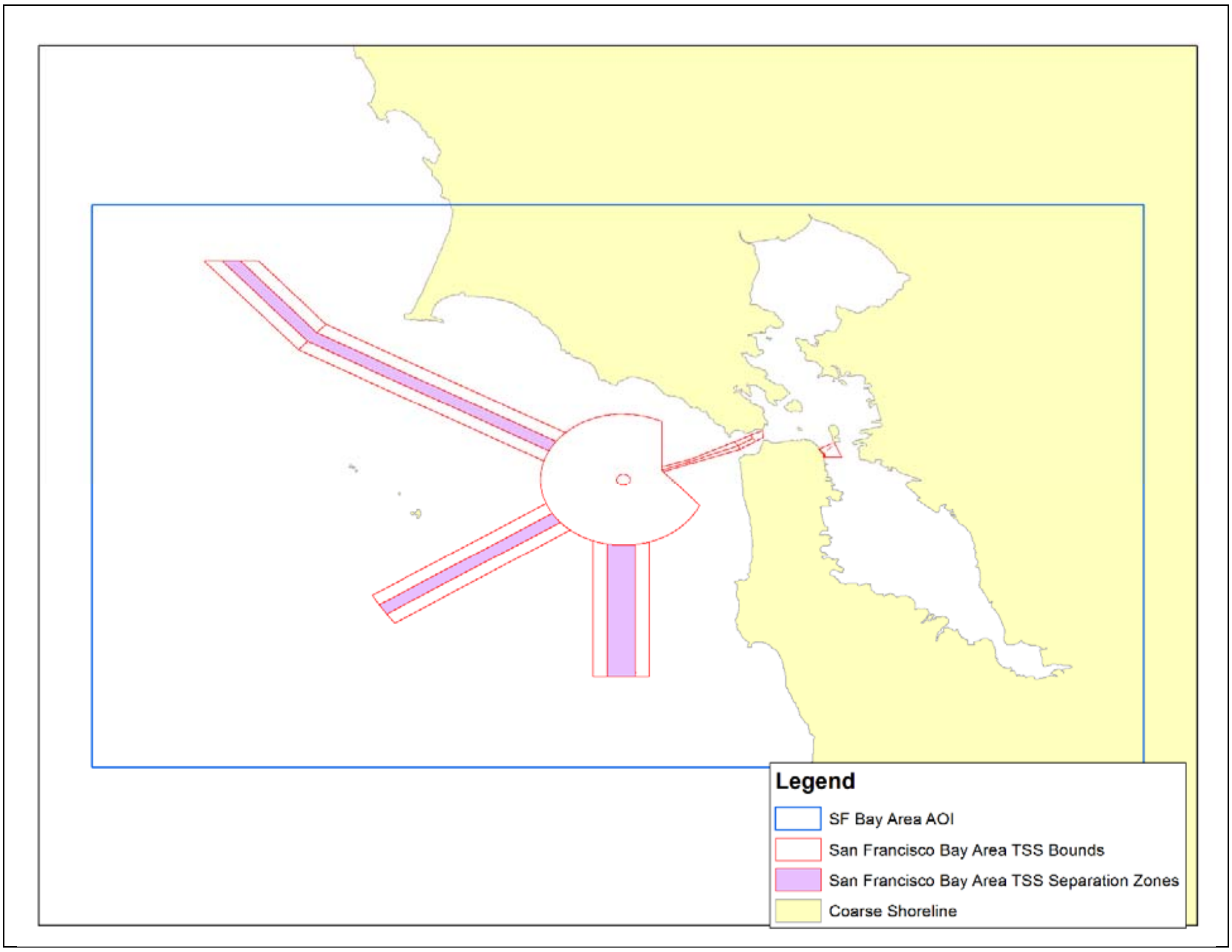

Figure 2 - San Francisco Bay AOI

To address the English Channel TSS area, while avoiding the near shore traffic, an irregular AOI was drawn, roughly parallel to the south-west to north-east channel orientation. This AOI is defined as the polygon bounded by the four longitude, latitude coordinate pairs (East, North positive), proceeding clockwise from the northernmost point: {1.966, 51.920}, {3.075, 51.450}, {0.899, 49.942}, {-0.033, 50.724}. An illustration of this AOI in context is included here. The English Channel AOI was the largest area examined in this study. The irregular AOI defined (displayed in Figure 3), runs approximately 200 kilometres along the TSS central axis and extends 100 kilometres wide along this length. The TSS in the area primarily describe northeast to southwest lanes between the North Sea and the southern extent of the English Channel. A branch to the TSS also runs east toward the Netherlands. Almost all traffic in this region travels along the northeast-southwest running lanes. A smaller portion splits from this route to head east-west through the TSS branch, while a number of vessels also cross the TSS directly between Dover and Calais.

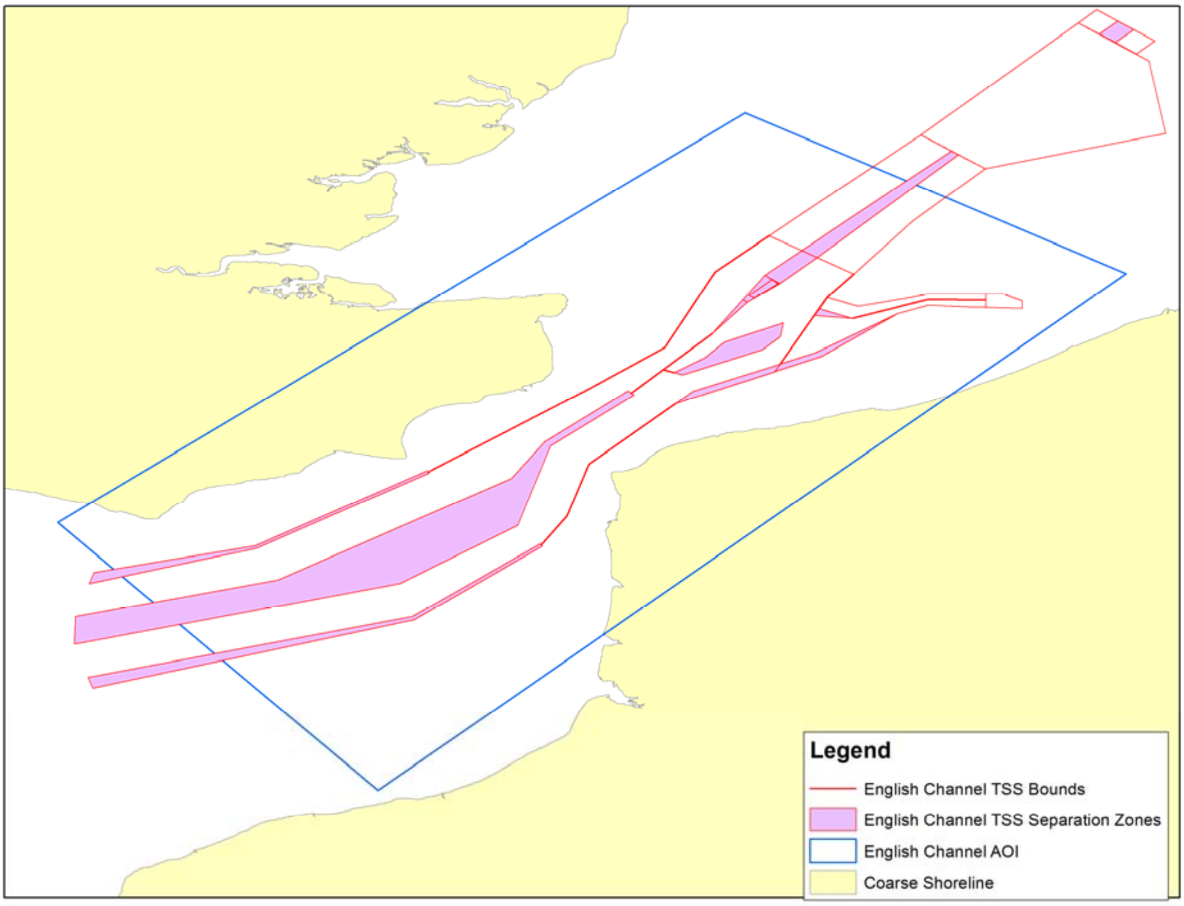

Figure 3 - English Channel AOI

2 Traffic Data Sources and Data Processing

2.1 Traffic Data Sources

The key data resource upon which the simulated traffic paths were constructed for this project was ground station based AIS (Automatic Identification System) position reports. For each of the three areas of interest, contact was made with the national marine authorities responsible for the waters, and requests were made for representative historical traffic reports from the recent past.

Initial contact was made with Singapore MPA, owing to their key role in the project, and a data request scope was developed. Due to the high volume of reports in the Singapore Strait area, it was decided to process only a representative quantity of data. Based on assessments of the size of the data files, for feasibility, it was determined that four 1-week periods spread across a given year should be adequate to explore any seasonal effects that might be present, while also ensuring that any intra-week effects are normalized (by avoiding discrete weekdays). Singapore MPA indicated that historic data were available for the years 2012 through 2014. Using the sampling scheme, a request was placed for four 1-week periods in each of those years, as available, preferring the weeks to be in January, April, July and October. Because of limitations with regard to the older data becoming unavailable (2012), and the latter part of 2014 not yet available; some adjustments had to be made to the ranges provided, as detailed below.

Table 1 - Singapore MPA AIS Date Ranges

Year	Period 1	Period 2	Period 3	Period 4
2012	September 23-29	October 4-5; 26-30	November 2-8	December 7-13
2013	January 4-10	April 1-7	July 11-17	October 3-9
2014	January 2-8	April 1-7	July 10-16	N/A

Using the established template for data time periods (four 1-week periods spanning a year), and the AOI already identified for the region, a request was placed with the United States Coast Guard (USCG). Having communicated the project goals, project lead and stakeholders to the USCG, they were able to provide four weekly samples of AIS data within the AOI for the year 2013: January 7-13, April 8-14, July 8-14 and October 7-13.

A request was made of the United Kingdom Maritime and Coastguard Agency similar to that forwarded to the USCG, adapted for the area of interest in the English Channel. Because of legislative constraints on data release, it was not possible to obtain data from the calendar year 2013; however, a prior request had been processed for 2012 data, facilitating the transfer of data from that year. Data transferred included the whole of the UK coast (not limited to the AOI), for four 1-week spans: January 9-15, April 9-15, July 9-15, and October 8-14.

GIS-suitable shoreline and TSS boundary data were also obtained to supplement the plotting of the simulated traffic results. In the Singapore region, a series of 5 Electronic Nautical Charts (ENC) were obtained from Singapore MPA, including chart numbers 5C4037, 5C4036, 5C4035, 5C4034 and 5C4041, spanning the area of interest. In the San Francisco Bay area, electronic charting data were extracted from the US National Oceanic and Atmospheric Administration ENC Direct to GIS service [3]. For the most part, the extraction spanned data from two charts, "San Diego to San Francisco Bay" and "San Francisco to Point Arena", and, for the study, was limited to traffic control features (i.e. TSS Bounds). In the English Channel area, charting data which would be well suited to use in GIS were not readily available. In lieu of a direct charting source, traffic separation features were geocoded manually from textual resources [4] and IMO circulars (particularly COLREG.2/Circ.42 and COLREG.2/Circ.59). The shoreline data used in this work were retrieved from the NOAA GSHHG dataset [5], at the finest resolution available ("full") for the entire world. This shoreline was used exclusively in the San Francisco Bay and English Channel areas, and as a supplement to the charts in the Singapore Strait area.

In order to round out the analysis of hazards in each of the regions under consideration, an attempt was made to secure and review information on historical collision incidents. It was only possible to obtain a discrete dataset containing all relevant incidents for the San Francisco Bay area. In this case, information was procured from the USCG Marine Information for Safety and Law Enforcement (MISLE) database [6]. This database contains information collected by USCG personnel for reported marine casualties and pollution incidents. A subset, containing information on vessel collisions in the San Francisco Bay AOI, was extracted for review. For the remaining two regions, Singapore Strait and the English Channel, a brief media review was conducted to enumerate recorded collision events from 2000 onward. In the Singapore region, the Singapore MPA news release site [7] was a primary resource for recent events, as was the UK Marine Accident Investigation Branch site [8] for the English Channel area. Specifics on the collated results from these sources, among others, are provided in the section "Incident Discussion".

2.2 Limitations in the Traffic Data Sources

The AIS data utilized for this simulation are, like most datasets, not without limitations. Most critically to assessing volumes of traffic, AIS data are limited in that only some vessels are required to carry AIS transponders, as described by the IMO [9]:

"*… AIS to be fitted aboard all ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships by 31 December 2004.*"

Vessels outside this scope may carry AIS at their discretion but, otherwise, this indicates that traffic volumes of smaller, non-passenger vessels will be under-represented in this dataset. As a vessel class, fishing vessels could be expected to be significant in number, and form part of this deficiency. This could be of some concern with respect to the project goal of identifying vessels crossing TSS, as fishing vessels would generally be expected to make up some of the crossing vessels. At the same time, any vessels not meeting the requirements of AIS carriage would also be exempt from "3 green lights" signal carriage.

In some cases, vessels which carry AIS are also permitted to deactivate the units, which would also result in gaps in coverage. More specifically, IMO Resolutions A.917(22) and A.956(23) permit a vessel's Master to turn off the AIS when it may compromise the safety or security of the ship. Being that the Malacca Strait is a known area for piracy, and that it is also adjacent to the Singapore Strait, it is possible units may be switched off prior to entry to the Malacca Strait (outbound from Singapore Strait) or left off when entering the Singapore Strait (inbound from Malacca Strait), resulting in gaps in the position data in the area.

Aside from limitations of AIS scope, some more practical limitations have also been noted with respect to the use of AIS data in analysis. Some of these have been noted by others in existing publications [10]. Without inferring cause of improper AIS use as operator error or malicious intent in this particular group of datasets, several features of the ancillary, user-specified data were noted that run contrary to the IMO regulations that define its proper operation:

- Failure to indicate any form of vessel static data message
- Failure to indicate appropriate movement indicator (particularly while stopped / moored)
- Failure to indicate a valid MMSI in AIS reports

In addition to errors and omissions in the ancillary data that accompanies the AIS reports, there are several technical limitations in the AIS message process that can cause difficulties with the messages themselves being transmitted, as well as the quality of the transmitted information.

- "Blind spots" for AIS receivers (i.e. message transmitted, but not received, leading to gaps in vessel tracks)
- Poor GPS fix (inaccurate position information inserted into transmitted record)

2.3 Data Processing

Processing of the raw AIS report data to convert it into the simulated vessel tracks was performed in a number of steps. Some steps were only necessary for particular AIS datasets due to the differences in their structure and prior processing. In general, the Singapore MPA AIS datasets were the most "raw", while the UK-MCA and USCG datasets had been subject to some further processing before we received them.

Before performing any form of modelling work on the MPA sourced data, the particulars of the AIS message data had to be parsed out from the binary-encoded records in the files provided. To this end, a parser was written [11], drawing from freely available libraries [12], and also from available information on the AIS protocol [13]. This parser translated the raw data into a format which could be used for modeling by providing the various AIS messages in decoded form.

The first task in preparing the data for modelling was to divide the source datasets on the basis of AIS message type. This was done to separate the messages which contain useful positional data to feed into the model from those which contain data describing vessels and also from those of no practical use in the model. Within the AIS specification, there are 5 message types associated with vessel positions: those with indicators 1, 2, 3, 18 and 19 (a full listing of the types can be found in Appendix 3A). All data records with these indicators were extracted from the aggregate data files, and subjected to further review. Reports in this subset indicating stopped vessels (i.e. those with AIS 'navigational status' values indicating that the vessel was stopped, moored, anchored, or otherwise not moving), were placed into a file of "stop" records (a full listing of navigational status indicators is included as Appendix 3B). The remaining records in this subset were inserted into files for further processing, marked "underway" to indicate reports from vessels while underway. A third set of records was established for message type indicators of 5, indicating "voyage" messages, wherein details about vessel particulars and the parameters of the voyages being undertaken by vessels are specified. Lastly, all other records were inserted into "rest" files, containing the rest of the messages, generally including reports and information not of use to this modelling and simulation exercise.

AIS data records provided by the USCG contained vessel particulars attached to each record, including vessel type, facilitating the division of the data on that basis. The datasets from the other two regions did not have vessel type attributes attached to the movement records, however, information about vessel types was included within the datasets as the content of the "type 5" - static voyage data records. The collections of type 5 records were compiled separately for the UK-MCA dataset and the Singapore MPA dataset. Within these compilations, best effort was made to develop cross-references between the Maritime Mobile Service Identity (MMSI) numbers and vessel particulars (specifically Name and Type). In many instances, there were discrepancies, particularly where vessels of a general type (e.g. Tanker), were found to carry alternating types of specific cargo, which led to multiple type definitions for a single MMSI. To address this issue, a more general categorization was constructed from the set of AIS type values as presented in Table 2 (a table of all AIS type values, is included as Appendix 3C).

Table 2 - AIS Vessel Type to Coarse Study Vessel Type Cross Reference

Study Vessel Type	Description	AIS Vessel Types Included
C	Cargo Vessels	7[0-9]
F	Fishing Vessels	30
G	Tug / Tow and Harbour Svc Vessels	31, 32, 50, 52, 53
H	High Speed Craft	4[0-9]
L	Pleasure Craft	36, 37
N	Unreferencable Vessels	No match with type 5 message*
O	Other Vessels	2[0-9], 33, 34, 35, 38, 39, 51, 54, 55, 56, 57, 58, 59
P	Passenger Vessels	6[0-9]
T	Tankers	8[0-9]
U	Unknown Type Vessels	null*, 01-19

** Unknown type vessels differ from unreferenceable vessels in that the latter records do not correspond (by MMSI) with any type 5 message, while the former records correspond to a type 5 message with a vessel type that is unrecognized / not expected to be in use.*

The aggregate sets of "underway" data from each data source were next divided into separate files, one per MMSI, to permit processing of each vessel's movements as a distinct entity. Generated files were labelled with the corresponding MMSI to facilitate sorting by type reference. At this point, the temporal ordering of the data was also re-checked to confirm that the reported positions were presented in the correct order.

The vessel traffic model was then developed using the files of MMSI-separated traffic data. In this process, the sequences of reported positions were considered for each vessel. Positions falling far outside the respective areas of interest were discarded from consideration, while the remaining positions were assessed, in sequence, to establish contiguous tracks within the data. Generally speaking, this process involved running a 3-point "window" over the positions, discarding any which suggested implausible speeds (160 kph / ~86 knots) as outliers, along with any duplicate points. The remaining sequences of positions were divided into sets of discrete track segments (one per MMSI), with divisions established where either of the two following criteria was noted:

1) temporal separation between consecutive points greater than 180 seconds, or
2) speed less than 0.5 knots.

The former was established as being beyond the upper limits of mandatory AIS reporting in congested areas (i.e. vessels should be reporting more frequently than 1 / 180s in these areas). The second filter was found to be necessary as very few vessels were appropriately applying the "at anchor" and "moored" designations in their AIS reports. Applying the second filter divided out sections of reporting where vessels are drifting around an anchored position, or where GPS drift is occurring while a vessel is moored (i.e. non-0, speed, for effectively stationary vessels). If vessels had effectively utilized the non-underway AIS designations, only the first filter would have been required, as the non-underway reports would have been stripped out, leaving sufficient temporal gaps in the data to identify discrete movements as tracks.

Using the MMSI to vessel type cross-reference developed earlier, the outputs of the modeling were sorted by type within each of the three regions under consideration. This permitted a review of the output showing the distribution of records by vessel type in each region. Table 3 depicts the overall number of files by MMSI noted within the data for each of the three regions (Note - these are not comparable between all regions, as the Singapore area has 11 weeks of data included in the aggregation, while the other two regions have only 4 weeks each. The values represent an overall summary of the distinct vessels noted within each area.).

Table 3 - Counts of MMSI-split Data Files (one per vessel) by Region

Vessel Type	Singapore Strait	SF Bay	English Channel
C	5518	219	3746
F	22	18	710
G	398	88	426
H	20	4	124

Vessel Type	Singapore Strait	SF Bay	English Channel
L	41	293	83
O	91	27	437
P	134	45	209
T	3271	81	1546
U	679	32	596
N (Unreferencable)	5858	16	1388
Total	16032	823	9265

From this information, it can be seen that both the Singapore and English Channel regions experience a much larger overall number of distinct vessels than does the San Francisco Bay region. In all regions, cargo vessels represent a significant portion of the vessels encountered. Because the data are aggregated into distinct MMSI as regional summary, it is not possible to draw direct conclusions between the three regions, given the differing time span and the aggregation method (i.e. distinct vessel counts cannot be averaged in a meaningful way). Distributions of vessels within each area can be examined, however.

Within the Singapore Strait area, there were a large proportion of unreferenceable vessels noted (approximately 30% of the total). This indicates that a large number of vessels operate AIS without also reporting any corresponding static voyage data. Overall, among the vessels for which type could be determined (10174), the heavily dominant types are cargo and tanker (8789 total), which is sensible given that the area encompasses a major international traffic lane along with significant cargo and oil handling facilities.

In the San Francisco Bay area, pleasure craft represent the highest number of distinct vessels, but these are relatively absent from the other regions, possibly due to the areas' more limited appeal as recreational travel areas.

The English Channel vessel type distribution is similar to that noted for the Singapore Strait, with the largest contributions coming from Cargo and Tanker vessels. Also prevalent in this area, however, are a measureable number of AIS-equipped fishing vessels, not noted in the other areas.

Outputs from this primary modeling step were then processed via a secondary script to generate GIS (Geographic Information System) formatted output for further analysis. This script was used to process all data for a given vessel type into a single GIS 'layer' of tracks, using the divisions established in the prior modeling step. A second pass was made in this script to flag any bad positions which were missed by the 3-point "window" used in the earlier process. The primary purpose of this script was to translate the sequences of positions into 'polyline' GIS records, each representing a discrete movement of a given vessel. Additional information about the vessel and the track was included in each record, including the MMSI, start and end dates of the track, original AIS vessel type, vessel name and the computed elapsed time in seconds for the track. Tracks with any positions suggested as "bad", due to excessive implied speed (160 kph / ~86 knots), were also identified via an annotation field.

2.4 Limitations in the Data Processing

Further to the overall limitations of AIS data as raw input for the modelling, the particular assumptions made in this analysis are noted here to identify limitations on the simulated results.

Conclusions drawn from the simulation must be tempered by the assumption that the overall traffic patterns in the areas are assumed to be well represented by the chosen samples, that is, that the traffic for a year might be roughly equivalent to extrapolating the 4 sampled weeks to a full 52 weeks. Barring any particularly unusual traffic events coinciding with the samples obtained, this was deemed a reasonable assumption, notwithstanding the partial data within the Singapore dataset for 2012 and 2014.

In assessing the data for spurious position information, a three point window was passed over the data corresponding to each MMSI, rejecting those positions which indicated speeds exceeding a prescribed threshold, presumably due to an erroneous position report. In this study, the maximum acceptable threshold speed was set at 160 kph / ~86 knots. Two assumptions are built into this process: Firstly, that a three point window is large enough to capture the maximum number bad positions occurring in sequence within the datasets (a maximum of two bad points in a row are permissible, by this method, as long as they do not both occur at the beginning of a sequence of positions). Secondly, that 160 kph / ~86 knots represents an effective upper bound on reasonable speeds for the vessels under consideration. The first assumption is supported by observations that there are very few tracks (<< 1%) detected that contain outliers based on speed in the second pass of processing (in which the tracks are also converted to GIS records). The second assumption also appears to be sound, given that the only vessels generally capable of speeds in excess of this value are competition racing and speed record vessels, well outside the scope of this exercise.

Because of the noted failure of AIS transmissions to reliably indicate moored, anchored or otherwise stopped vessels, it was necessary for this study to determine measures to identify the termination of vessel movements. Two criteria were established for this purpose; time between sequential underway position reports, and minimum inferred speed. Because the AIS interval for autonomous transmission for moored vessels is set at 3 minutes, this value (180s) was set as the cut-off between reports for vessels presumed to be underway. In practice, underway vessels, regardless of transponder type (A or B) would be expected to report, at minimum, every 30 seconds [14]. While the International Telecommunication Union documentation on AIS [14] suggests that vessels travelling slower than 3 knots are effectively moored, it was decided to be more conservative and only assess vessels as moored where their speeds were identified as less than 0.5 knots. It can be noted in the results that, in some occasions, this choice failed to divide tracks that clearly had some form of stop. This choice, however, also prevented vessel transits from being divided in areas of low speed manoeuvring.

For further specifics on the preparation of the simulated traffic data, please refer to the data cleaning and preparation document "Data Processing Report: FSA - Vessels Crossing TSS and Precautionary Areas in Singapore Strait".

3 Traffic Volume Summaries

In this analysis, segments of vessel tracks were simulated from historic data to assess the traffic volumes in each of the three areas of interest. Efforts were made to utilize these simulated track segments to assess hotspots of particularly high volume, as well as interactions between traffic flows, where crossing interactions might be expected to occur.

3.1 Overall Traffic Volume

Overall traffic volumes from the simulated track segments were reviewed and compared between regions for a single year. The available 2012 and 2013 data were considered for the English Channel and San Francisco regions, respectively, and the single complete sample year, 2013, was used for the Singapore region. Data were compared overall, but also across the four 1-week samples from separate months. Three measures were assessed across the three areas: total count of segments, total track segment length sums, and elapsed transit time for the segments.

Total counts of segments are simple to compute, but only give rough estimates of traffic volume, can be biased by the methods used to divide the track segments, and give more weight to areas in which there are a larger number of discrete movements, which might not constitute "traffic" in a meaningful way. Track segment lengths provide a better assessment of traffic within a given area than simple counts, as the length of track is a more refined measure of the spatial exposure of a vessel to a given environment. Elapsed time provides an assessment of the temporal exposure of a vessel within a given environment. With uniform vessel speeds, the length and time measures would be roughly equivalent, however, the more the vessel speeds in a given area vary, the greater the expected difference between the measures. Otherwise, the critical difference between these two measures is in interpreting the result; whether it is more critical to know the distance travelled by vessels within the area, or the amount of time spent travelling in the area. For this study, crossings involve both spatial and temporal aspects (i.e. vessels in the same area at the same time), so it was considered helpful to review all available measures.

In terms of raw track segment counts, over the yearly sample, Singapore had the greatest number by a significant margin, in spite of being the smallest area under consideration. This might be due to the confluence of the high traffic in the area as well as the port and anchorage operations. The English Channel area noted the second highest number of track segments, with the San Francisco area having the least. Seasonal differences were noted within each of the areas, none of which were found to correlate across the areas. In the Singapore region, the highest segment count appeared in the October sample, with the least traffic arising in the January sample. For San Francisco, highest traffic segment counts occured in July, and lowest numbers in January. The English Channel region had its highest segment count in October, and its lowest in April. The totals are included in Table 4 and Figure 4.

Table 4 - Track segment total counts (4 weeks within 1 year)

	January	April	July	October	Total
Singapore 2013	42057	44243	49656	50751	186707
San Francisco 2013	4853	6359	8527	6760	26499
English Channel 2012	12610	11087	12420	20074	56191

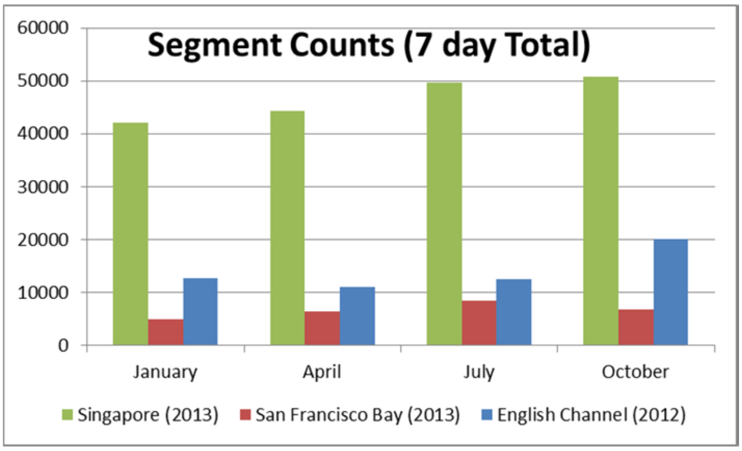

Figure 4 - Monthly Traffic Segment Counts by Area (7 day total)

When measuring track segment length totals over the yearly sample, the English Channel area, rather than Singapore, noted the highest overall amount, with San Francisco still remaining the lowest. This is most likely due to the larger spatial extent of the English Channel area, involving much longer track segments. Distribution between sample months remained identical for the Singapore and San Francisco areas to that noted for the segment counts. Interestingly, the segment length totals in the English Channel area for January and July were much higher than for October, while the minimum was still noted to be in April. This seems to suggest that a significant proportion of segments were longer in distance in January and July than in October within the English Channel region itself. This pattern does not appear in the other regions, and it is unclear as to why this might be. The computed totals are presented in Table 5 and Figure 5.

Table 5 - Track segment length totals (km - 4 weeks within 1 year)

	January	April	July	October	Total
Singapore 2013	284220	295354	307002	316548	1203124
San Francisco 2013	50315	57645	660756	62812	236847
English Channel 2012	420142	232885	386294	312604	1351925

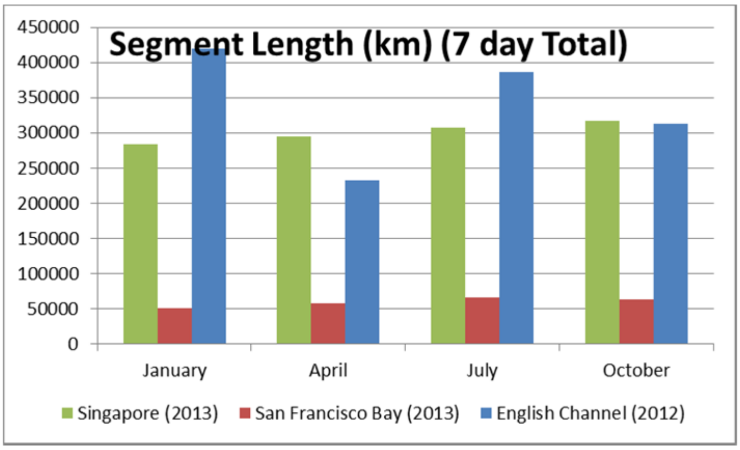

Figure 5 - Monthly Traffic Segment Length Totals by Area (7 day total)

The distribution of vessel transit time total amounts among the three regions matched the distribution for track segment count totals, with Singapore are having the highest, followed by the English Channel area and finally the San Francisco area. Distribution between the monthly samples was the same for the regions as that noted for distance. Results are presented in Table 6 and Figure 6.

Table 6 - Elapsed time totals (ship-days within sampled time periods)

	January (/ 7 days)	April (/ 7 days)	July (/ 7 days)	October (/ 7 days)	Total (/ 28 days)
Singapore 2013	1255.3	1291.7	1272.7	1372.0	5191.7
San Francisco 2013	129.5	142.1	160.9	160.4	593.0
English Channel 2012	1365.6	856.4	1214.9	1093.0	4530.0

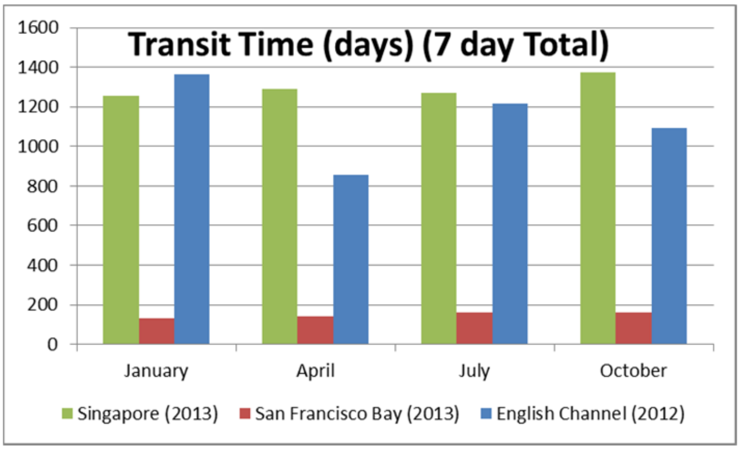

Figure 6 - Monthly Elapsed Transit Time by Area (7 day total per month)

3.2 Regional Traffic by Type

In order to provide some background on the makeup of the traffic populating each region, the traffic segments were broken down into groups according to their gross vessel type. The intention of this exercise was to determine the dominant traffic types in each area in hopes that the information might be of some value in assessing the risks. Comparisons between types were made using the same measures (total segment count, total segment length and total elapsed time) used to compare between the regions.

3.2.1 Singapore Strait

In terms of overall numbers within the Singapore area, vessels which were not successfully referenced were, unfortunately, dominant in both segment count and total segment length. Putting aside these vessels, tankers, cargo vessels, passenger vessels and those of unknown (AIS) type made up the top four types for all three metrics. In segment length and elapsed time totals, cargo and tanker vessels were identified as the top two types, with tankers being top in total segment length and cargo top in elapsed time (again, putting aside unreferenceable vessels). As a known primary international shipping route, this meshes with expectations. Passenger vessels were noted as having moderately high total segment length, but lower elapsed time; this is most likely due to the comparatively high rates of speed for passenger carrying vessels. Fishing and pleasure craft were noted in fairly low numbers, though it is suspected that they are indeed present within the area. Their absence from these totals is most likely due to their lack of carriage of AIS transponders, placing most of them outside the scope of the available data.

Table 7 - Singapore Strait Traffic by Vessel Type (2013 - 4 week totals)

	Total Segment Count	Total Segment Length (km)	Elapsed Time (Days)
C - Cargo	15831	221304.3	1755.3
F - Fishing	258	1972.9	14.8
G - Tug / Harbour Svc.	10581	38769.7	211.1
H - High Speed Craft	1688	11240.1	24.7
L - Pleasure Craft	368	446.7	2.7
N - Unreferencable	76707	354262.3	1186.7
O - Other	313	2990.4	14.8
P - Passenger	21427	190899.9	342.0
T - Tanker	30997	258983.7	1177.6
U - Unknown	28537	122253.9	462.0

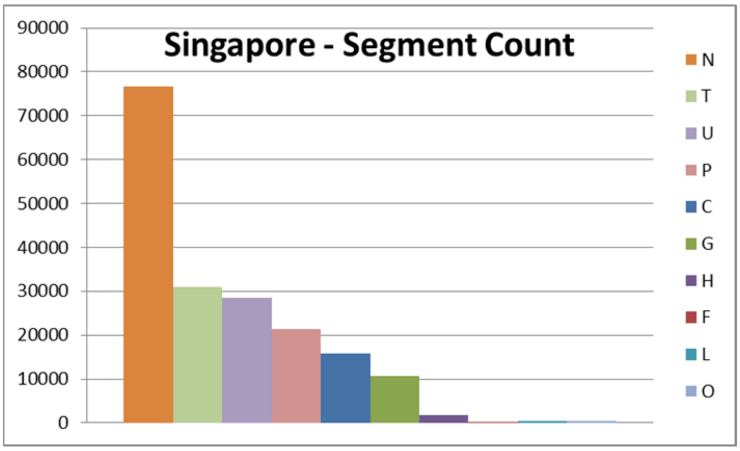

Figure 7 - Singapore Traffic Segment Count by Type (4 week total)

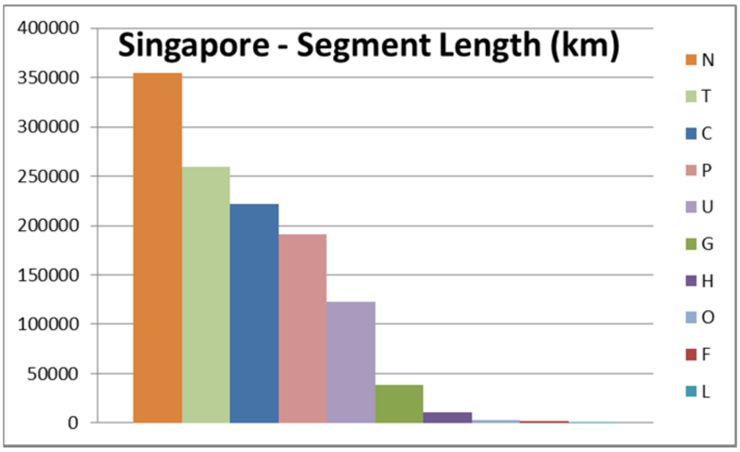

Figure 8 - Singapore Traffic Segment Length by Type (4 week total)

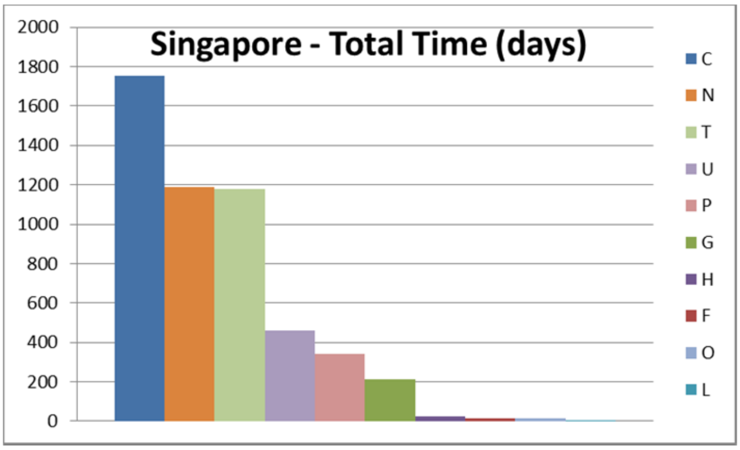

Figure 9 - Singapore Elapsed Transit Time Totals by Type (4 week total)

3.2.2 San Francisco Bay Area

Traffic from Tug and Harbour Service vessels were found to dominate all metrics within the San Francisco Bay area. This is not especially surprising, given that the bulk of the area is a sheltered bay with significant quantity of shoreline facilities. Passenger, cargo and pleasure craft round out the top four types noted in terms of total segment length and elapsed time. The higher numbers of passenger and pleasure craft in the traffic mix are most likely due to the highly populated shorelines within the AOI, as well as the general amenability of the area to recreational on-water activities. Because of the limited numbers of pleasure craft required to carry AIS, it might be expected that the actual on-water volume of pleasure craft in the area is quite high. Tanker vessels were not noted in this region to the same extent as in the others, a likely result of more constrained numbers of production facilities in this particular port, and the limited quantity of pass-through traffic in the AOI. Fishing vessels were again noted in limited numbers, likely due to limited AIS carriage relative to the size of vessels expected in the area.

Table 8 - San Francisco Bay Area Traffic Measures by Vessel Type (2013 - 4 week totals)

	Total Segment Count	Total Segment Length (km)	Elapsed Time (Days)
C - Cargo	1717	41938.1	78.0
F - Fishing	237	3009.1	10.3
G - Tug / Harbour Svc.	10246	72673.6	245.8
H - High Speed Craft	230	1883.7	2.8
L - Pleasure Craft	3443	20385.8	71.8
N - Unreferencable	1	119.1	0.3
O - Other	967	3418.4	10.9
P - Passenger	7247	63969.8	102.2
T - Tanker	611	20073.3	44.6
U - Unknown	1800	9376.3	26.3

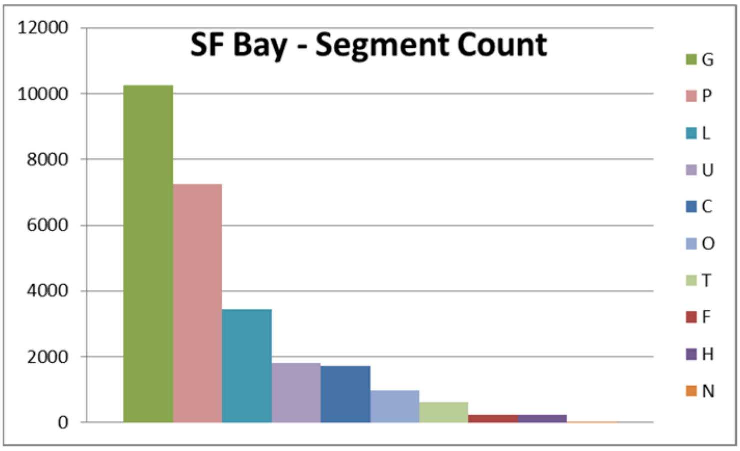

Figure 10 - SF Bay Traffic Segment Count by Type (4 week total)

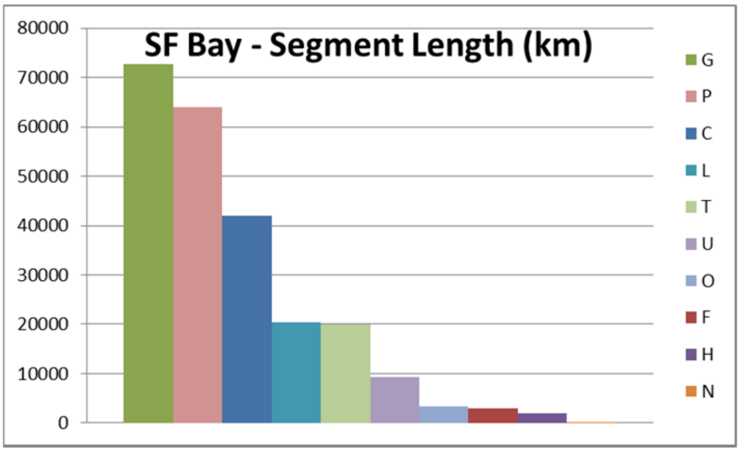

Figure 11 - SF Bay Traffic Segment Length by Type (4 week total)

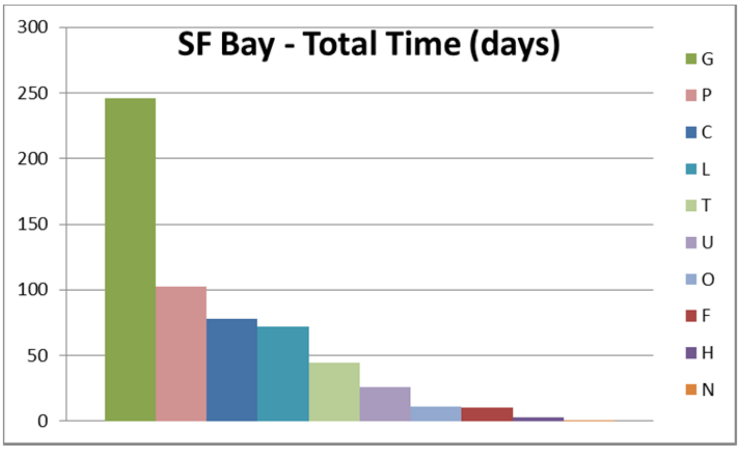

Figure 12 - SF Bay Elapsed Transit Time Totals by Type (4 week total)

3.2.3 English Channel

Cargo vessels were the primary vessel type noted within the English Channel across all measurements assessed. Because of the Channel's role as a major shipping route for goods, this is somewhat expected. With this in mind, tanker traffic was also noted to be significant in terms of segment length total and elapsed time in the area, if not in segment count. Fishing Vessels and High Speed Craft were found in large quantities when assessing counts of traffic segments, but less so in the other measures. In terms of fishing vessels, their presence at all within the dataset suggests that the either the vessels themselves are of significant size, or that their operators are proactive in carriage of AIS. Their lower measure in terms of total segment length and time relative to segment count might be indicative of a large number of short transits with time spent primarily fishing rather than underway. With high speed craft transits, the limited totals for segment length and time are more likely due to the nature of the vessels' modes of operation: large numbers of short fast point-to-point transits, rather than long periods of extended cruising.

Table 9 - English Channel Traffic by Vessel Type (2012 - 4 week totals)

	Total Segment Count	Total Segment Length (km)	Elapsed Time (Days)
C - Cargo	14382	707021.6	2448.8
F - Fishing	8417	57151.2	318.7
G - Tug / Harbour Svc.	4899	25755.6	101.4
H - High Speed Craft	7969	42730.1	102.4
L - Pleasure Craft	256	3369.0	17.4
N - Unreferencable	2065	20372.2	63.4
O - Other	3219	40075.4	146.7
P - Passenger	4120	126231.3	196.4
T - Tanker	6034	284155.2	954.7
U - Unknown	4830	45063.2	180.0

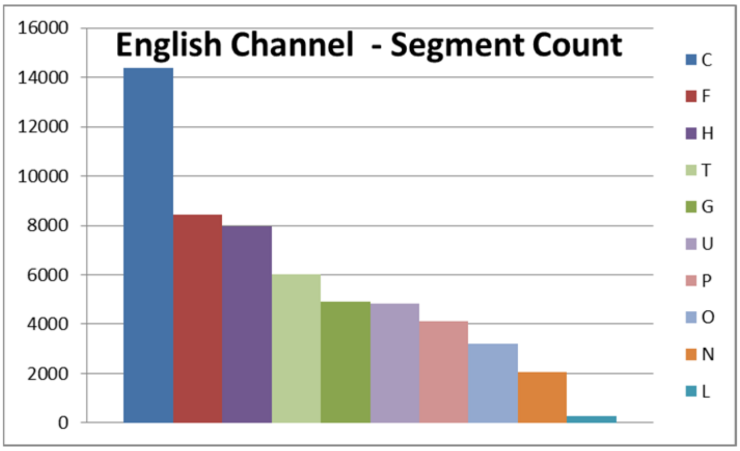

Figure 13 - English Channel Traffic Segment Count by Type (4 week total)

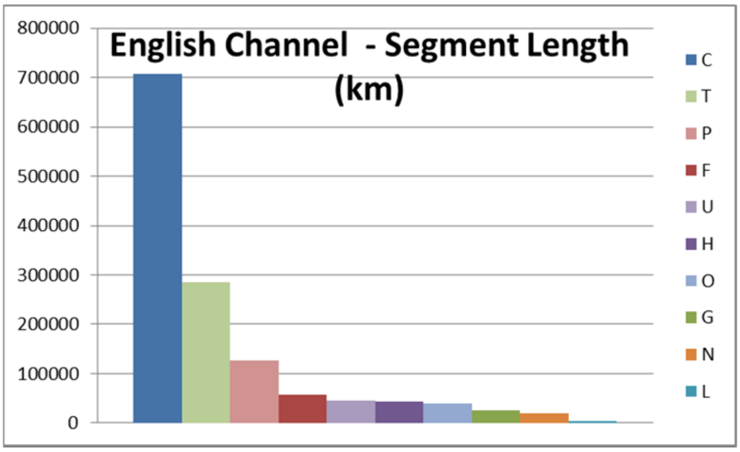

Figure 14 - English Channel Traffic Segment Length by Type (4 week total)

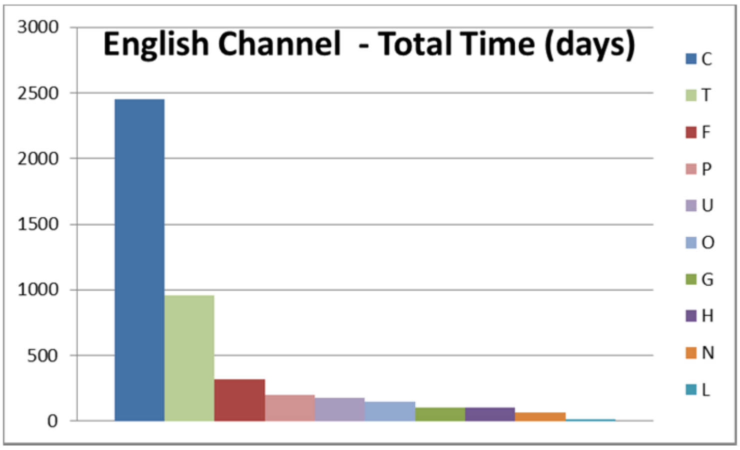

Figure 15 - English Channel Elapsed Transit Time Totals by Type (4 week total)

4 Traffic Density Summaries

In order that the results of the simulated traffic might be better interpreted visually, the generated traffic segments were subjected to an interpolation process. Raw track lines within each of the study areas are of sufficient volume that it is not possible to identify discrete patterns (see Figure 16). To mitigate this issue, the input lines were aggregated to a regular grid for visualization. The first step of aggregation was to calculate the portions of the lines (by length) found to occur within a given radius of each grid cell (1.5x the cell edge length). These lengths were used to compute the proportion of each line falling in / near each cell. This proportion was used to weight the values attached to each track line (elapsed time, in particular), which were then totalled into the cells. The result of this operation is a gridded representation of the segments which is more easily visualized and interpreted. The output measures, as displayed in the generated images, are in units of vessel-days, with 1 representing 24 hours of vessel time within a single grid cell.

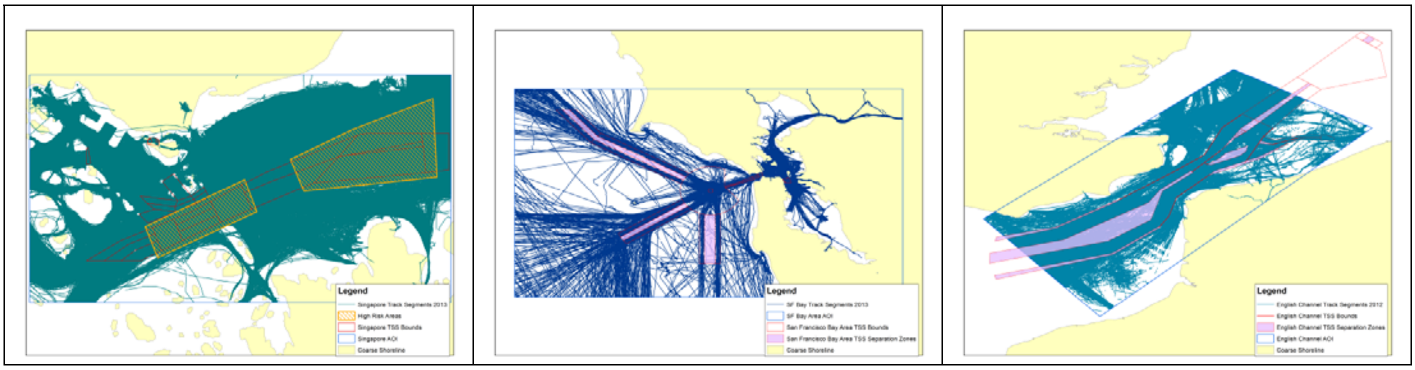

Figure 16 - Raw Track Line Samples

4.1 Singapore Strait

The results of the traffic simulation in the Singapore Strait for the 2013 subset of the data are included in Figure 17 through Figure 31. The figures illustrate the overall density for the sample, followed by plots for the four temporal periods and finally plots for each of the ten vessel categories established earlier.

Overall traffic in the Singapore Strait area is most heavily concentrated on the two primary traffic lanes running east-west through the AOI. Also densely populated are the primary routes running north-south from the western precautionary area into the centre of the Port of Singapore. Traffic can also be seen travelling between the anchorage area to the north of the traffic lanes and the port of Singapore via the smaller TSS lanes just north of the lanes passing through the area. Finally, paths running perpendicular to the TSS lanes (implying direct crossing) can be noted originating from several points on shore to the south of the TSS, of particular concern to the project at hand.

Within the traffic plots presenting each of the four weekly samples, no features appear to be significantly affected by the time period. All of the four plots presented are roughly similar to the overall traffic plot, albeit with reduced traffic volumes.

Considering the plots by traffic type, a greater differentiation in traffic patterns can be identified. Within the generated plots, the following features were considered notable:

Table 10 - Observations in Singapore Strait AOI Traffic Plots (2013) by Type

Vessel Type	Observations
Cargo Vessels	• Primarily concentrated in traffic lanes • Make use of anchorages to north of traffic lanes • Transits noted in both primary fairways • No clear direct crossing paths
Fishing Vessels	• Very low volume • Appear to use landing north of western anchorage
Tug / Harbour Svc.	• Low volume • Some use of primary traffic lanes
High Speed Craft	• Appear to be mostly on TSS crossing routes • Same areas as passenger vessel traffic
Pleasure Craft	• Almost absent from plots
Unreferenced Vessels	• Higher volume, concentrated in port area
Other Type Vessels	• Almost absent from plots
Passenger Vessels	• Large volume on paths appearing to cross TSS • Multiple routes noted originating from southern shoreline, heading north • Several intra- Port of Singapore routes noted
Tankers	• Primarily concentrated in traffic lanes • Some traffic between anchorage and Port of Singapore via secondary lanes, north of main TSS lanes
Unknown Type Vessels	• Low volume, mostly in port • Some more significant traffic paths running south of Sentosa

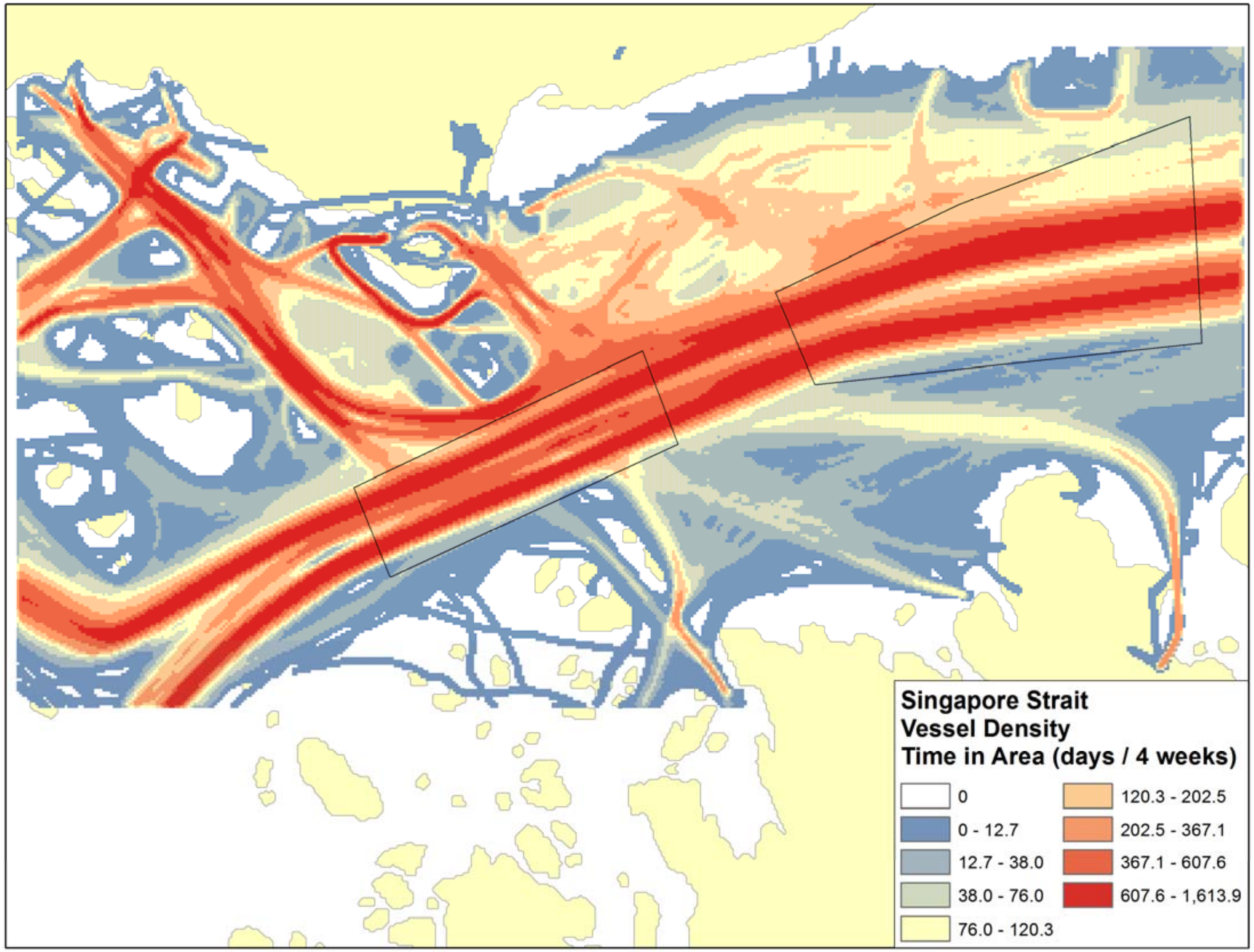

Figure 17 - Singapore Strait Overall (2013) Vessel Density (Vessel - Days in area / 4 weeks)

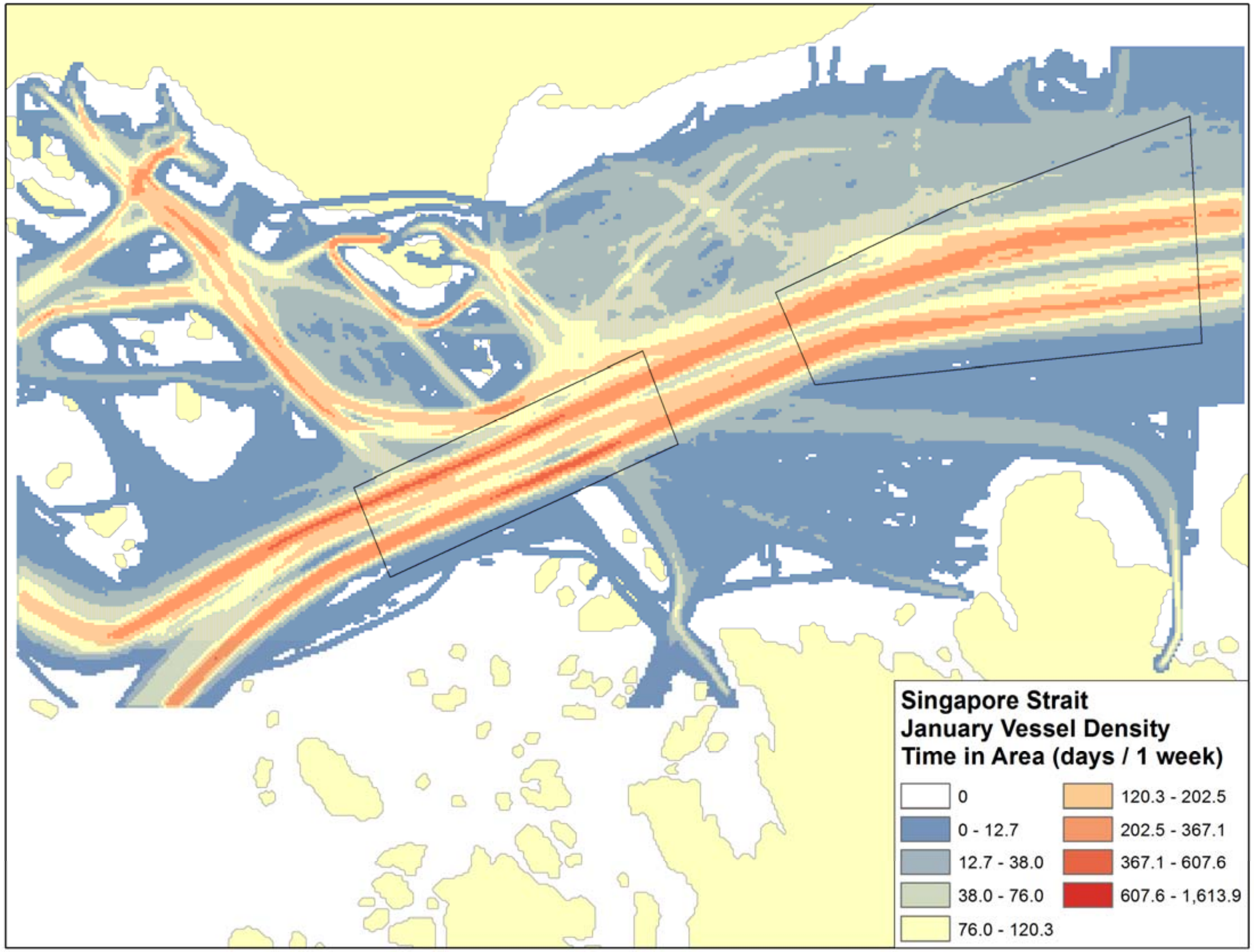

Figure 18 - Singapore Strait January (2013) Vessel Density (Vessel - Days in area / 1 week)

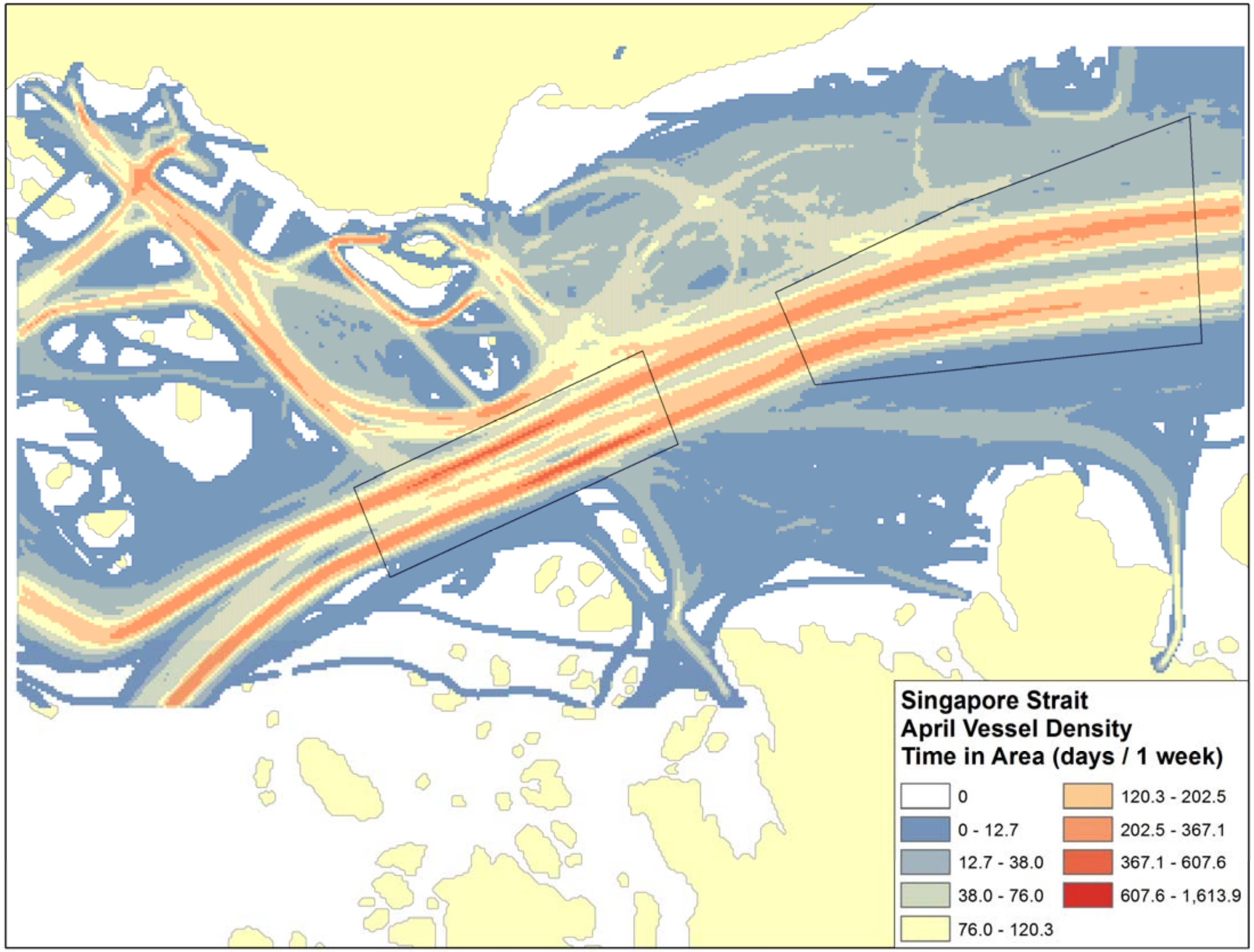

Figure 19 - Singapore Strait April (2013) Vessel Density (Vessel - Days in area / 1 week)

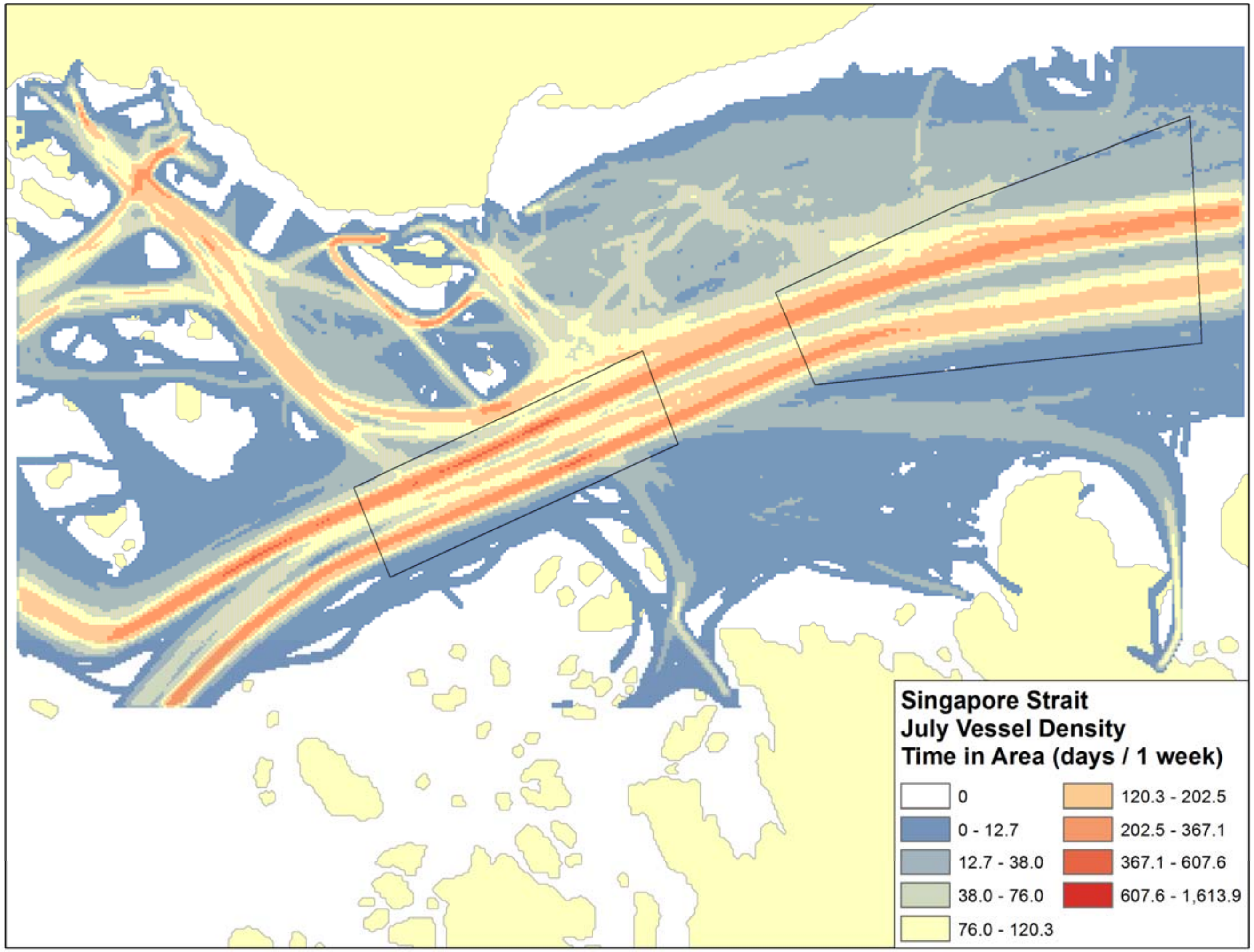

Figure 20 - Singapore Strait July (2013) Vessel Density (Vessel - Days in area / 1 week)

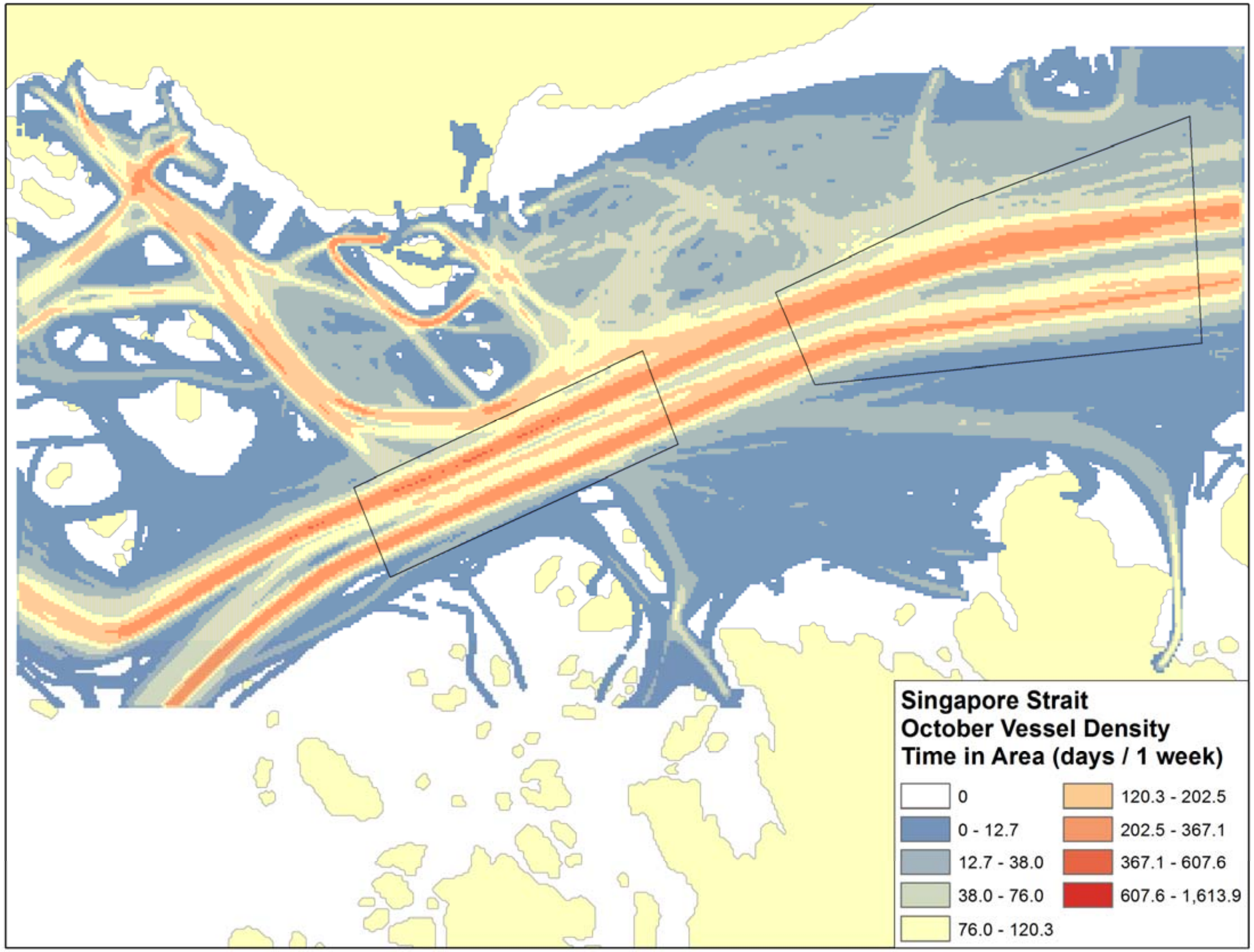

Figure 21 - Singapore Strait October (2013) Vessel Density (Vessel - Days in area / 1 week)

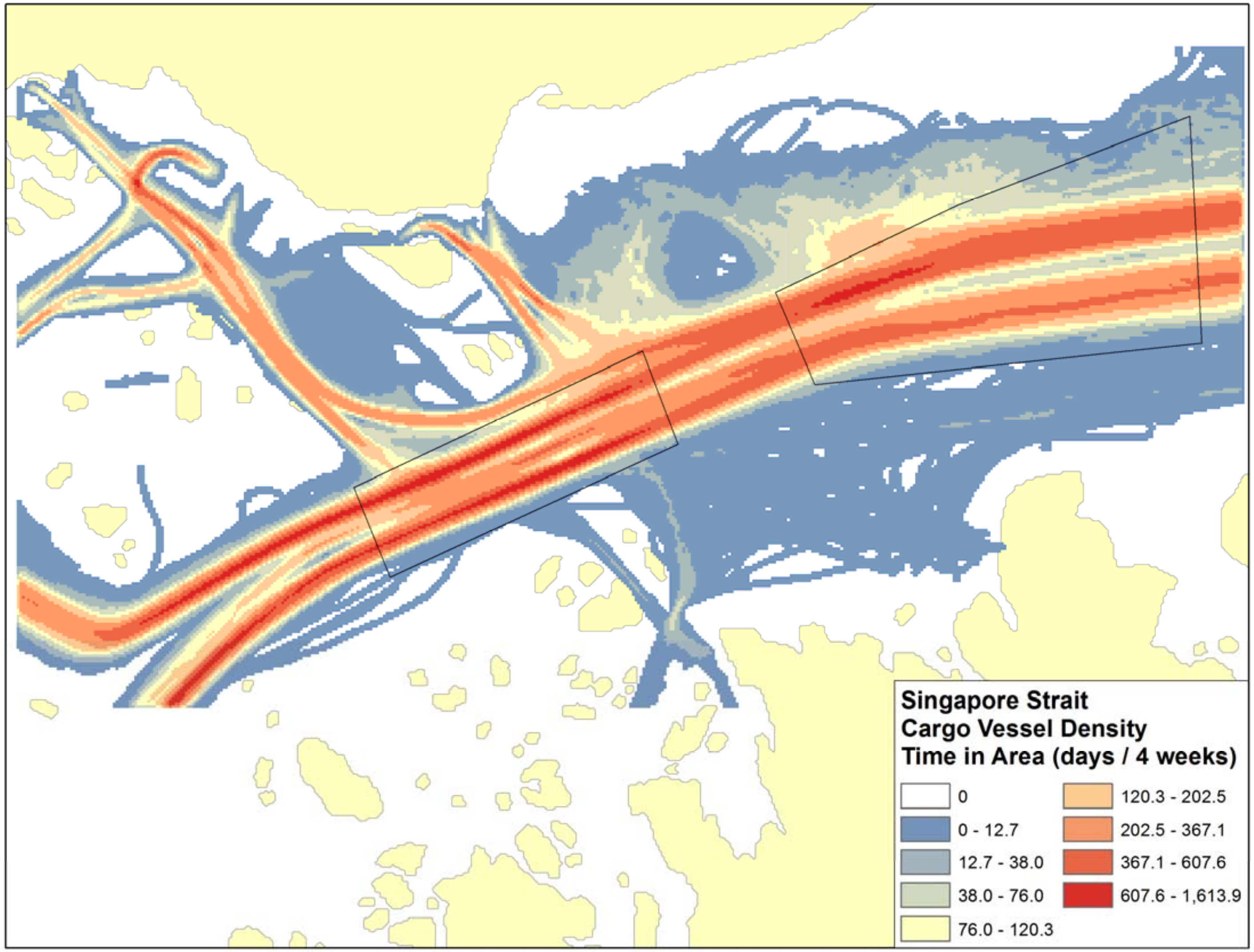

Figure 22 - Singapore Strait (2013) Cargo Vessel Density (Vessel - Days in area / 4 weeks)

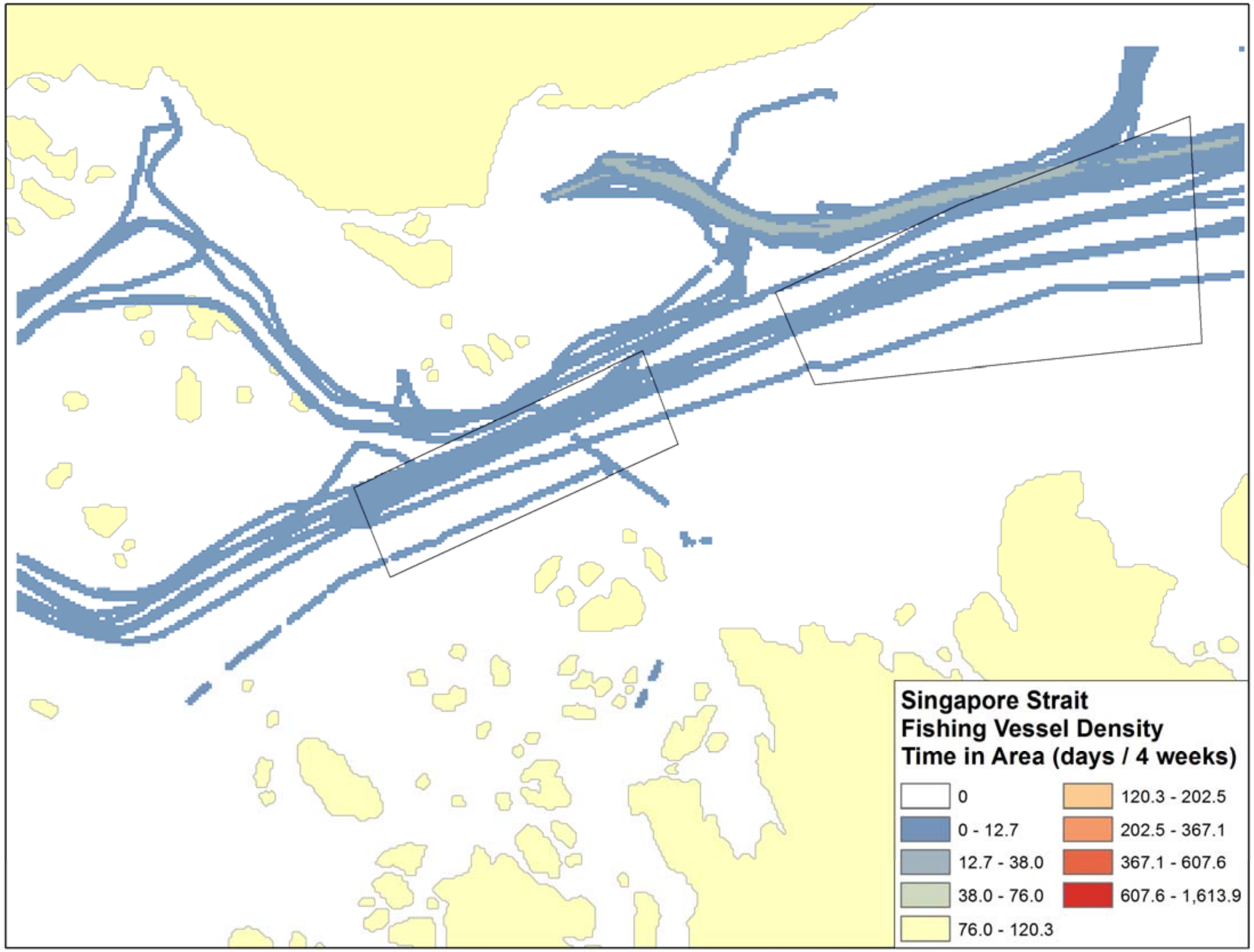

Figure 23 - Singapore Strait (2013) Fishing Vessel Density (Vessel - Days in area / 4 weeks)

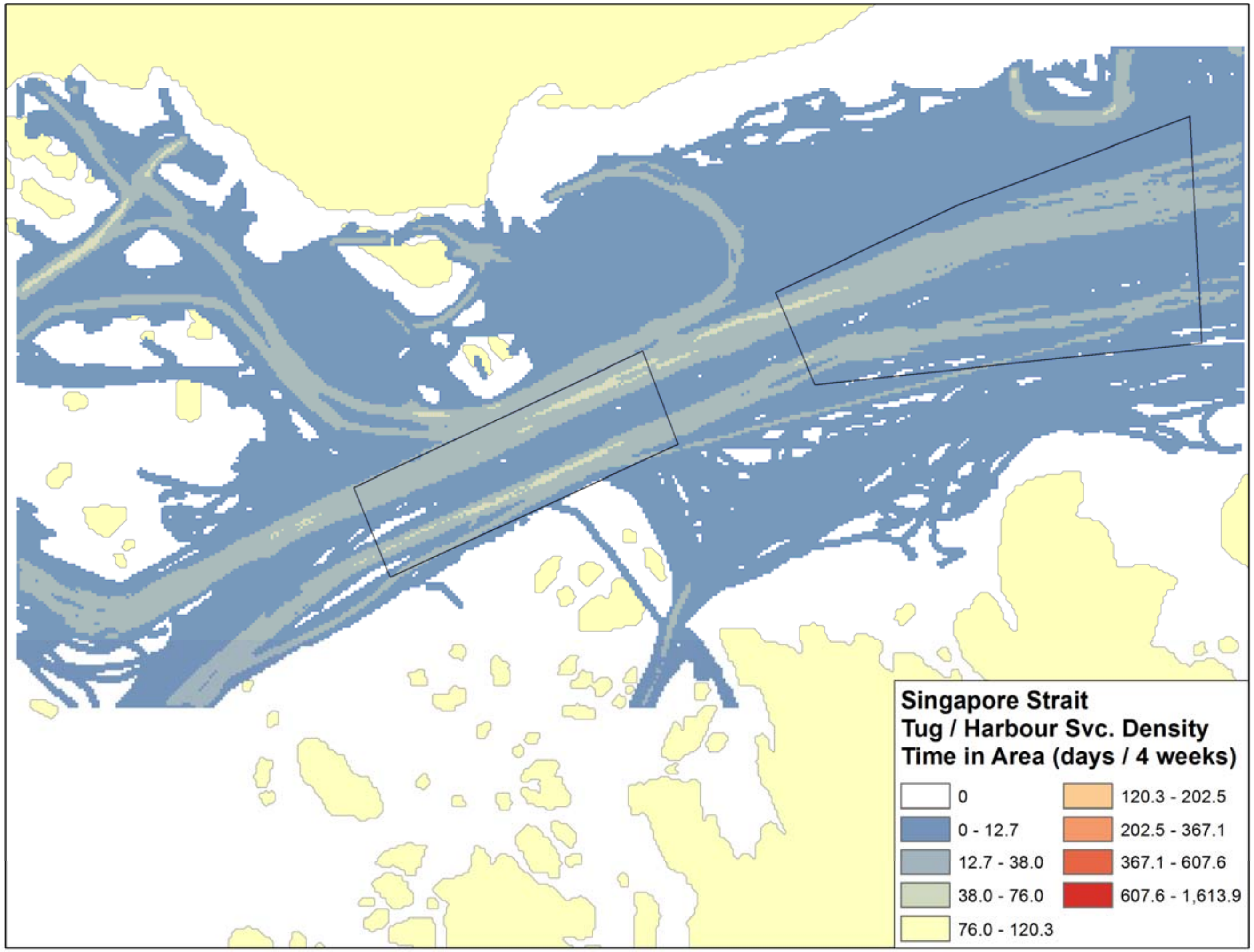

Figure 24 - Singapore Strait (2013) Tug / Harbour Service Vessel Density (Vessel - Days in area / 4 weeks)

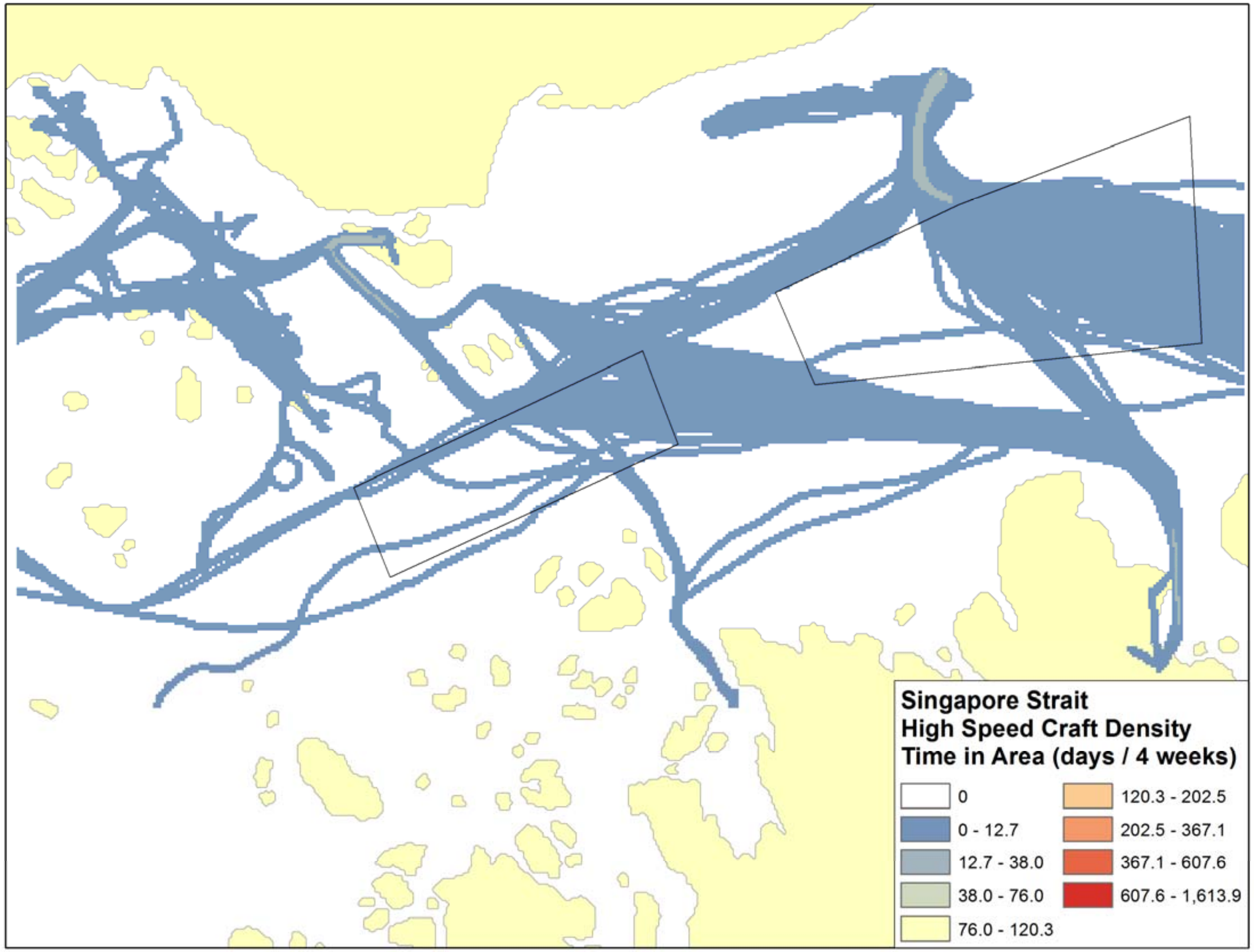

Figure 25 - Singapore Strait (2013) High Speed Craft Density (Vessel - Days in area / 4 weeks)

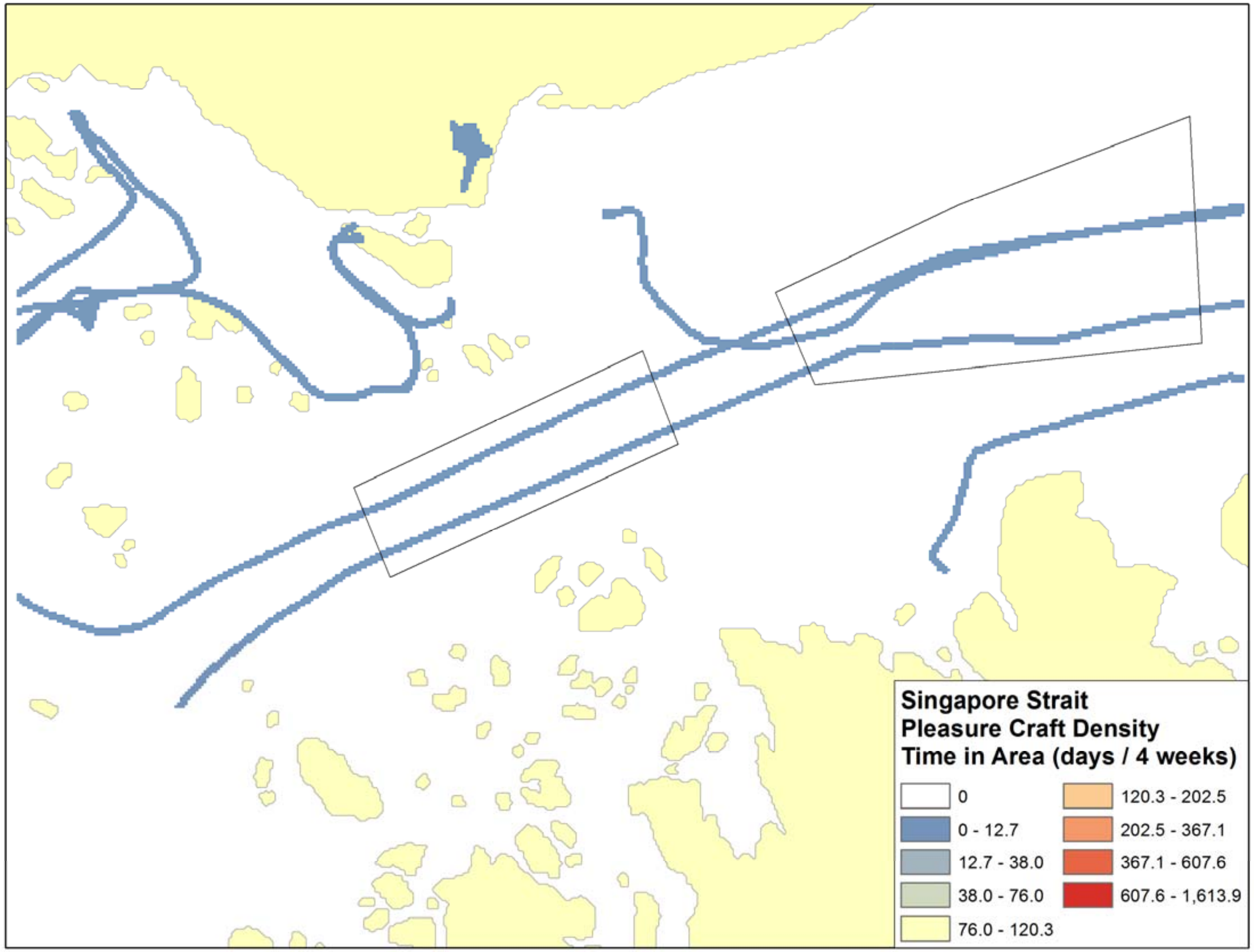

Figure 26 - Singapore Strait (2013) Pleasure Craft Density (Vessel - Days in area / 4 weeks)

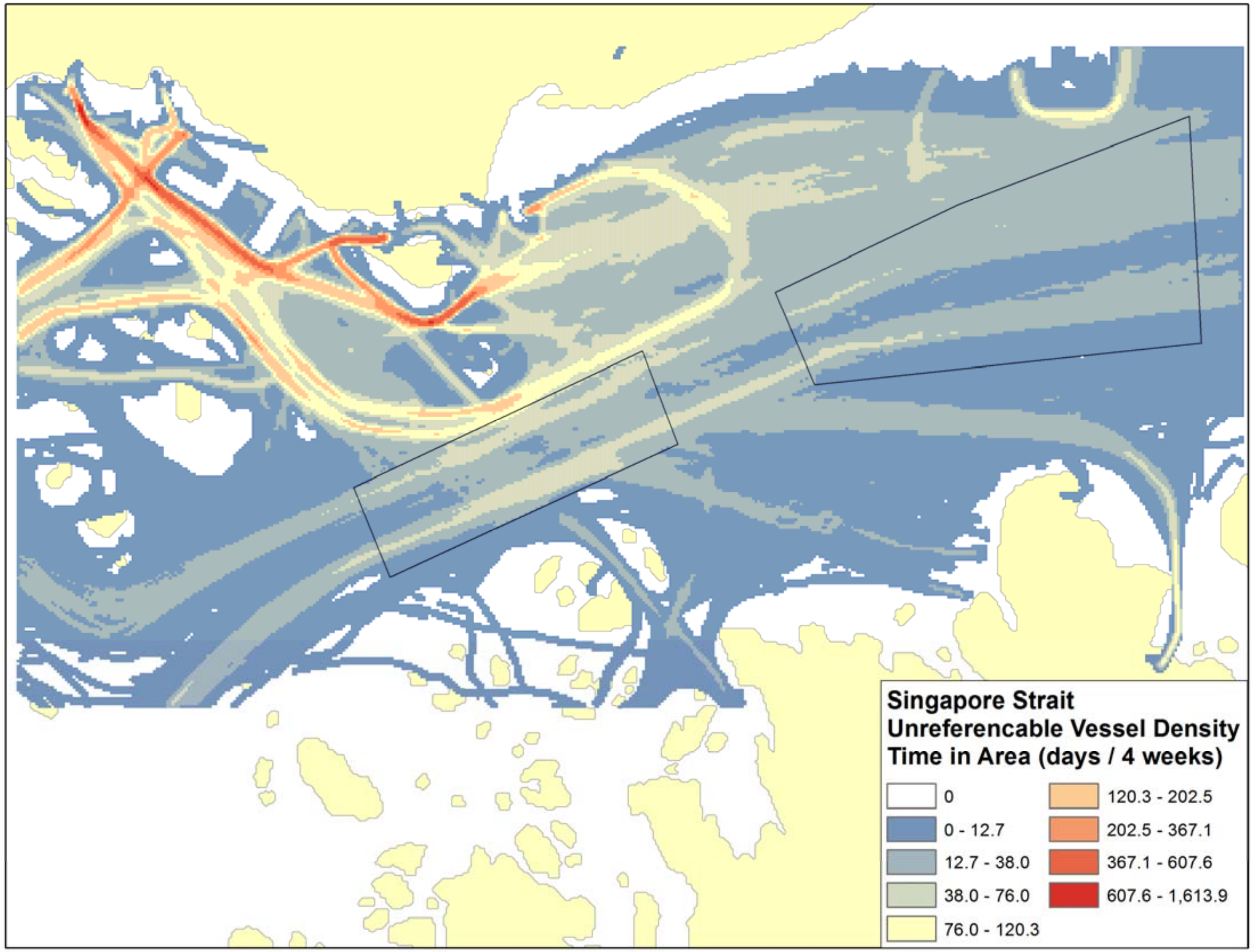

Figure 27 - Singapore Strait (2013) Unreferencable Vessel Density (Vessel - Days in area / 4 weeks)

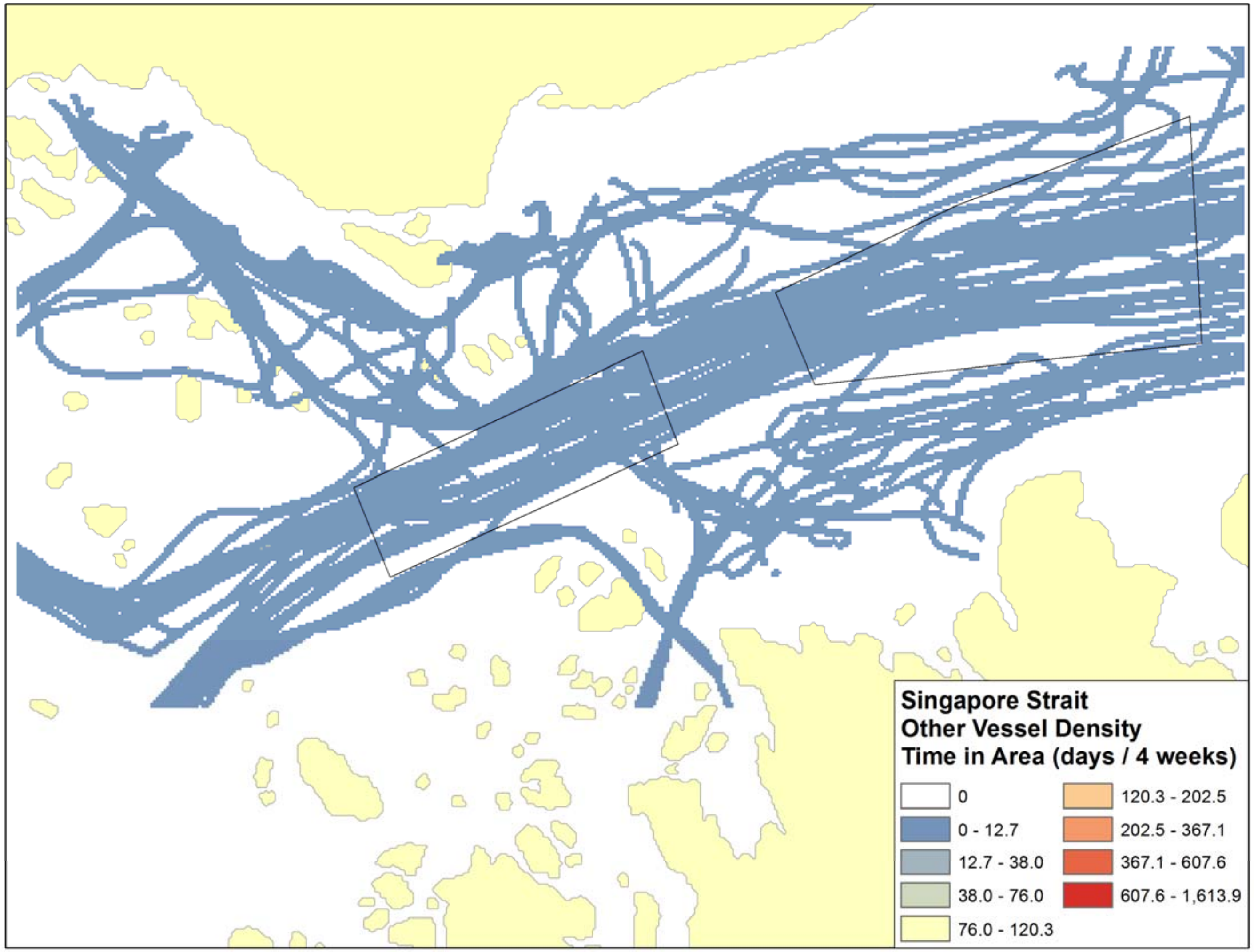

Figure 28 - Singapore Strait (2013) Other Type Vessel Density (Vessel - Days in area / 4 weeks)

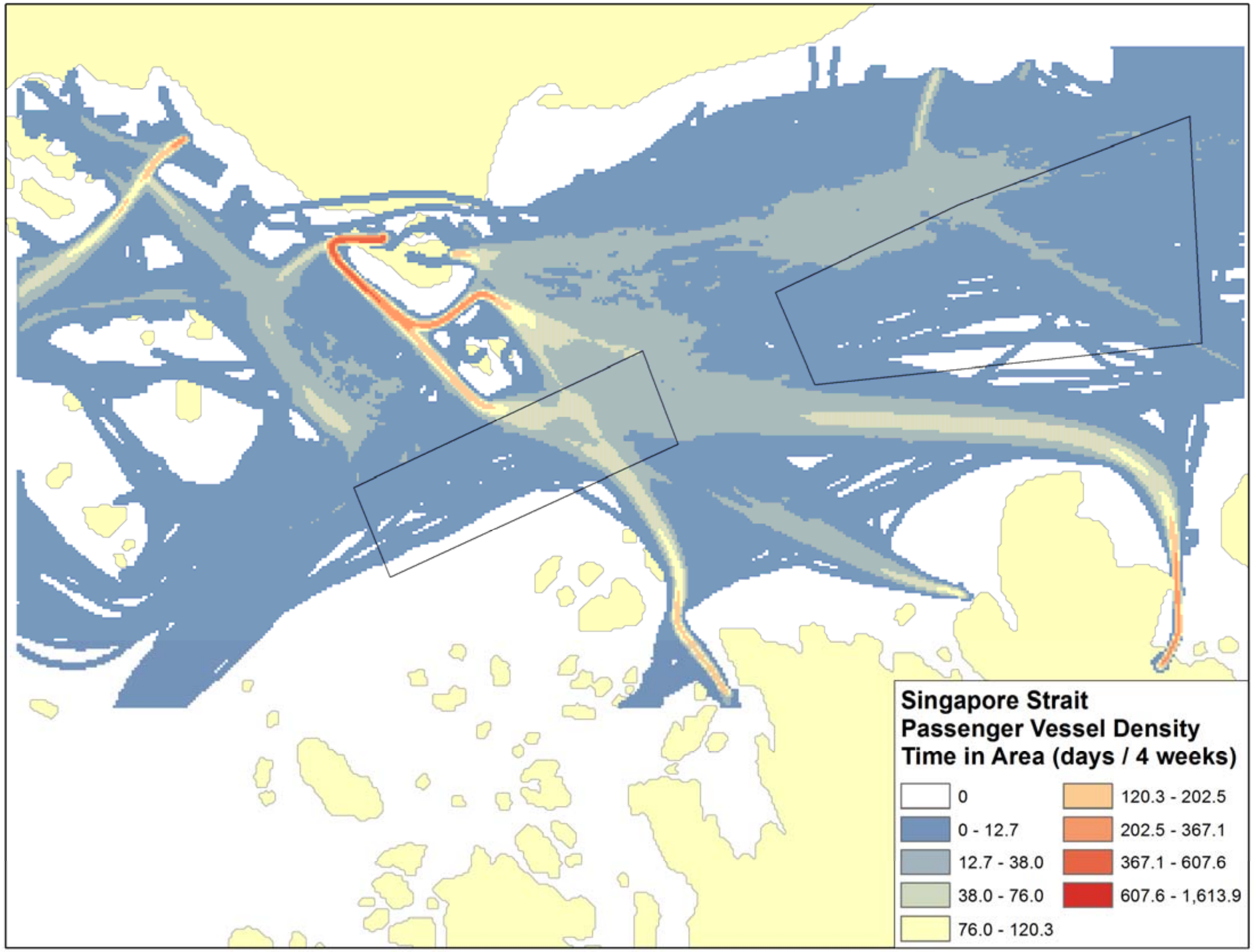

Figure 29 - Singapore Strait (2013) Passenger Vessel Density (Vessel - Days in area / 4 weeks)

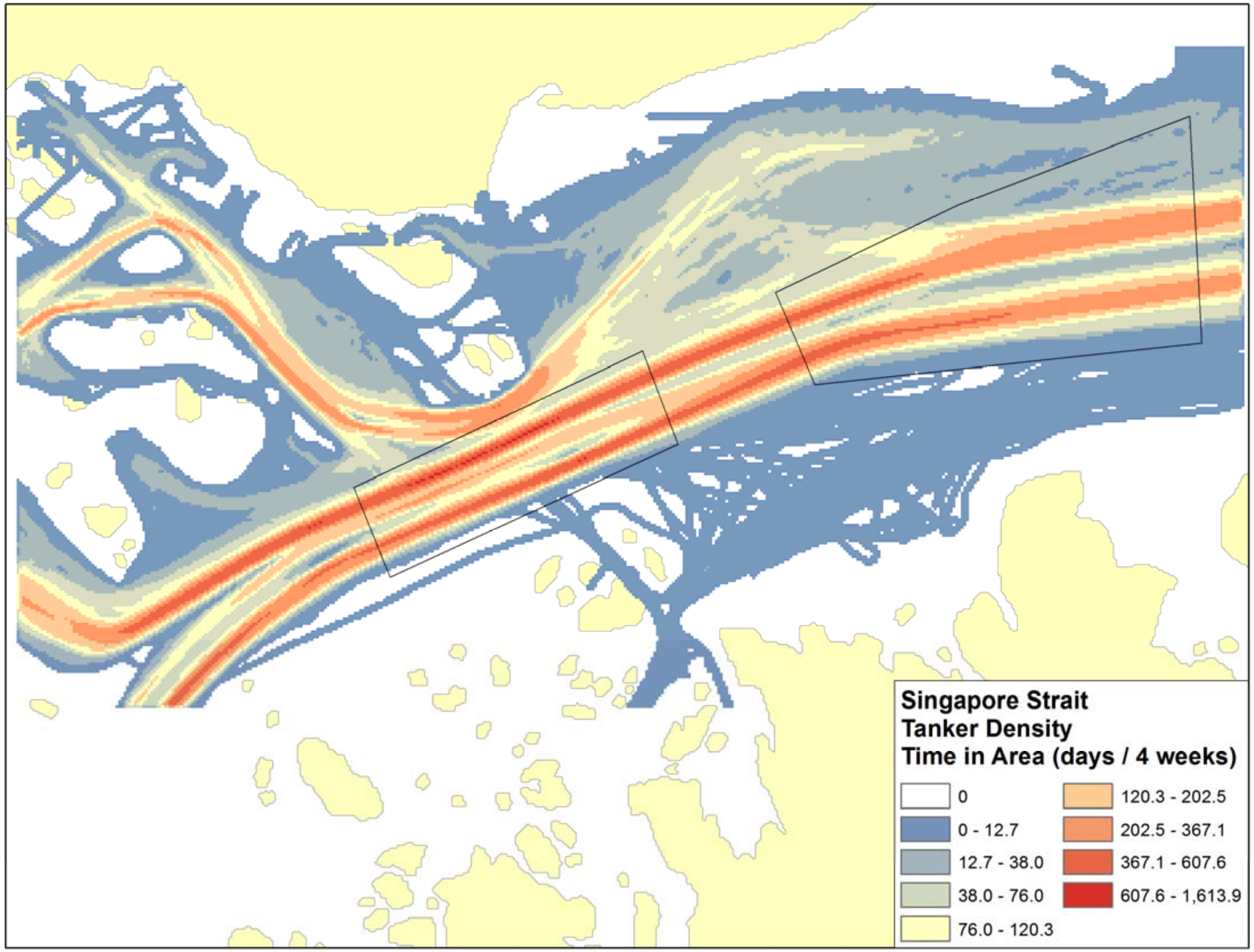

Figure 30 - Singapore Strait (2013) Tanker Density (Vessel - Days in area / 4 weeks)

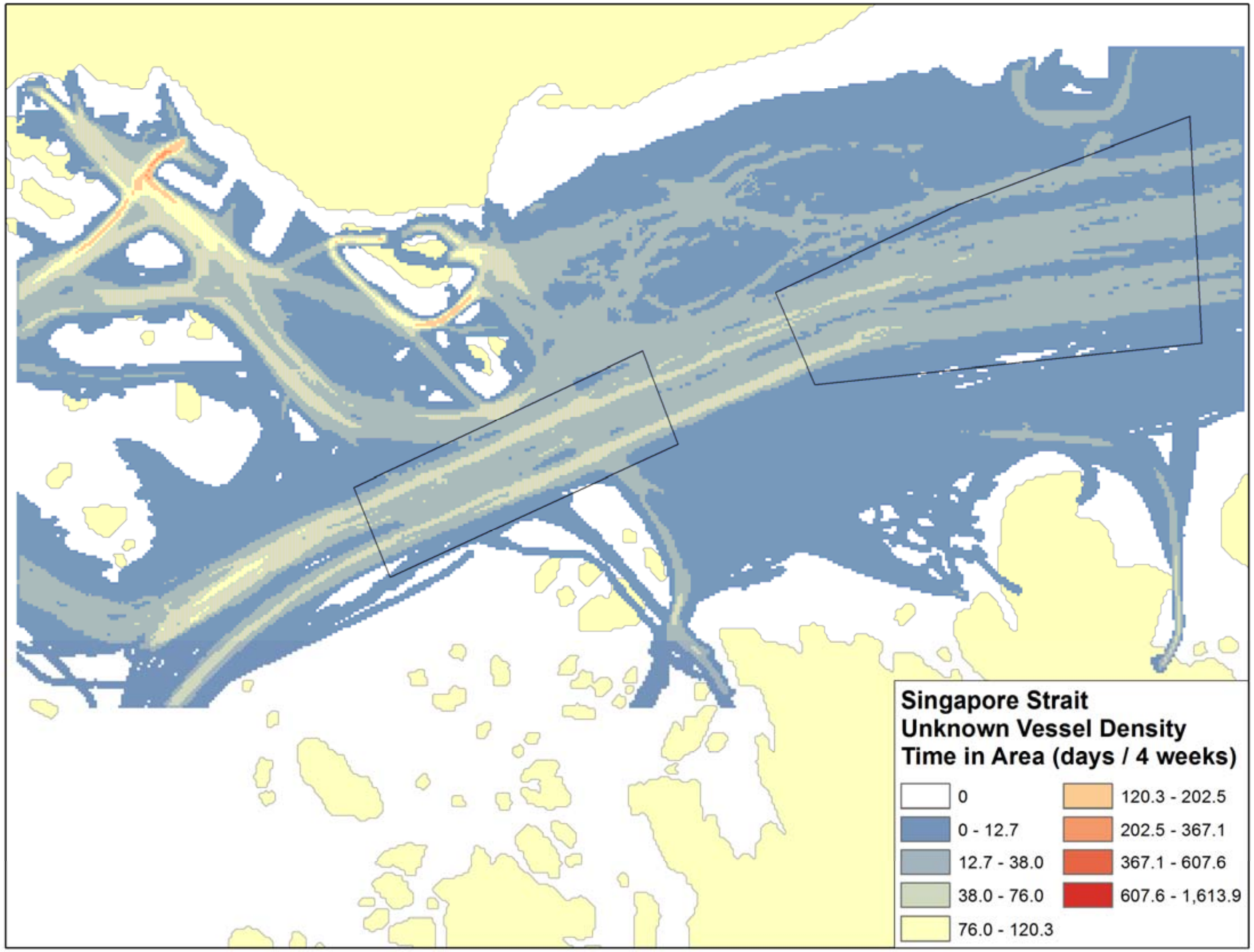

Figure 31 - Singapore Strait (2013) Other Type Vessel Density (Vessel - Days in area / 4 weeks)

4.2 San Francisco Bay Area

Gridded results of the traffic simulation results in the San Francisco Bay area for the 2013 dataset are presented in Figure 32 through Figure 46. As was done for the plots for the Singapore Strait area, the overall result plot is presented first, followed by temporally divided plots and concluding with plots for each of the ten vessel categories.

The plot of overall traffic in the area clearly depicts a bottleneck in the Golden Gate Bridge area, at the entrance to the Bay. This high density area extends into the precautionary area and TSS to its west and to a variety of Bay Area destinations to its east, including San Francisco to the south, Oakland directly east, Richardson and San Rafael Bay to the north west, Richmond to the north, and through the San Pablo Bay and Carquinez Strait extending further north and east. Of the three traffic lanes to the west of the area, the centre of the three, southwest to northeast appears to contain the greatest share of the traffic. While there do not appear to be many crossings of the TSS lanes themselves, the closely clustered nature of the high density paths in the centre of the area suggest that most of the traffic travels through an area in which encounters occur between vessels at multiple orientations. Of relevant note to TSS crossings generally, the high density traffic confluence does extend to the inner bay precautionary area.

As with the temporally separated plots for the Singapore Strait region, no exceptional features were noted as having significant seasonal variation. Some small temporal effect was noted on traffic in the vicinity of Half Moon Bay, outside the Bay, to the southeast of the TSS. For this area, traffic was noted to be present only in the July and October time periods.

In the San Francisco Bay AOI, some differentiation was noted between the various traffic types. From among the generated plots, the following features were considered notable:

Table 11 - Observations in San Francisco Bay AOI Traffic Plots (2013) by Type

Vessel Type	Observations
Cargo Vessels	• Noted to observe TSS lanes • Generally destined to Oakland or north through San Pablo Bay and Carquinez Strait
Fishing Vessels	• Very low volume • Small hotspot at mouth of Bay
Tug / Harbour Svc.	• High volume noted • Primarily utilizing southwest-northeast traffic lane • Traffic between: mouth of Bay, SF port, Oakland, Richmond, Redwood and north through San Pablo Bay and Carquinez Strait
High Speed Craft	• Low volume noted • Noted running between SF port and Richardson bay, likely as ferry
Pleasure Craft	• Moderate volume noted • Patterns diffuse, running through centre of Bay

Vessel Type	Observations
Unreferenced Vessels	• Single path only noted
Other Type Vessels	• Low volume noted • Patterns diffuse, running through centre of Bay

Passenger Vessels	• Moderate to high volume noted
	• Several ferry paths evident by density:
	  o Golden Gate Ferry
	  o Tiburon to San Francisco
	  o Sausalito to San Francisco
	  o Angel Island to San Francisco
	  o Oakland to San Francisco
	  o Vallejo to San Francisco
	  o Oyster Point to Oakland
	• Several ferry paths cross the in-Bay precautionary area

Tankers	• Moderate to low volume noted • Primarily utilizing southwest-northeast traffic lane • Generally destined to San Francisco, Richmond or north through San Pablo Bay and Carquinez Strait
Unknown Type Vessels	• Low volume noted • Similar in extent to passenger vessel traffic

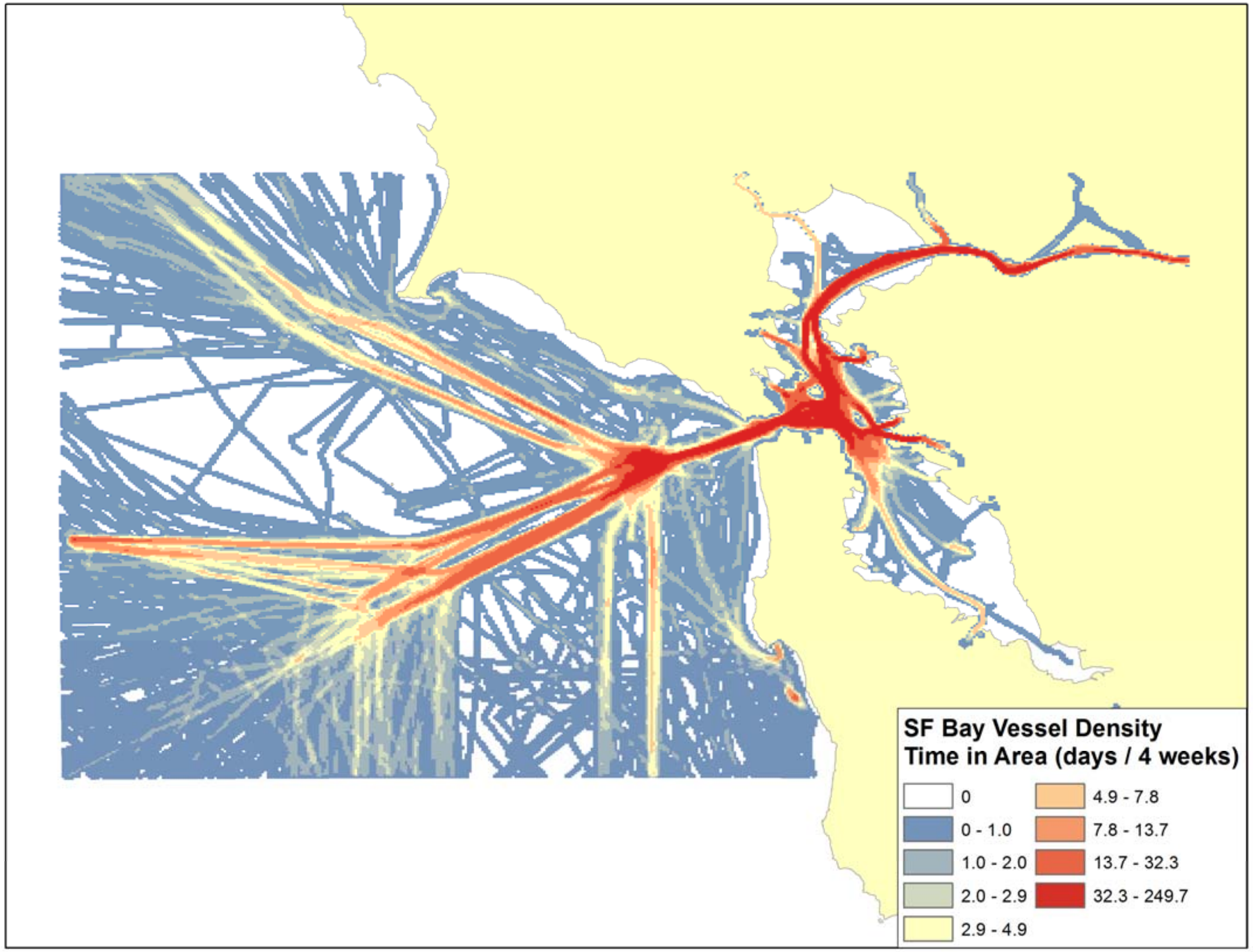

Figure 32 - San Francisco Bay Area Overall (2013) Vessel Density (Vessel - Days in area / 4 weeks)

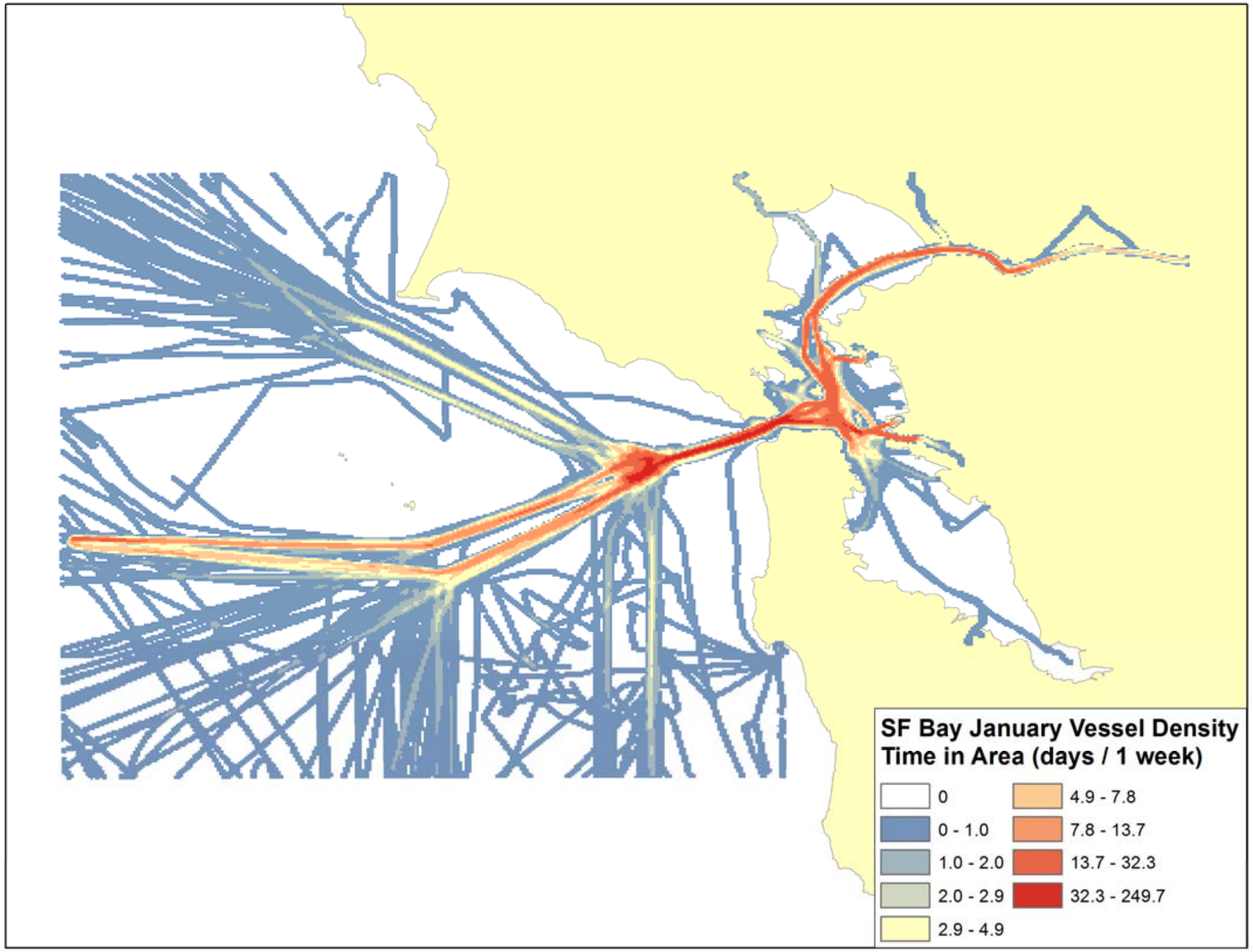

Figure 33 - San Francisco Bay Area January (2013) Vessel Density (Vessel - Days in area / 1 week)

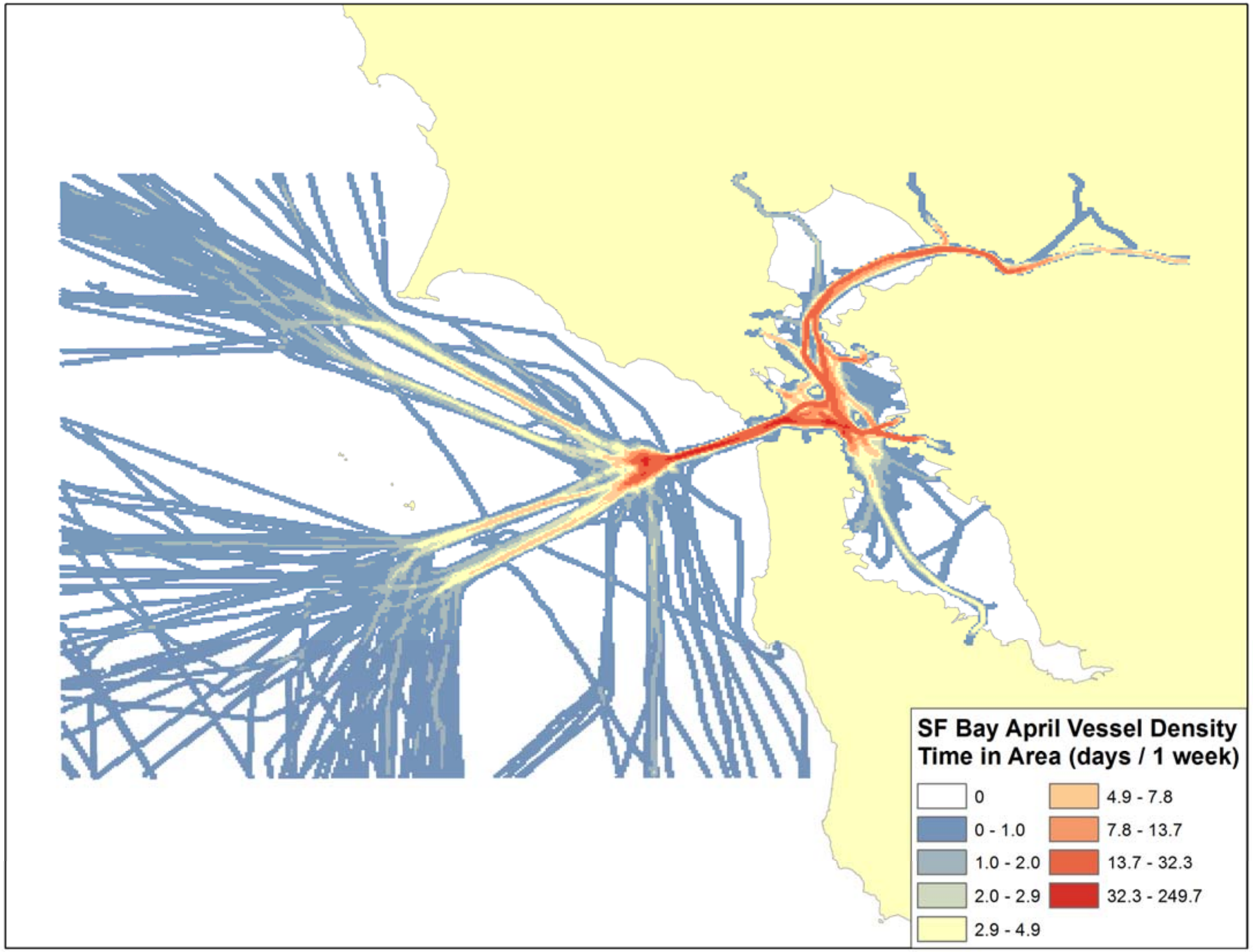

Figure 34 - San Francisco Bay Area April (2013) Vessel Density (Vessel - Days in area / 1 week)

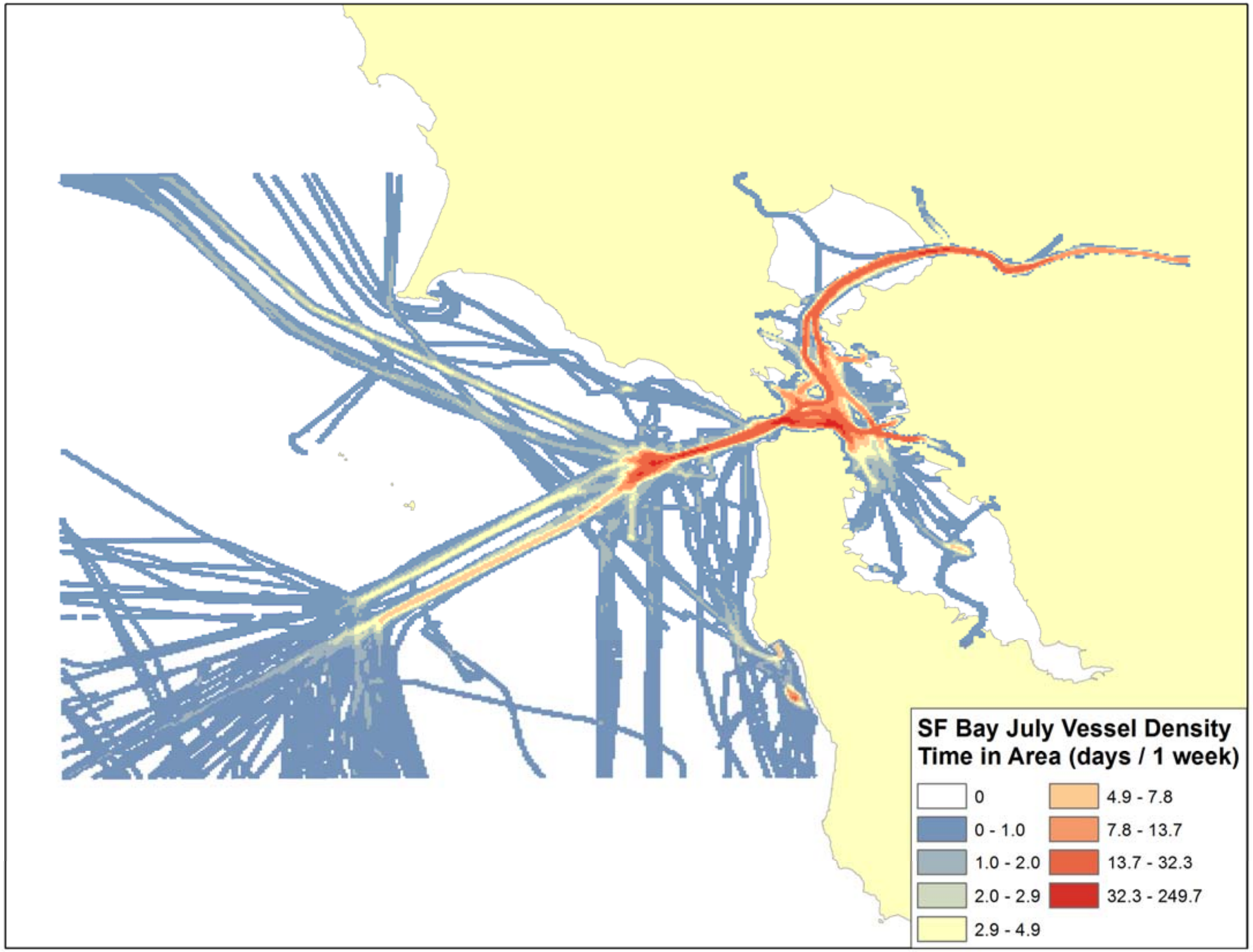

Figure 35 - San Francisco Bay Area July (2013) Vessel Density (Vessel - Days in area / 1 week)

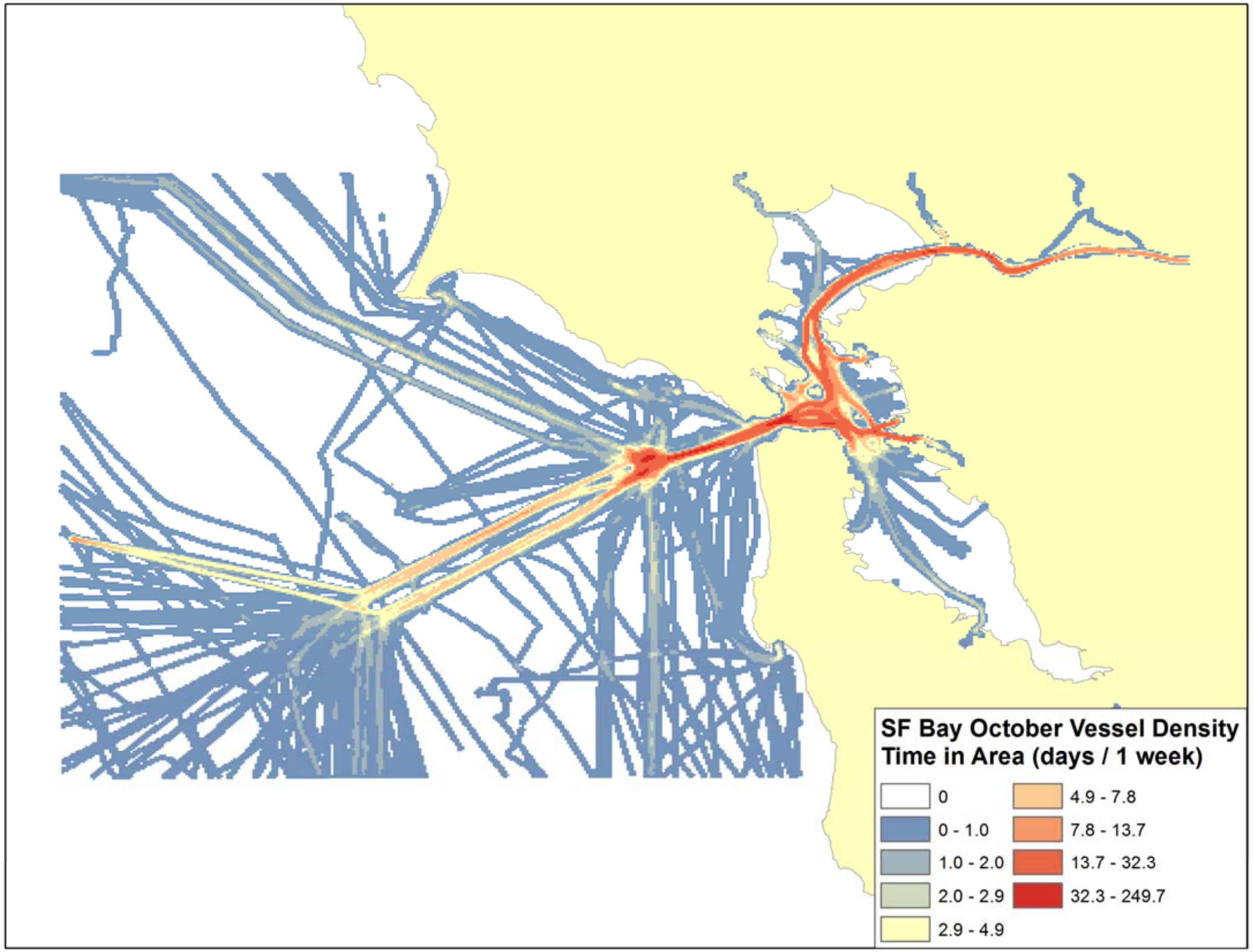

Figure 36 - San Francisco Bay Area October (2013) Vessel Density (Vessel - Days in area / 1 week)

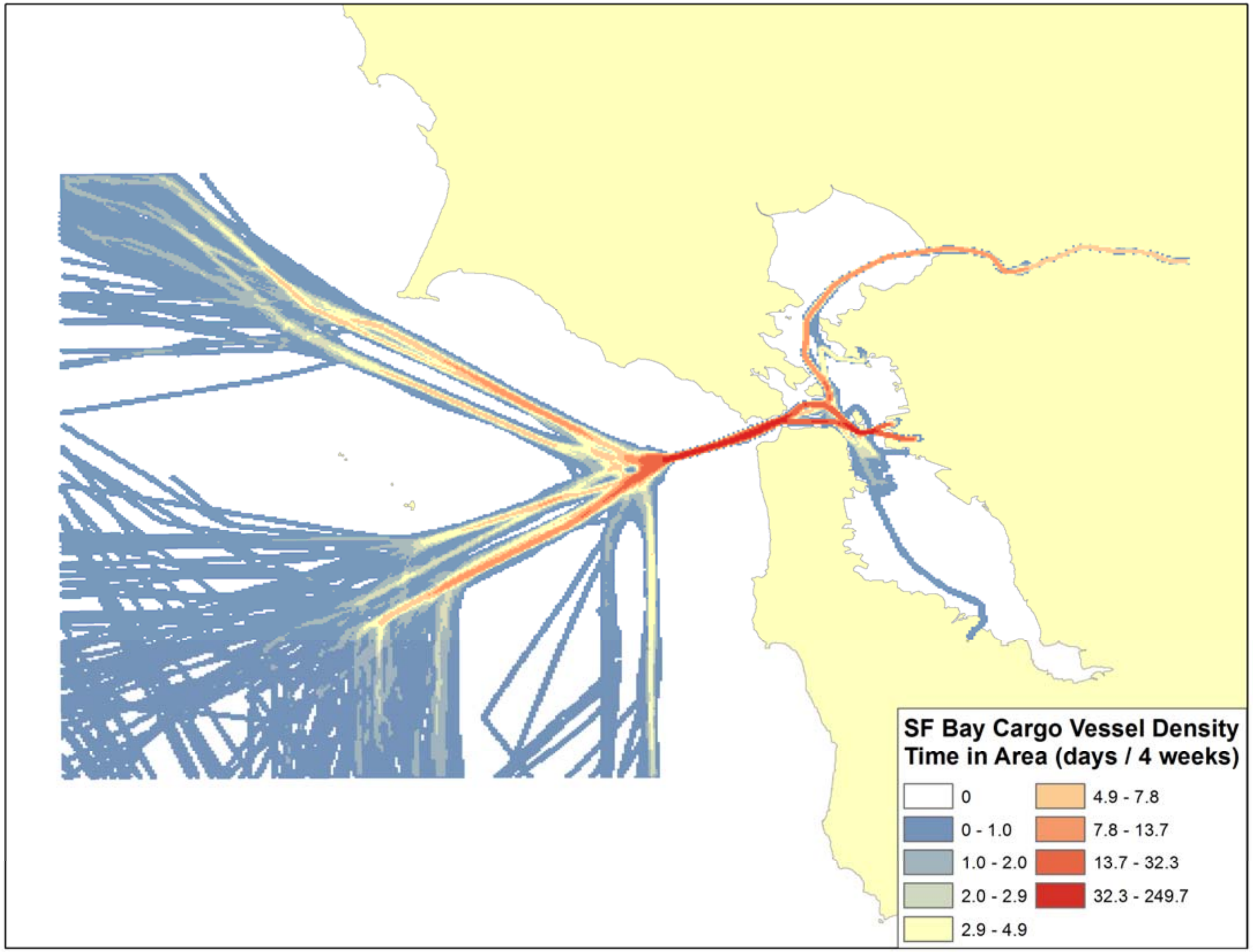

Figure 37 - San Francisco Bay Area (2013) Cargo Vessel Density (Vessel - Days in area / 4 weeks)

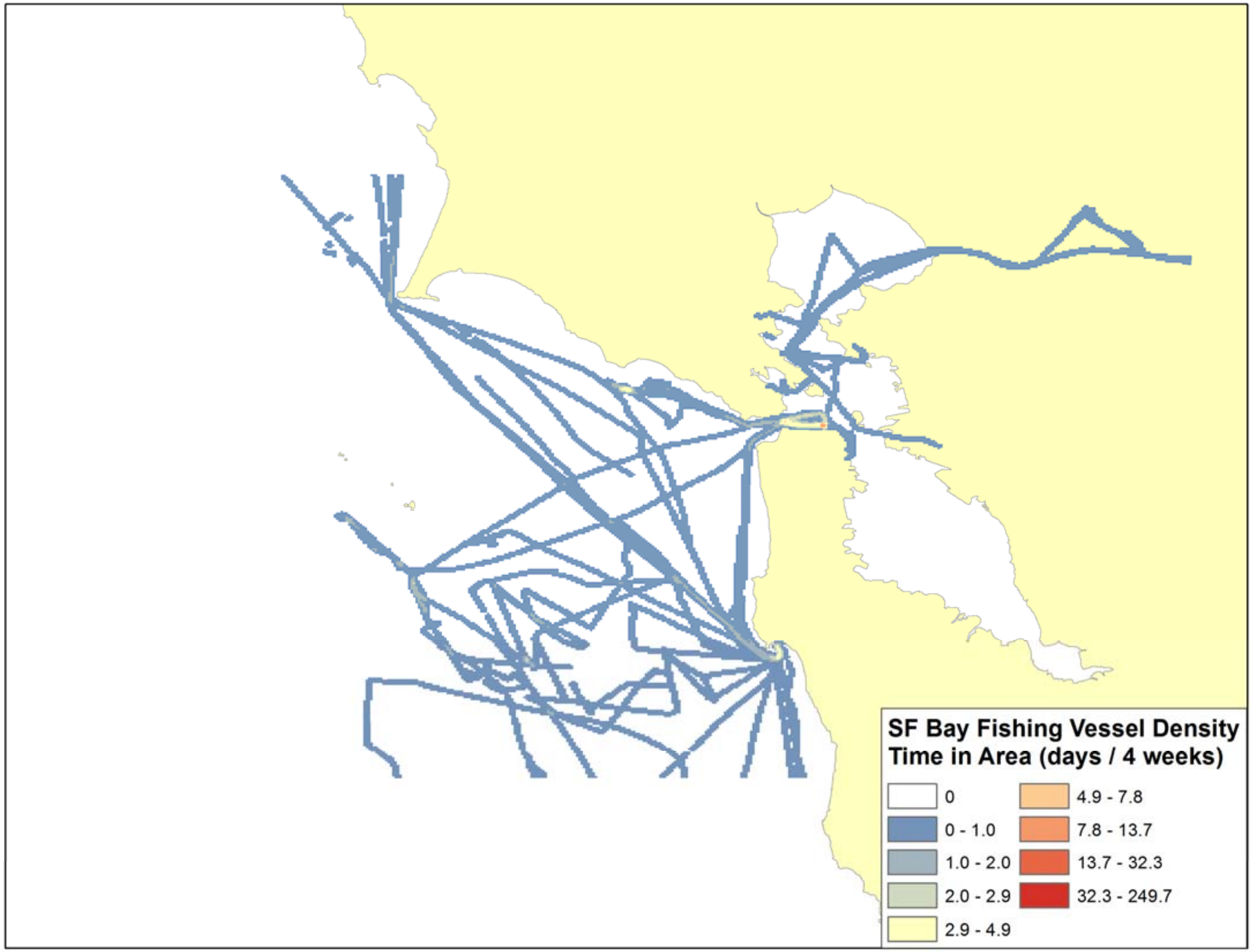

Figure 38 - San Francisco Bay Area (2013) Fishing Vessel Density (Vessel - Days in area / 4 weeks)

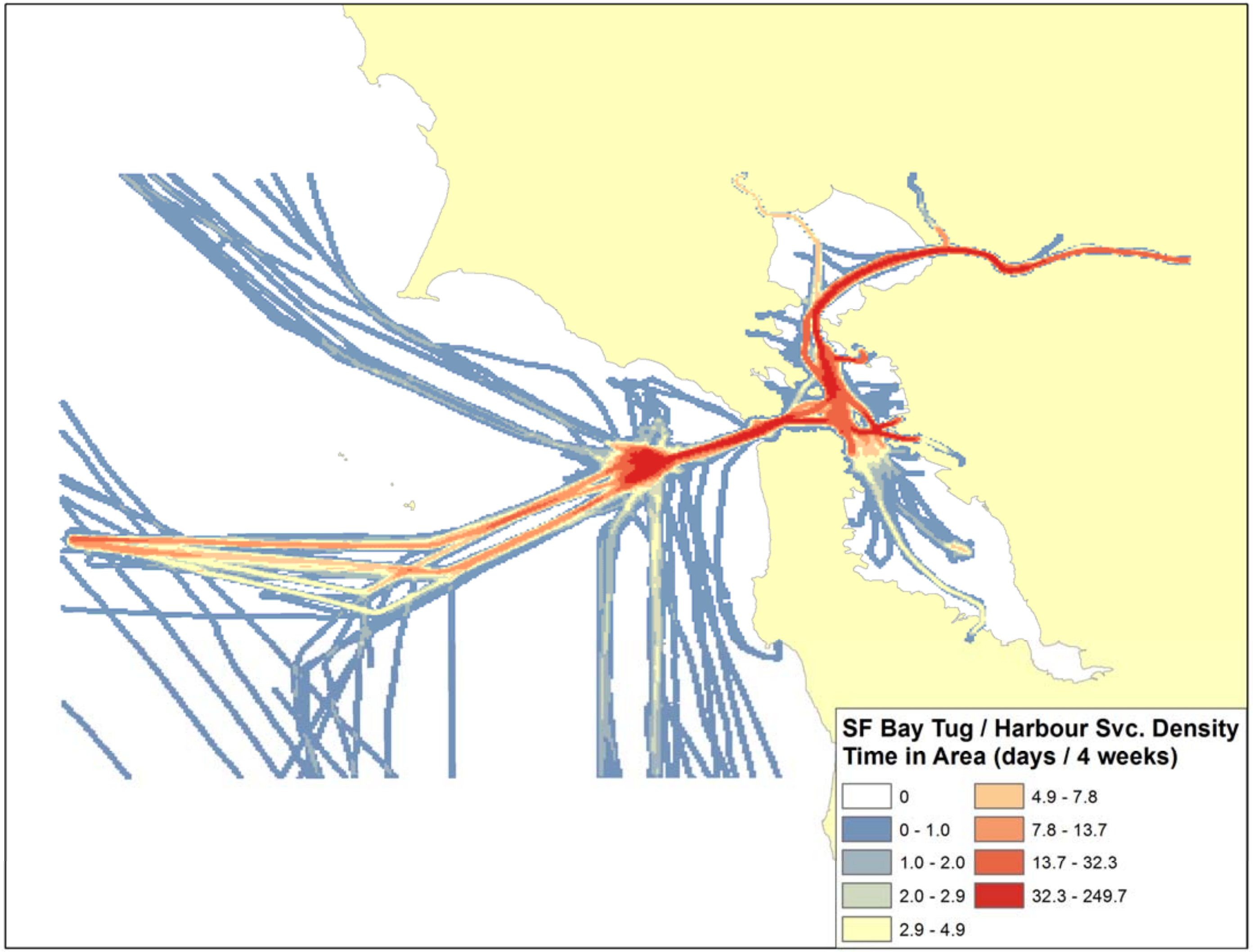

Figure 39 - San Francisco Bay Area (2013) Tug / Harbour Service Vessel Density (Vessel - Days in area / 4 weeks)

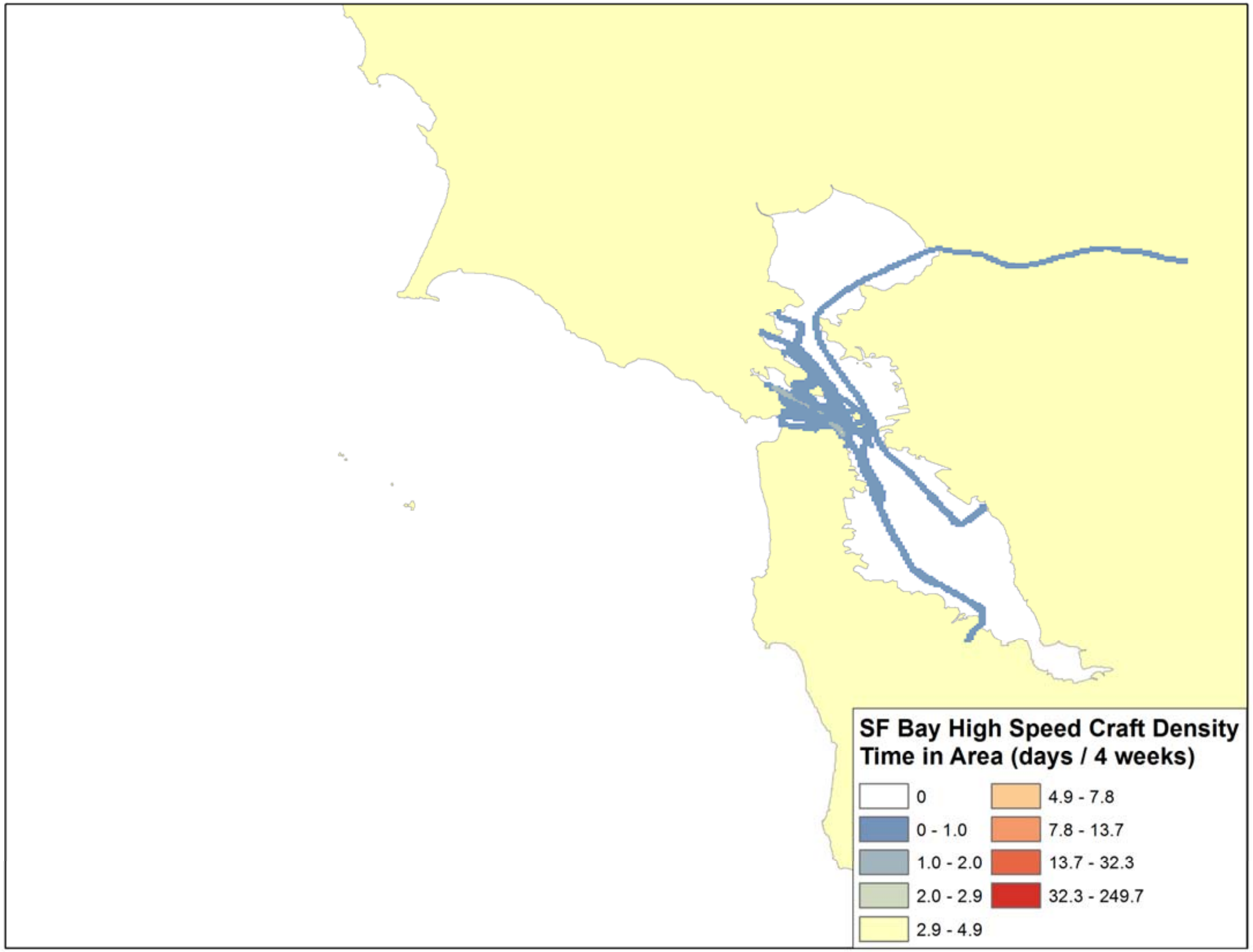

Figure 40 - San Francisco Bay Area (2013) High Speed Craft Density (Vessel - Days in area / 4 weeks)

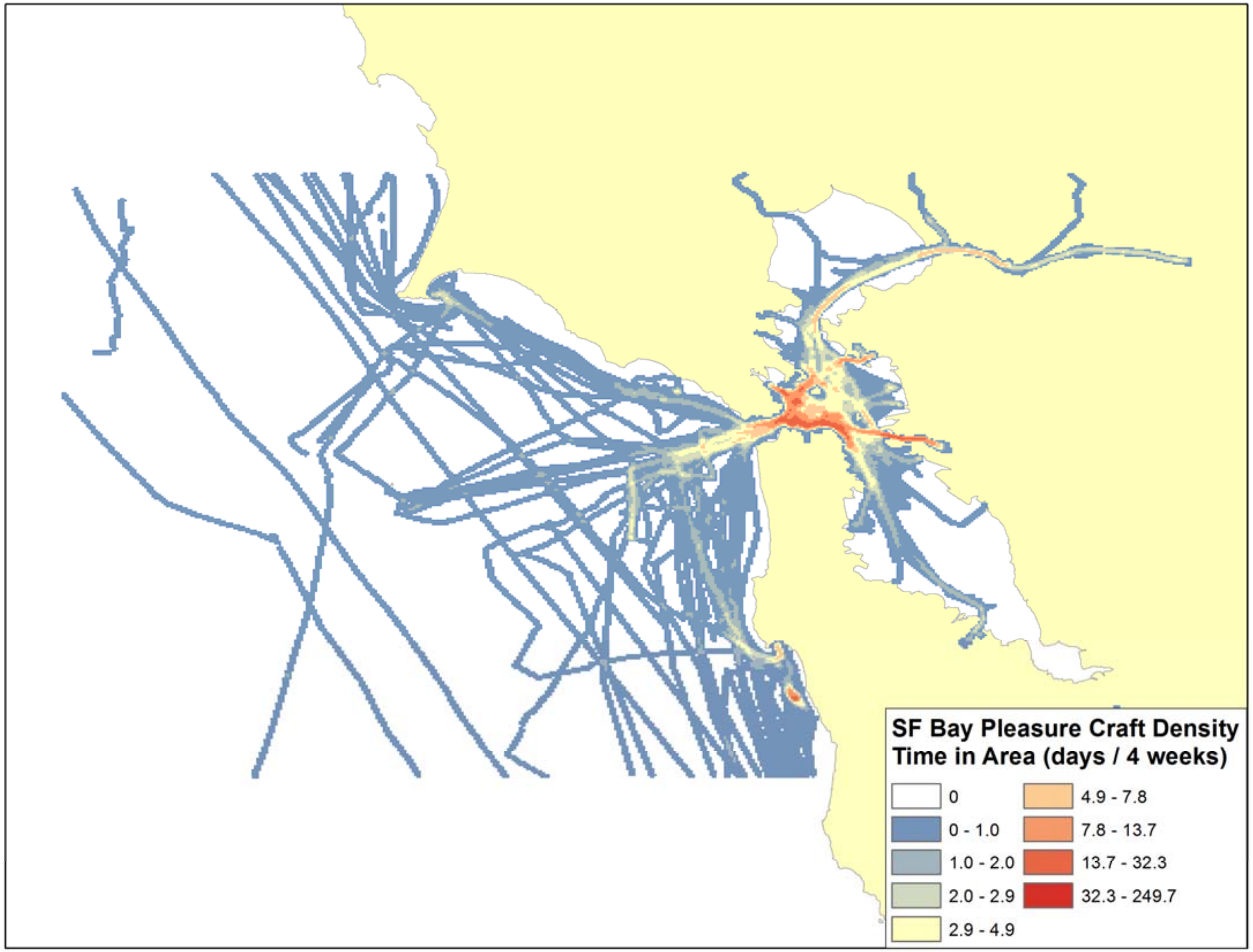

Figure 41 - San Francisco Bay Area (2013) Pleasure Craft Density (Vessel - Days in area / 4 weeks)

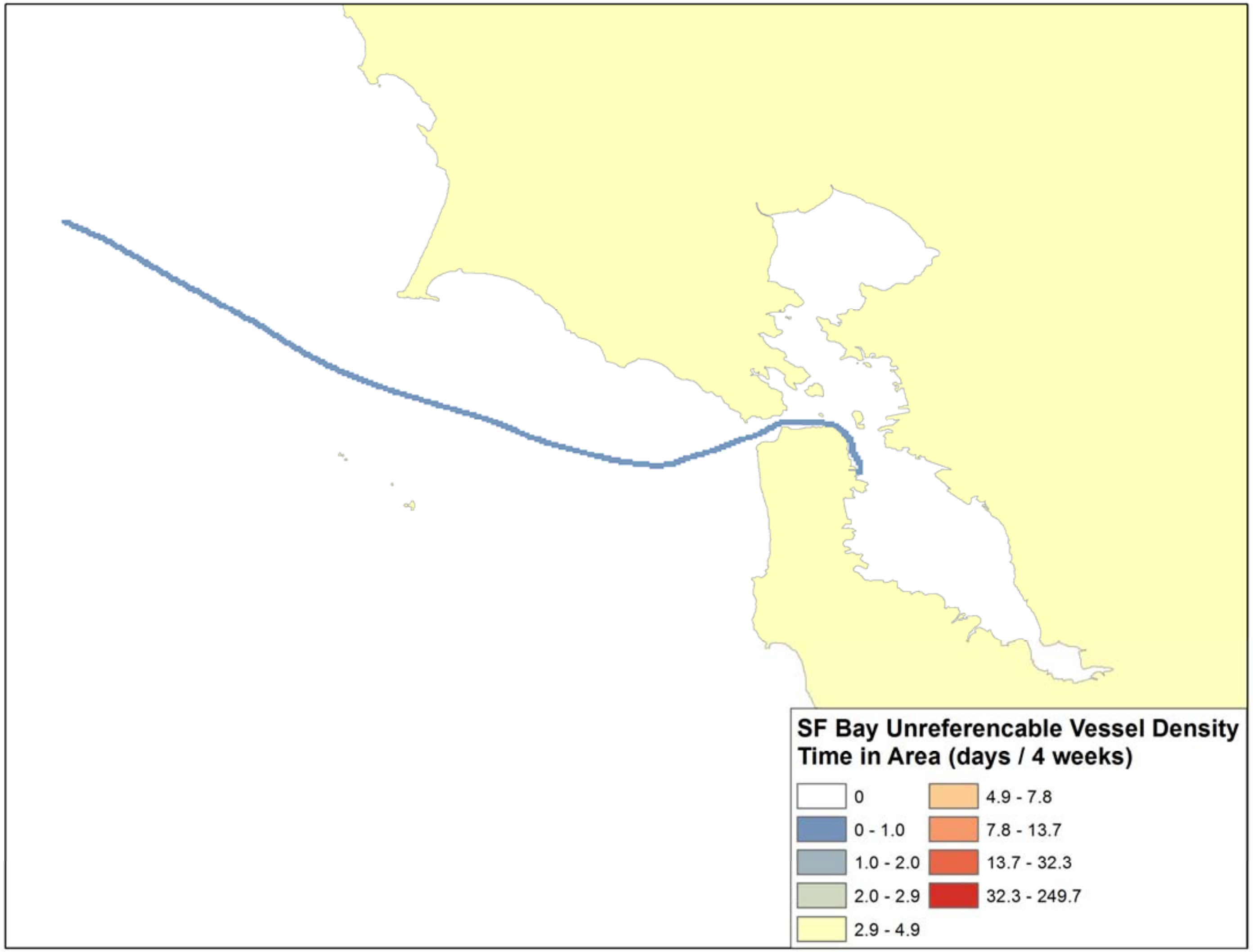

Figure 42 - San Francisco Bay Area (2013) Unreferencable Vessel Density (Vessel - Days in area / 4 weeks)

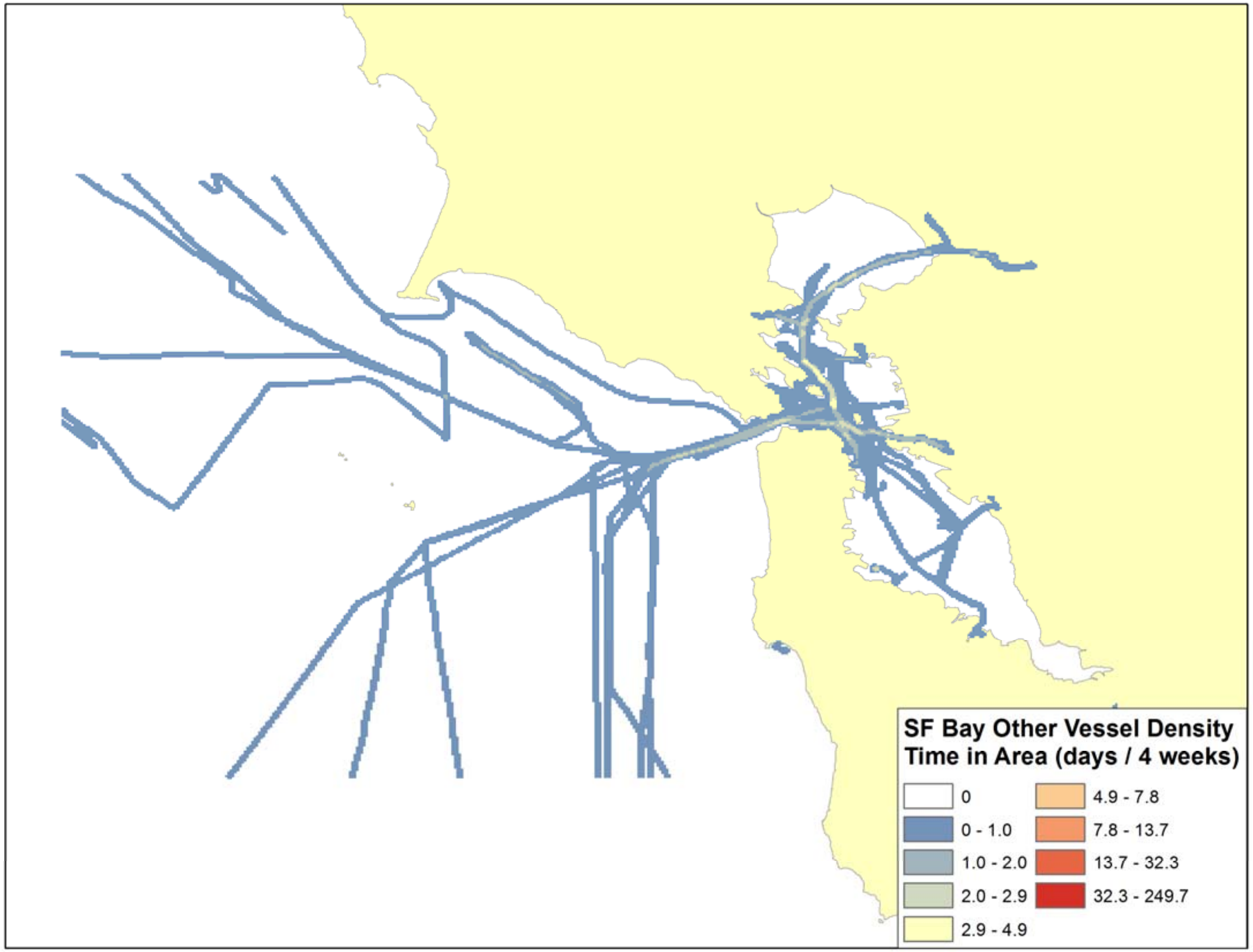

Figure 43 - San Francisco Bay Area (2013) Other Type Vessel Density (Vessel - Days in area / 4 weeks)

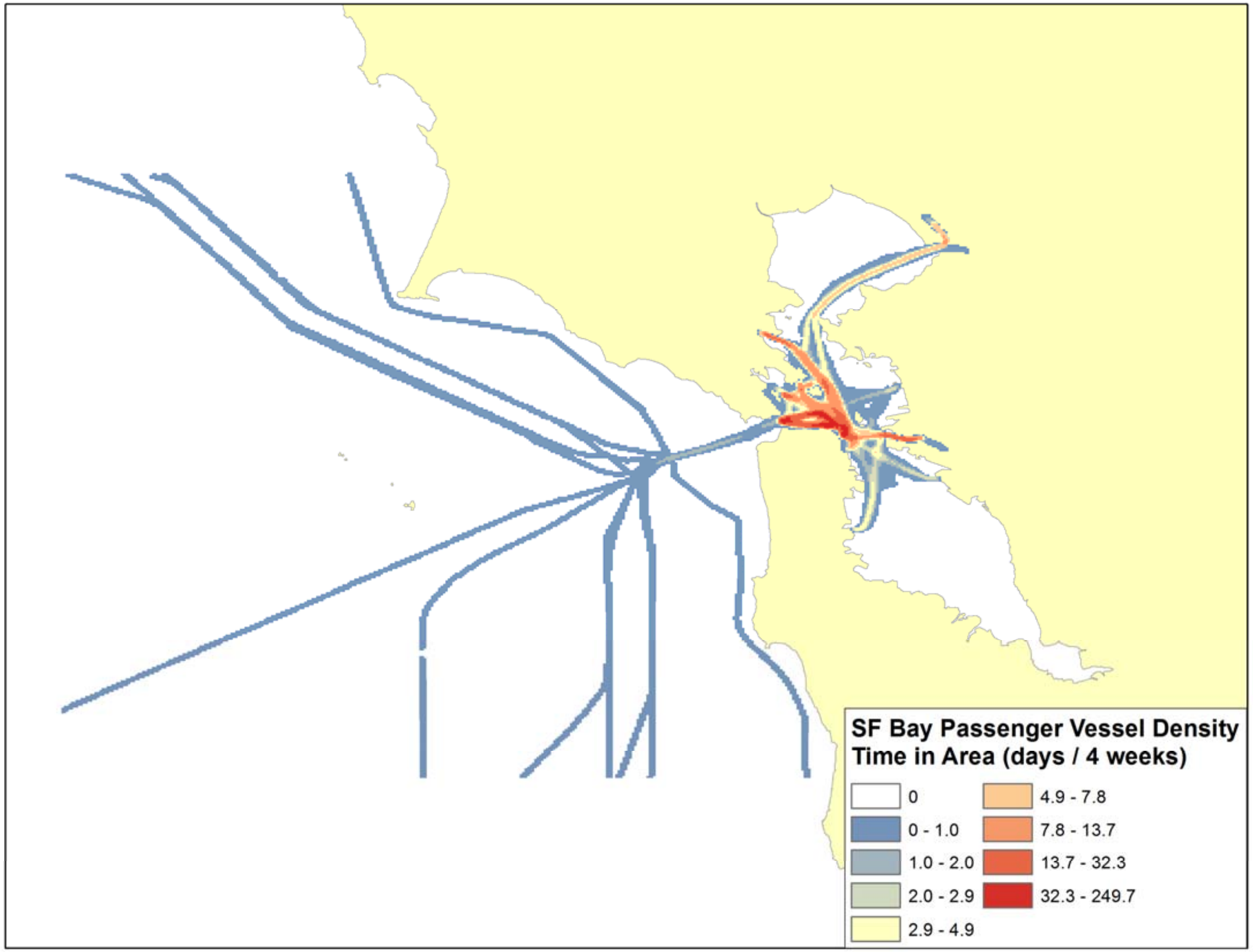

Figure 44 - San Francisco Bay Area (2013) Passenger Vessel Density (Vessel - Days in area / 4 weeks)

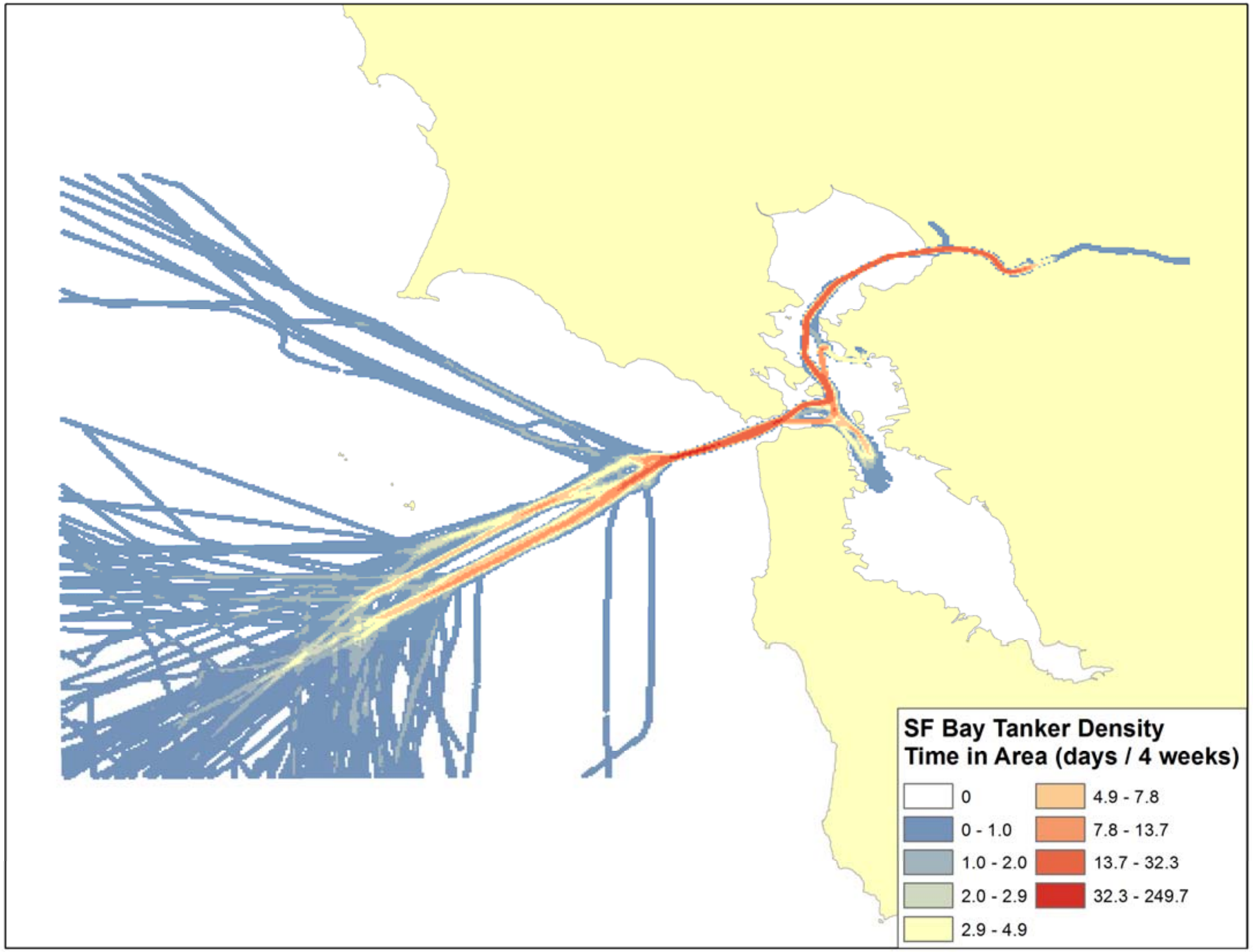

Figure 45 - San Francisco Bay Area (2013) Tanker Density (Vessel - Days in area / 4 weeks)

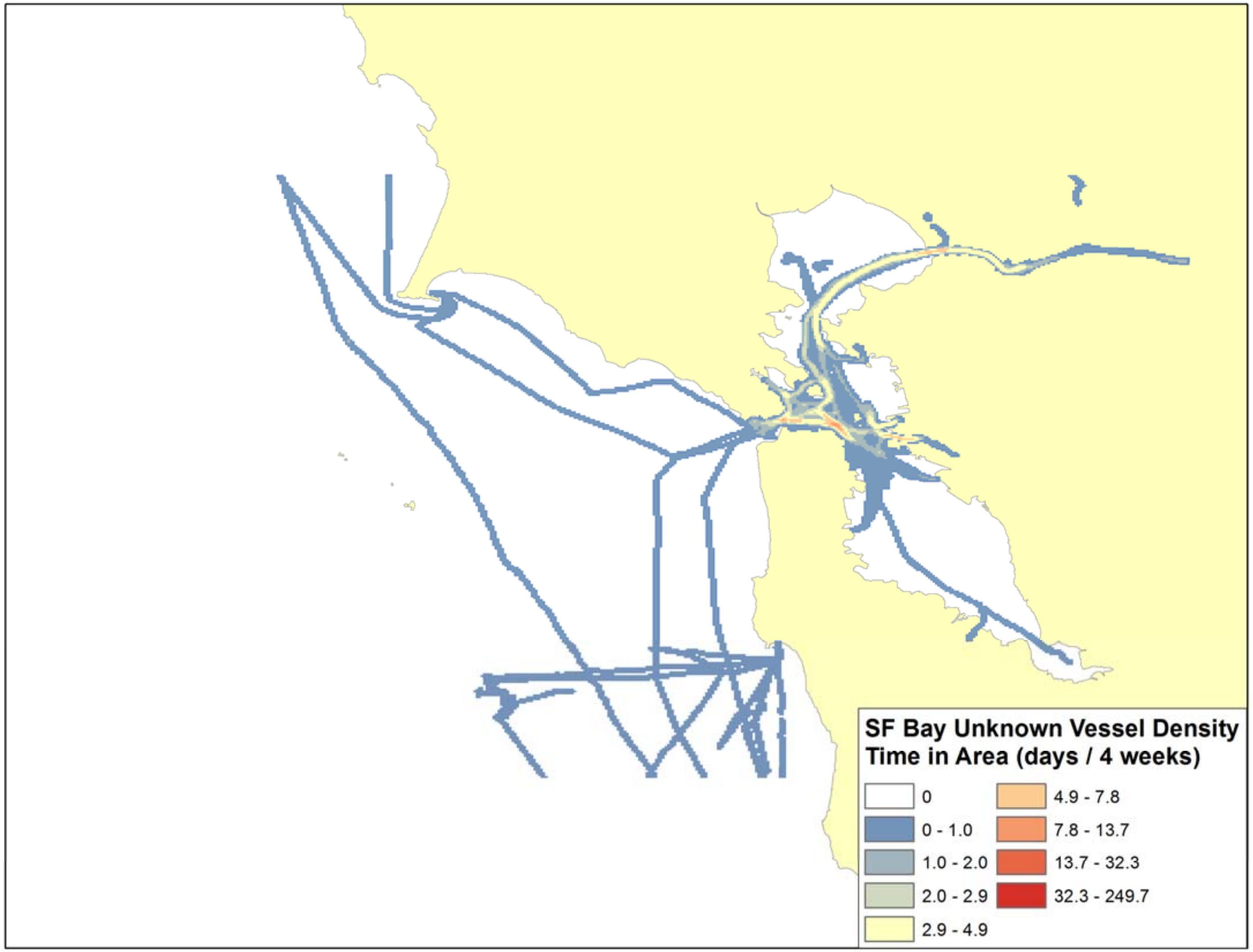

Figure 46 - San Francisco Bay Area (2013) Unknown Type Vessel Density (Vessel - Days in area / 4 weeks)

4.3 English Channel

The results of interpolating the simulated historic vessel traffic segments for the English Channel 2012 dataset are included in this section as Figure 47 through Figure 61. Similarly to the other two regions, a summary plot is presented first, followed by temporally divided plots and concluding with plots for each of the ten vessel categories.

Within the English Channel overall plot, the key traffic feature in terms of density is the pair of southwest to northeast running traffic lanes. Traffic is also notable in the eastbound fork of the TSS ("At West Hinder") and around the Sunk Precautionary Area in the Thames Estuary. Most critical in terms of crossing assessment are the area around the TSS fork, and the crossings between Dover and Calais / Dunkirk.

In the English Channel AOI, some seasonality was noted in that in the April and October samples, traffic heading to and from the East of the TSS via the eastbound fork was greatly diminished. Drivers for this difference were not identified.

The plots of data by traffic type were reviewed, and a number of differences identified in the density patterns exhibited by the different types. Categorized by type, the following features were considered notable:

Table 12 - Observations in English Channel AOI Traffic Plots (2012) by Type

Vessel Type	Observations
Cargo Vessels	• High volume noted • Densities primarily constrained to TSS lanes
Fishing Vessels	• Moderate to low volume noted • Densities diffused across much of AOI • Hotspots suggest homeports of Eastbourne and Boulogne-sur-Mer
Tug / Harbour Svc.	• Moderate to low volume noted • Densities diffused across much of AOI
High Speed Craft	• Single trajectory identified from Ramsgate heading north
Pleasure Craft	• Low volume noted • Densities diffused across much of AOI with some Dover to Calais crossing evident
Unreferenced Vessels	• Low volume noted • Densities diffused across much of AOI with some Dover to Calais crossing evident
Other Type Vessels	• Moderate to low volume noted • Some along-lane traffic noted • Hotspot noted near Dunkirk

Vessel Type	Observations
Passenger Vessels	• Moderate volume noted • Dover to Calais and Dunkirk crossings clear
Tankers	• Moderate volume noted • Densities primarily constrained to TSS lanes
Unknown Type Vessels	• Low volume noted • Densities diffused across AOI with some traffic in TSS lanes

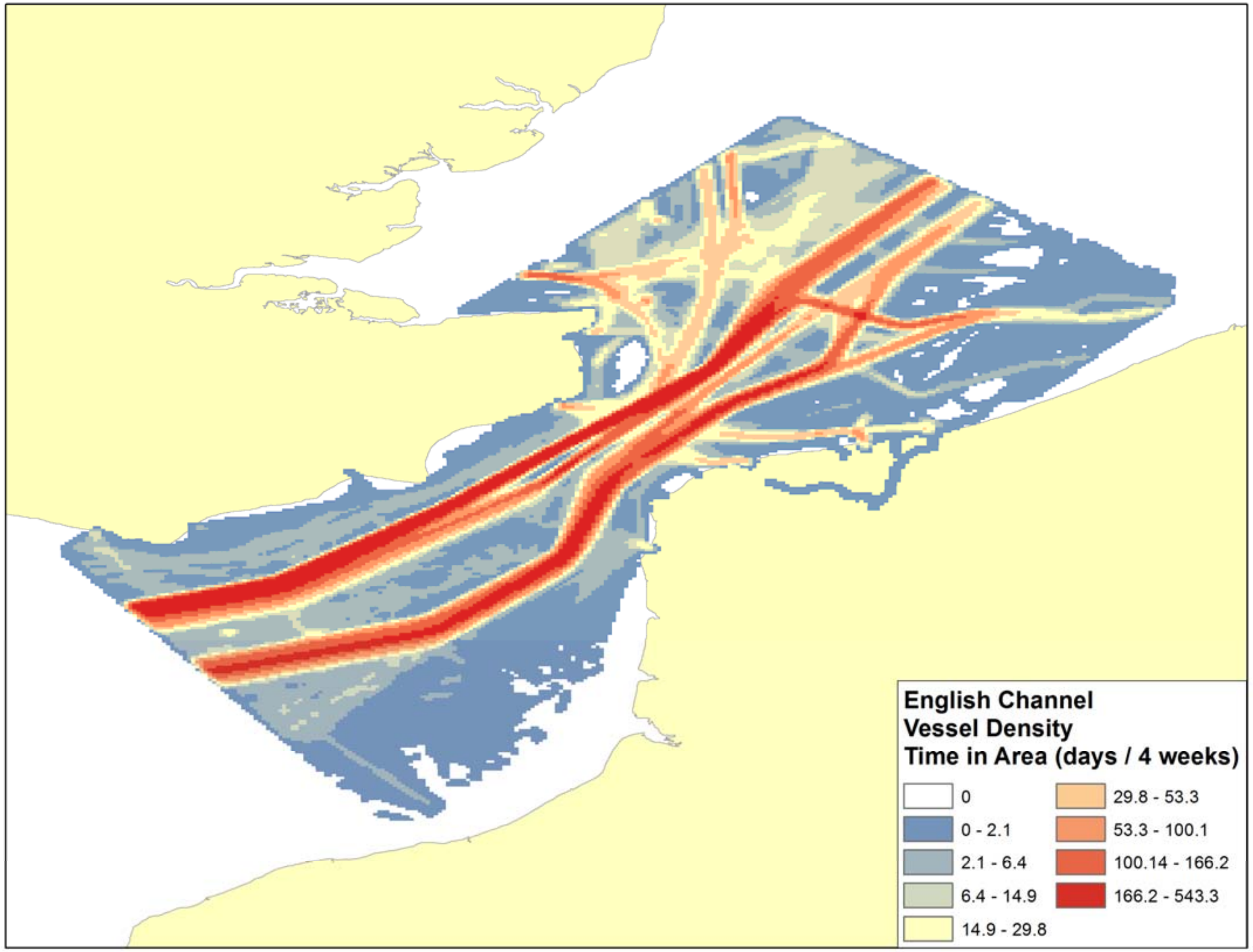

Figure 47 - English Channel Area Overall (2012) Vessel Density (Vessel - Days in area / 4 weeks)

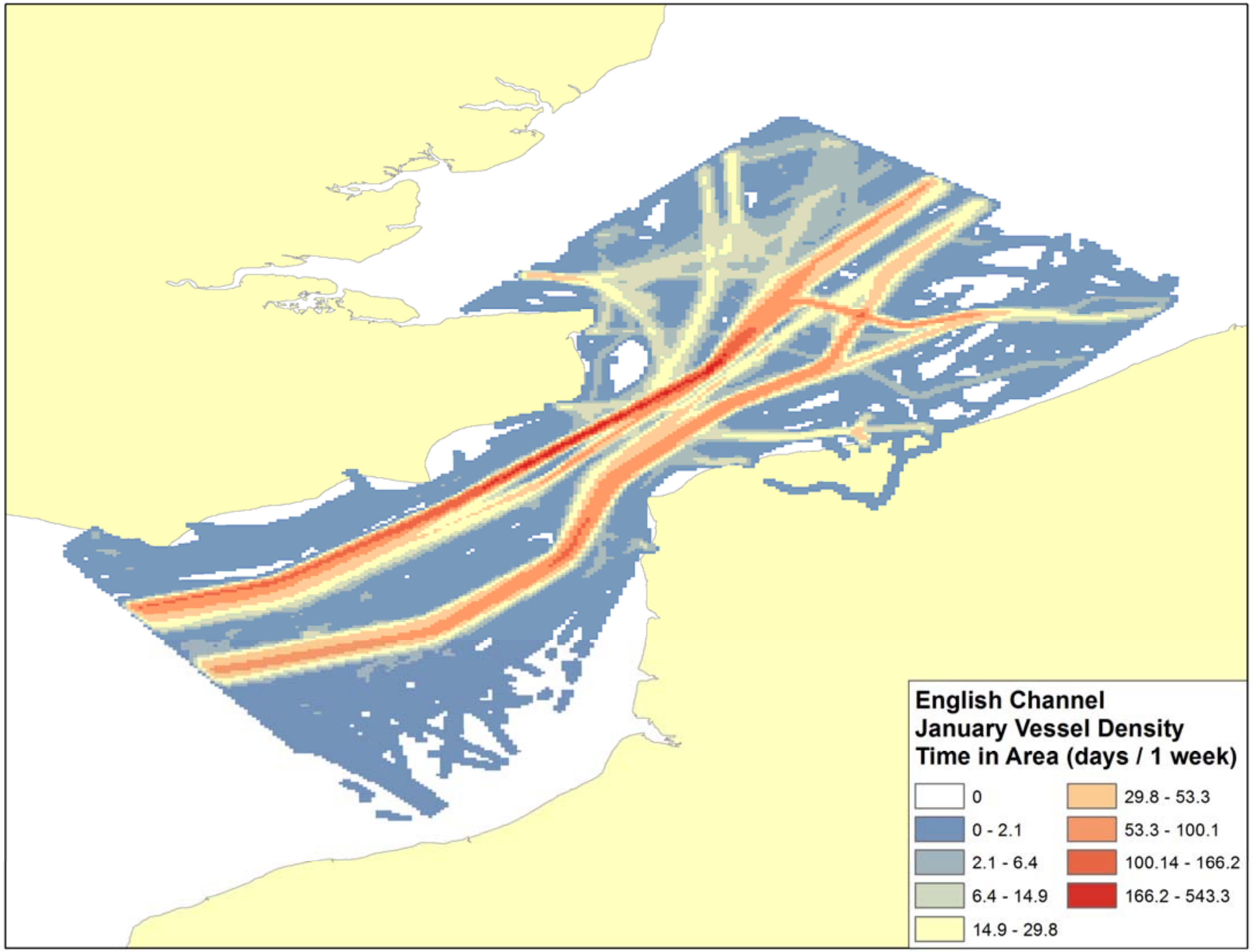

Figure 48 - English Channel Area January (2012) Vessel Density (Vessel - Days in area / 1 week)

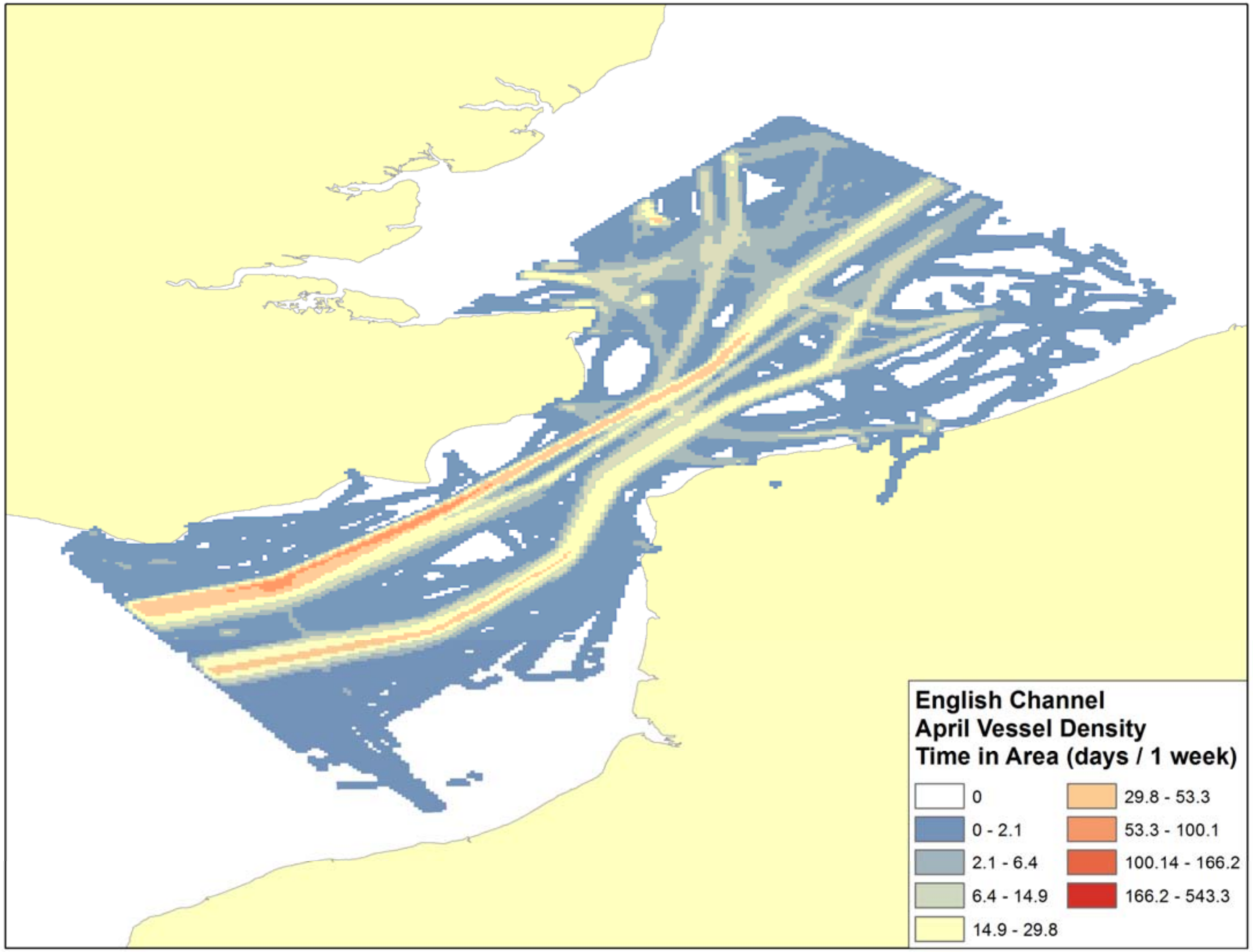

Figure 49 - English Channel Area April (2012) Vessel Density (Vessel - Days in area / 1 week)

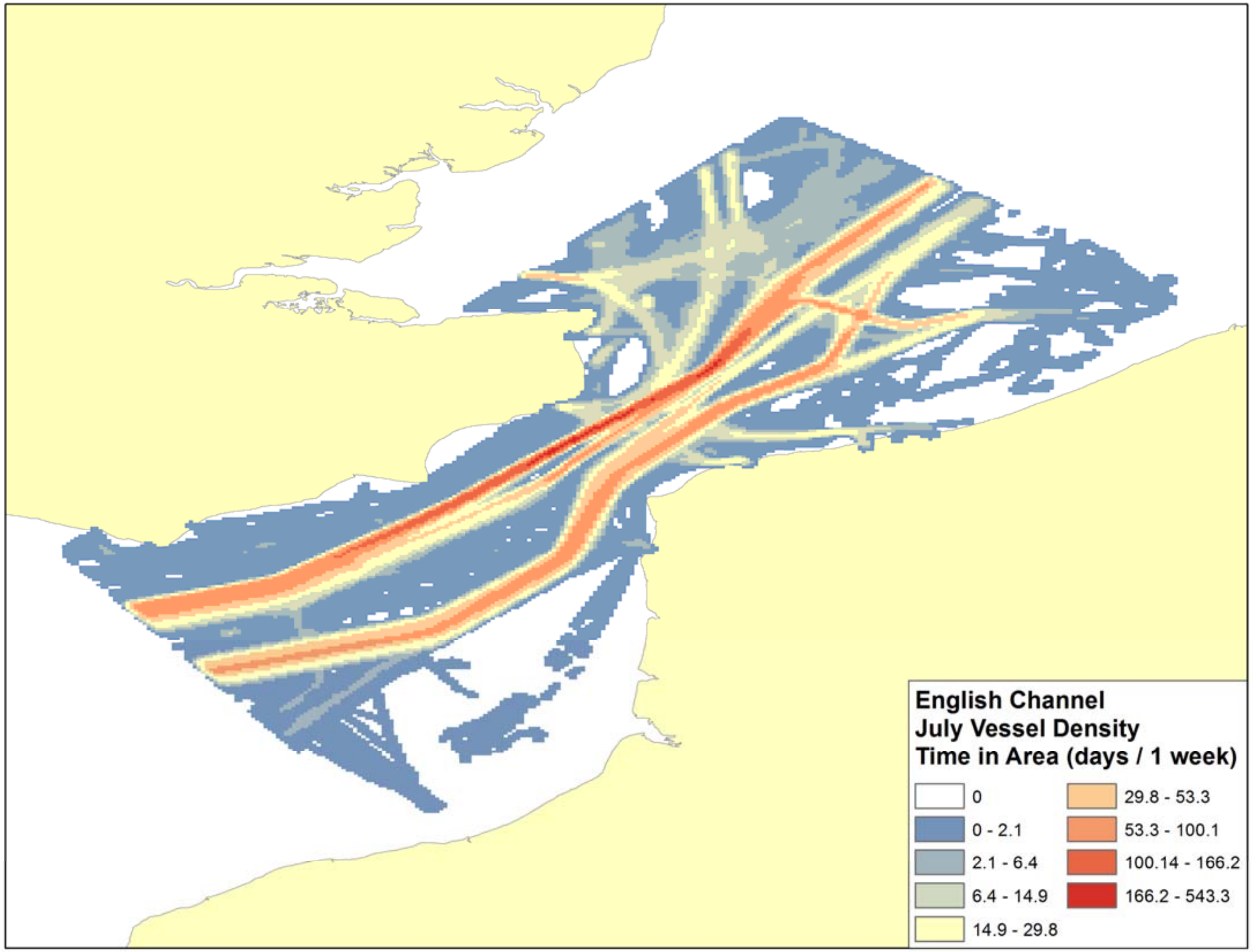

Figure 50 - English Channel Area July (2012) Vessel Density (Vessel - Days in area / 1 week)

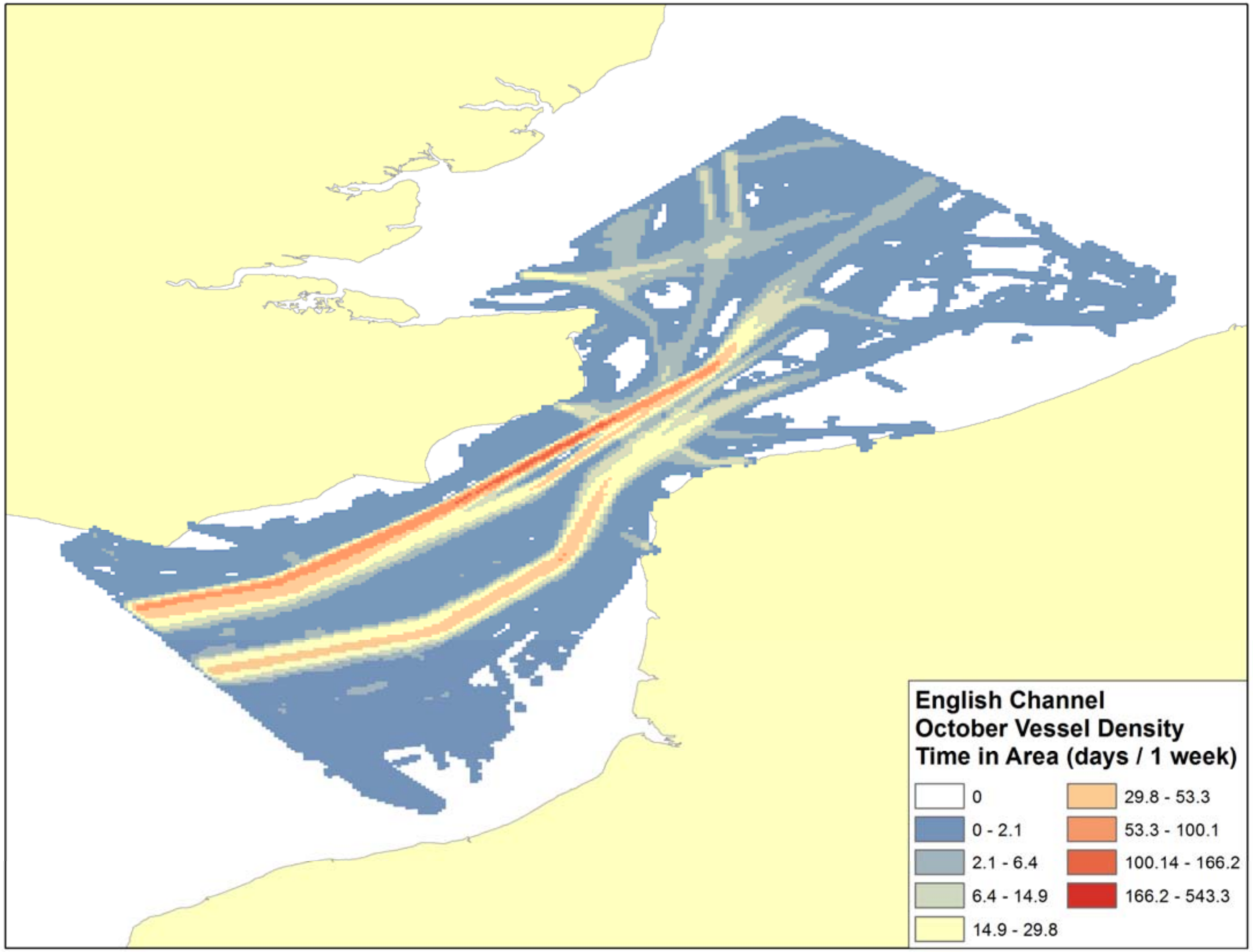

Figure 51 - English Channel Area October (2012) Vessel Density (Vessel - Days in area / 1 week)

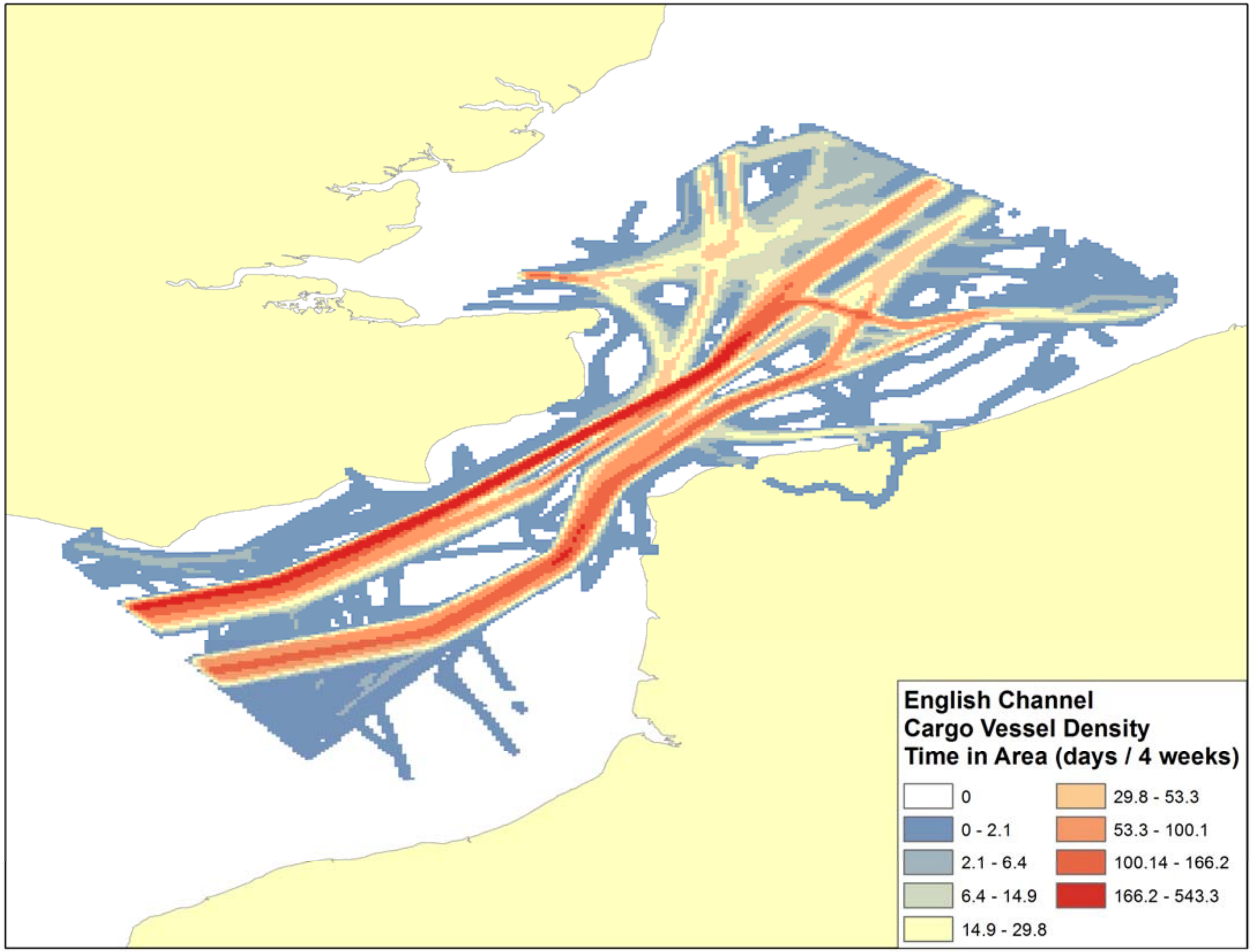

Figure 52 - English Channel Area (2012) Cargo Vessel Density (Vessel - Days in area / 4 weeks)

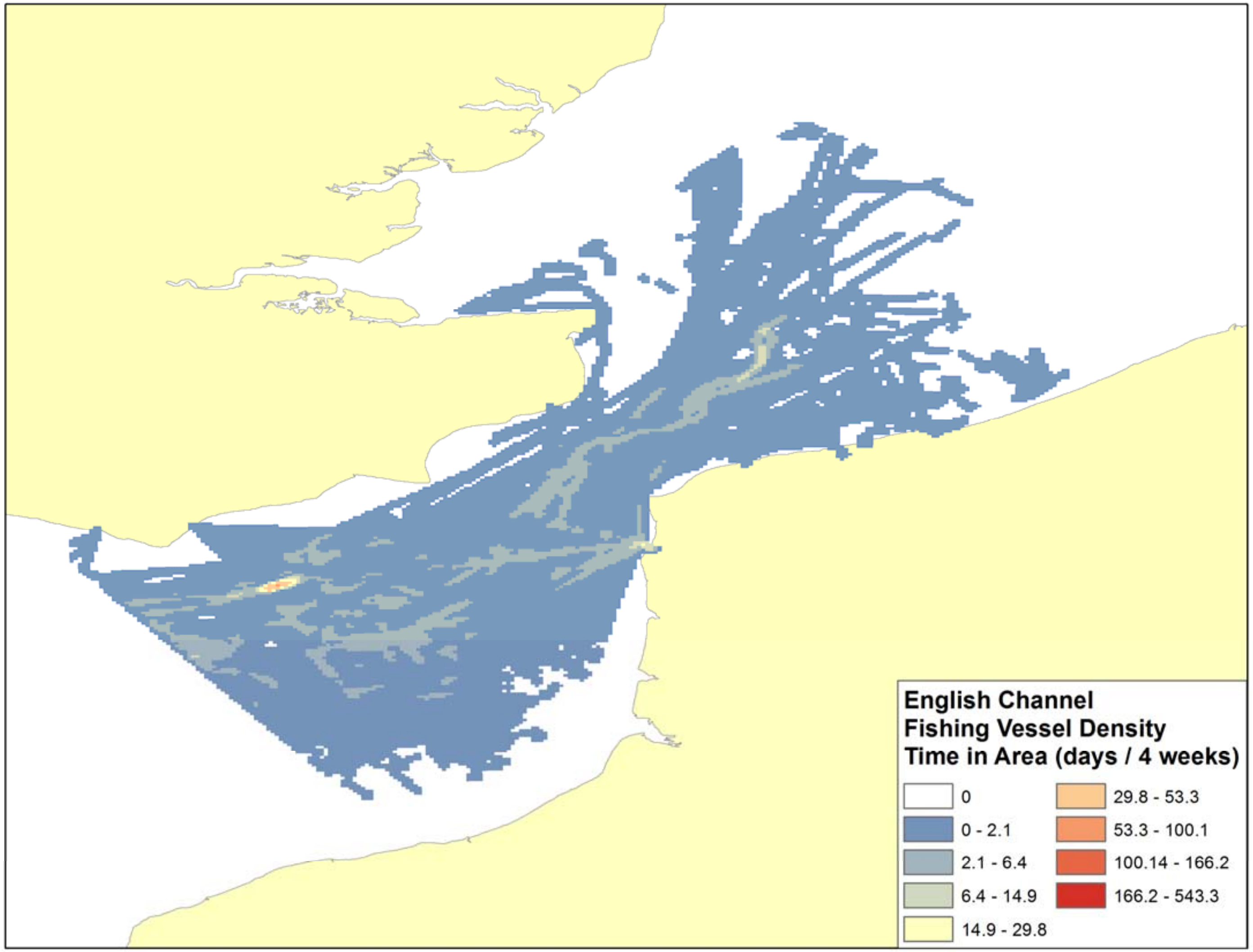

Figure 53 - English Channel Area (2012) Fishing Vessel Density (Vessel - Days in area / 4 weeks)

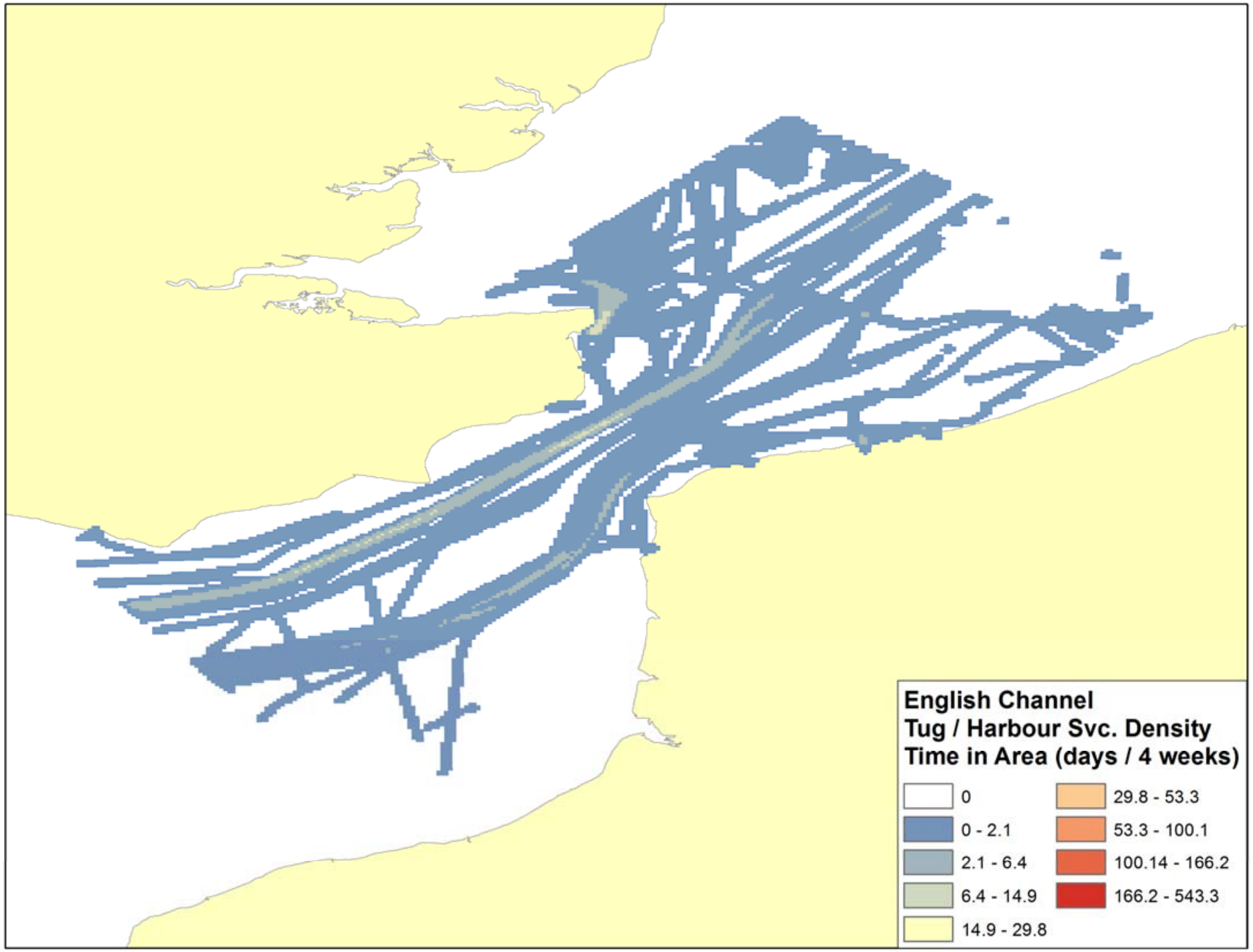

Figure 54 - English Channel Area (2012) Tug / Harbour Service Vessel Density (Vessel - Days in area / 4 weeks)

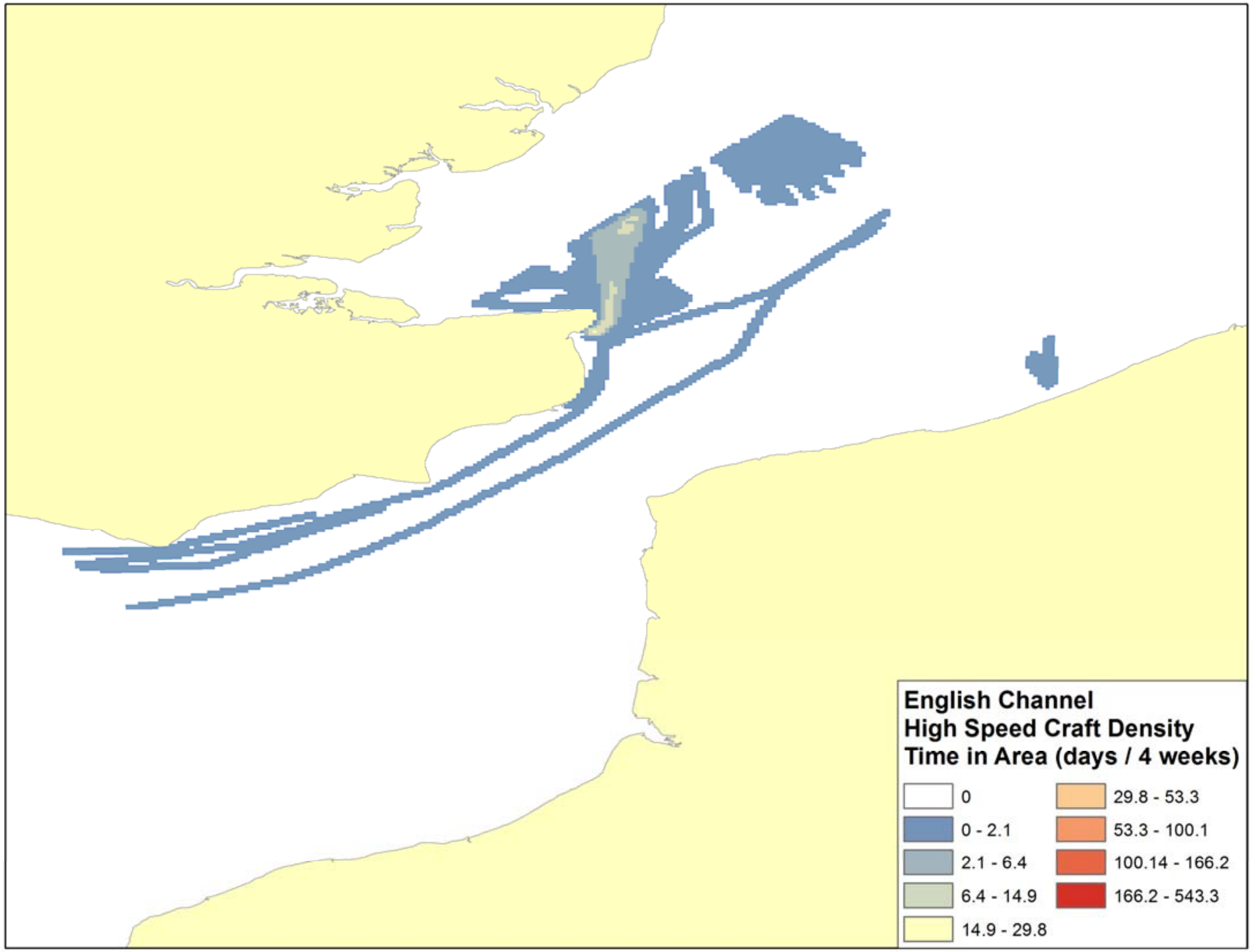

Figure 55 - English Channel Area (2012) High Speed Craft Density (Vessel - Days in area / 4 weeks)

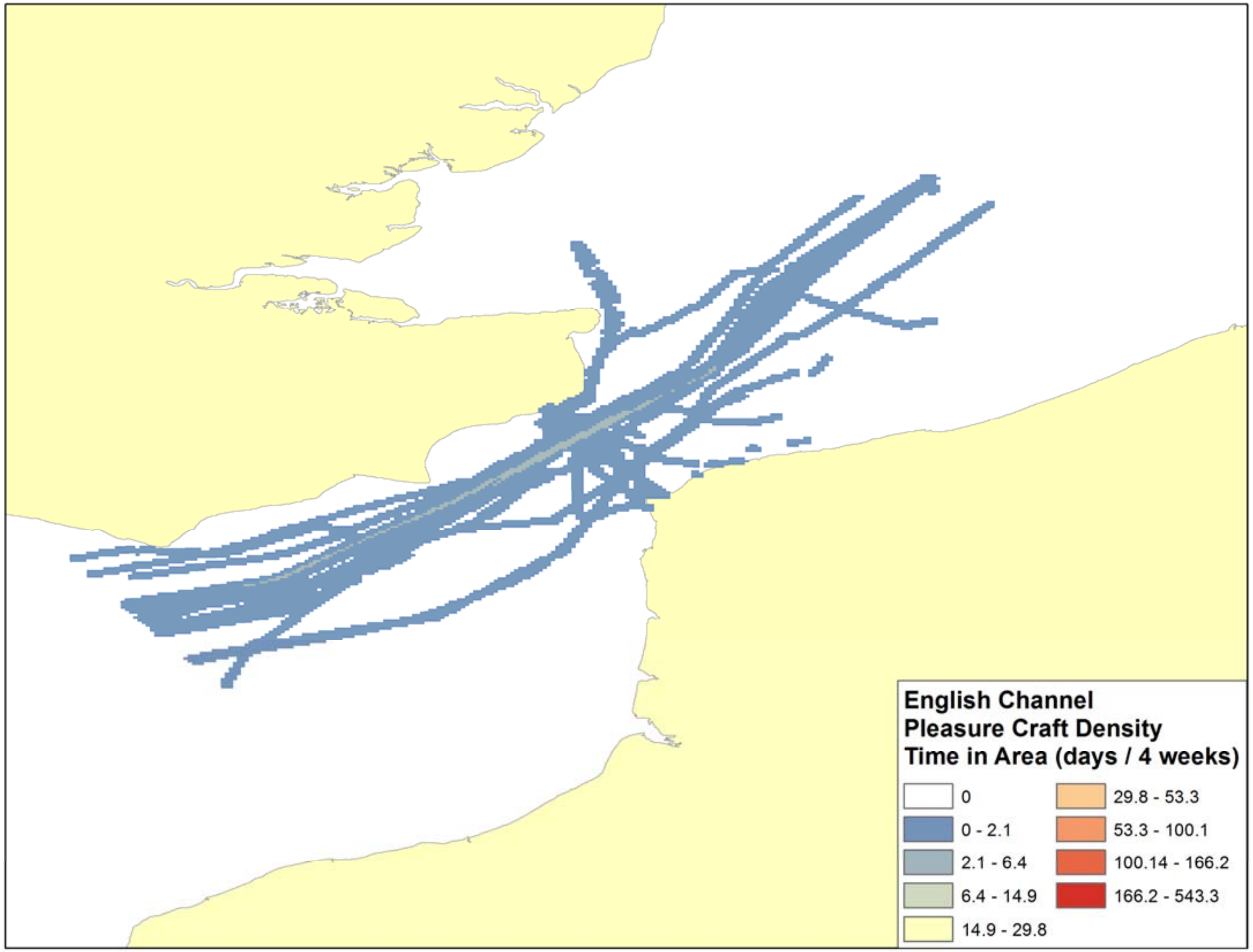

Figure 56 - English Channel Area (2012) Pleasure Craft Density (Vessel - Days in area / 4 weeks)

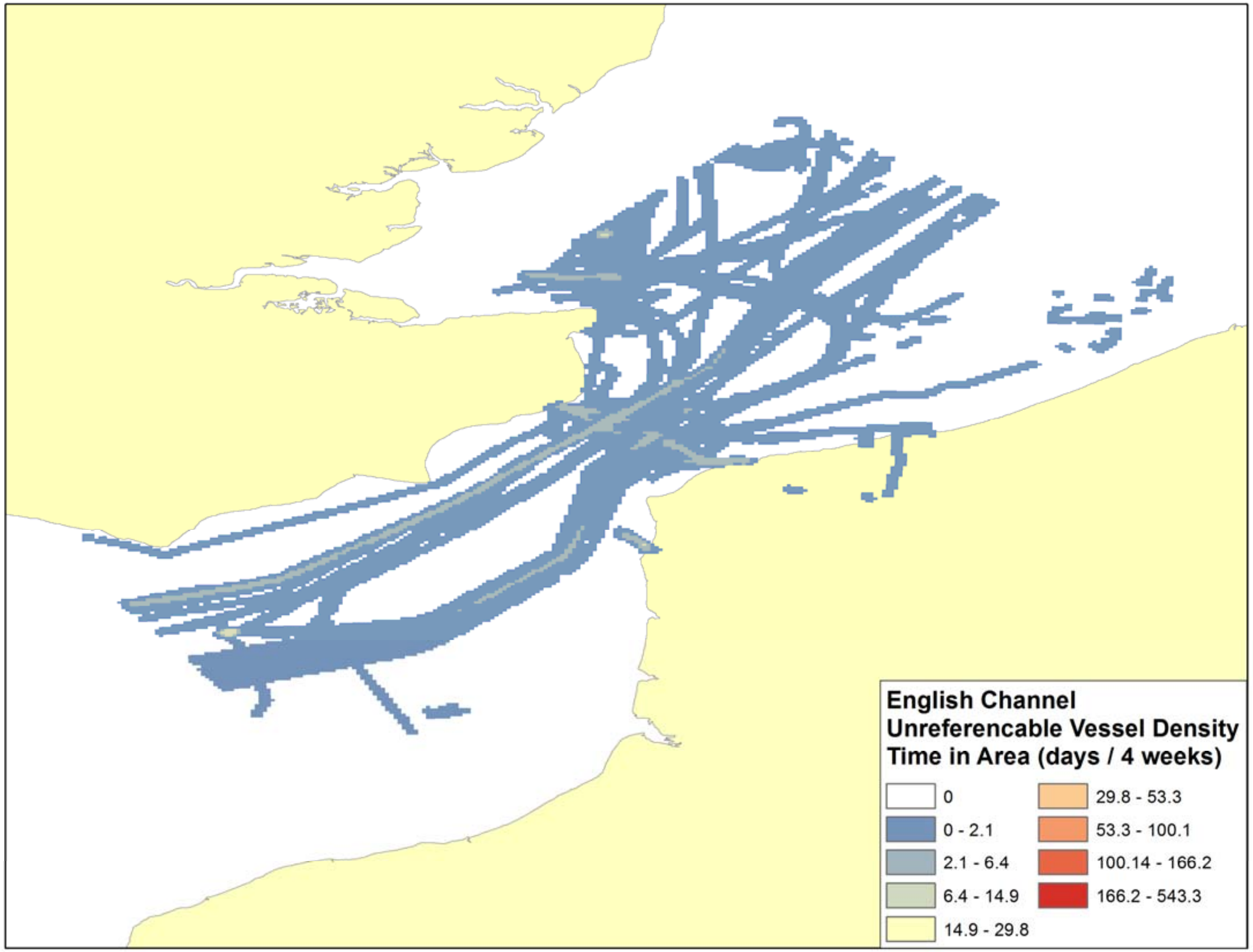

Figure 57 - English Channel Area (2012) Unreferencable Vessel Density (Vessel - Days in area / 4 weeks)

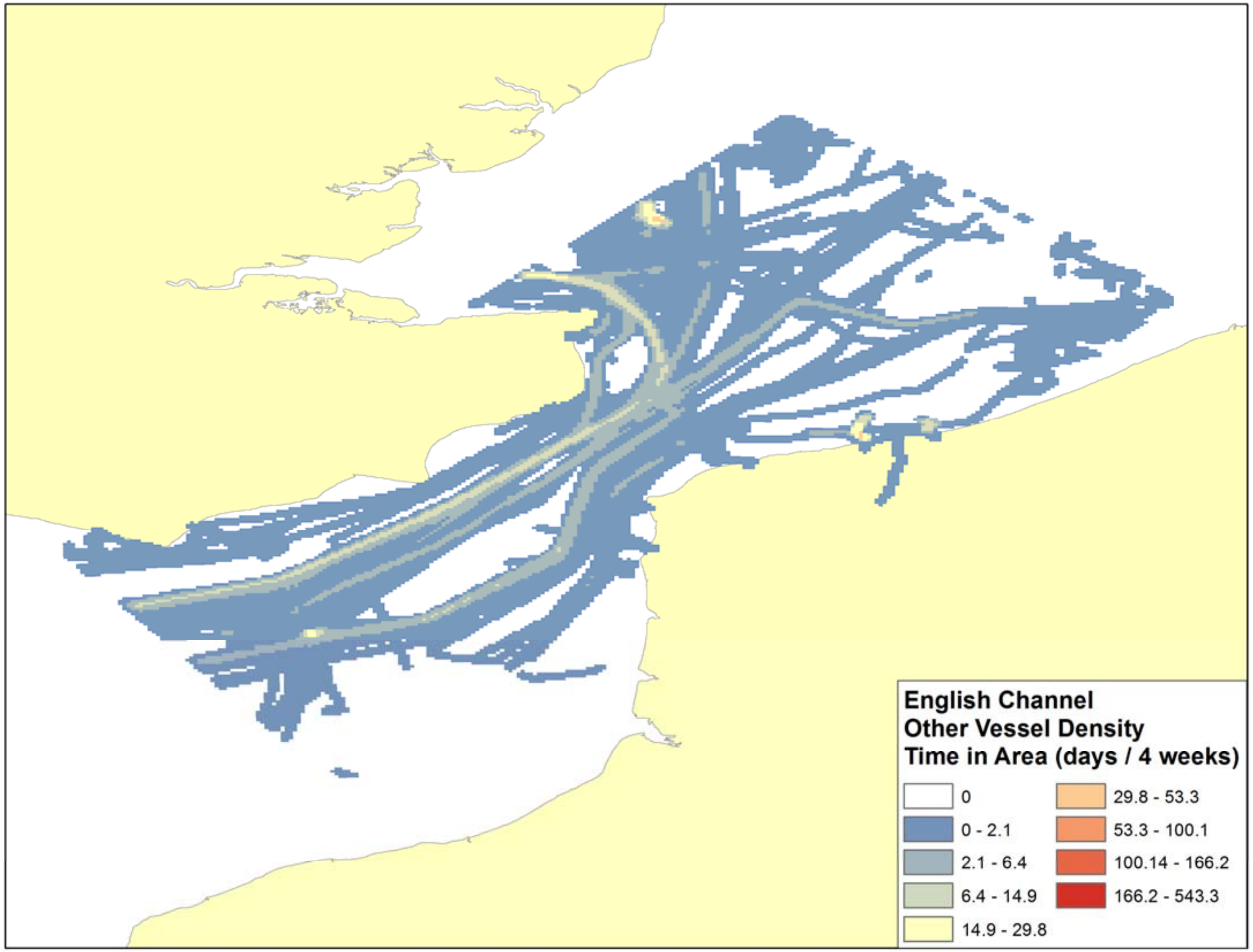

Figure 58 - English Channel Area (2012) Other Type Vessel Density (Vessel - Days in area / 4 weeks)

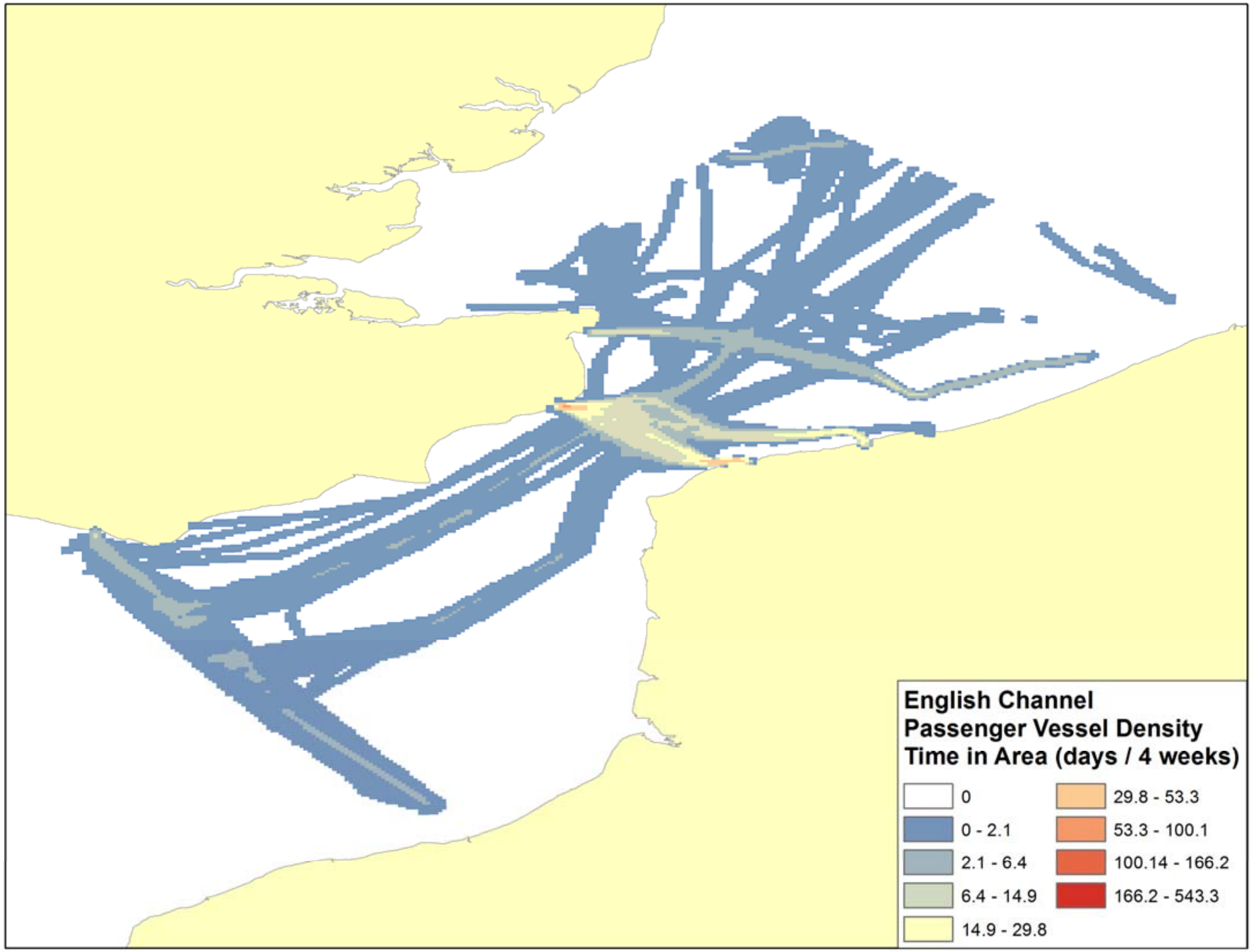

Figure 59 - English Channel Area (2012) Passenger Vessel Density (Vessel - Days in area / 4 weeks)

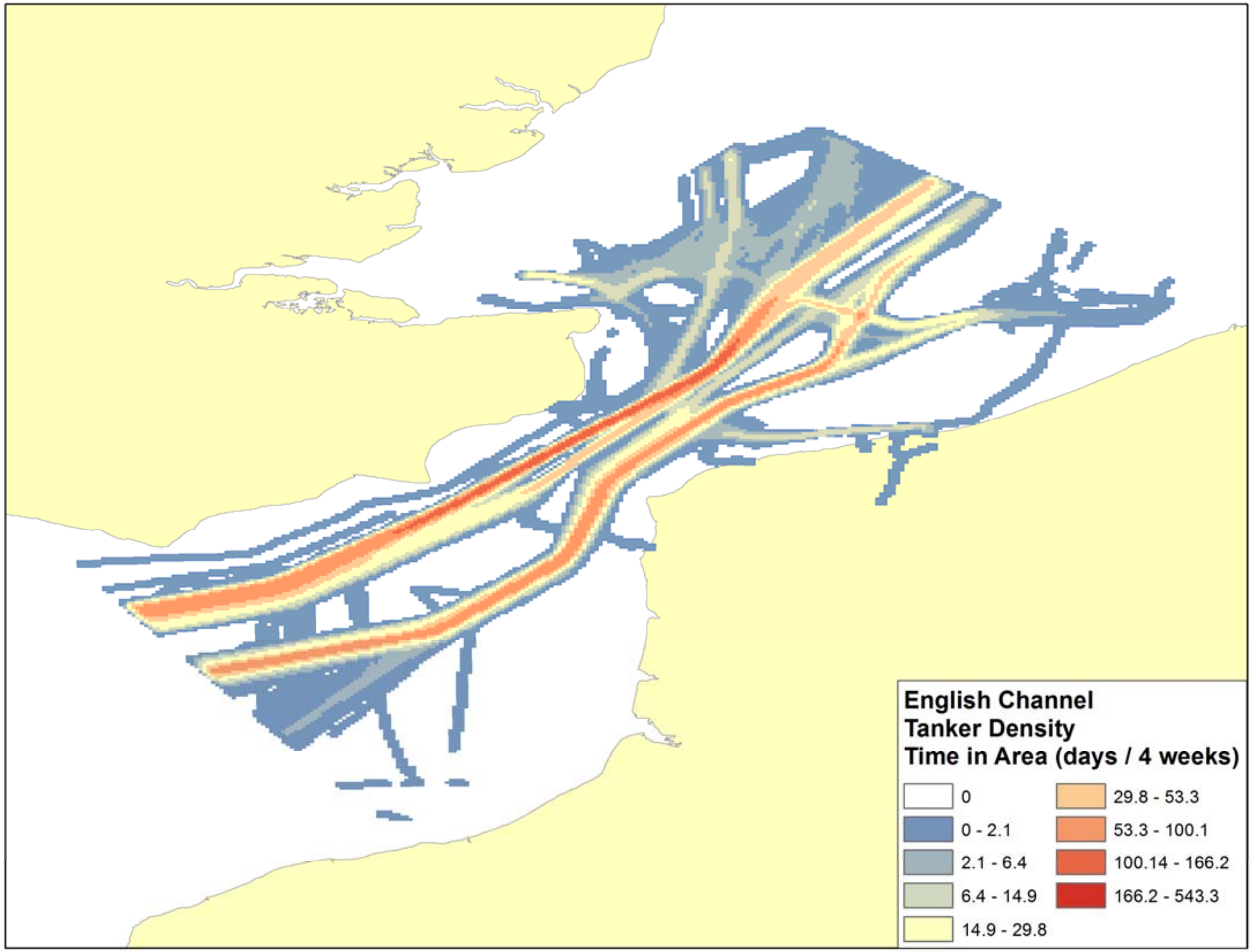

Figure 60 - English Channel Area (2012) Tanker Density (Vessel - Days in area / 4 weeks)

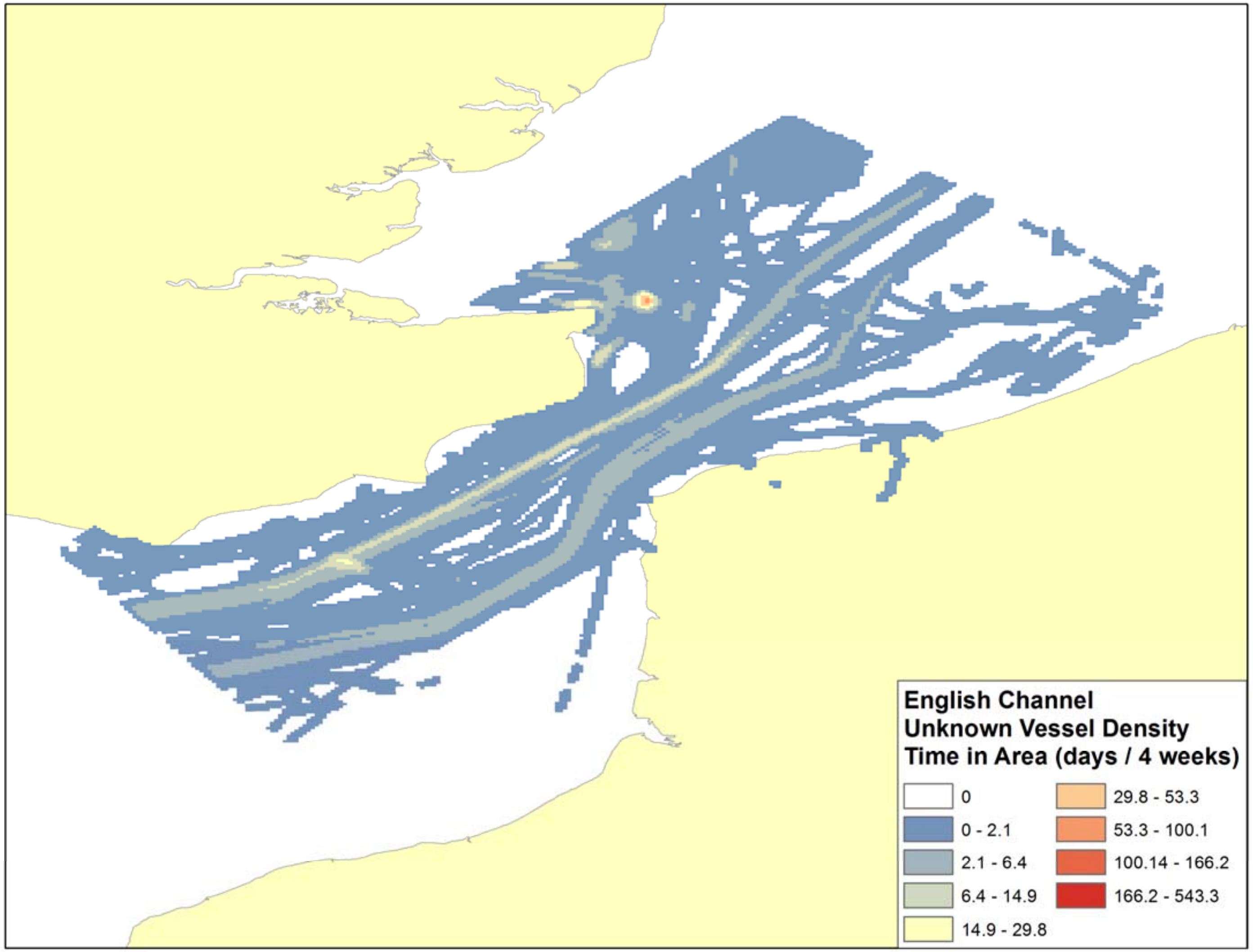

Figure 61 - English Channel Area (2012) Unknown Type Vessel Density (Vessel - Days in area / 4 weeks)

5 Cross and Along Track Measurements

One goal of the traffic simulation effort was to provide information in support of both the HAZID and the bridge simulation exercise regarding the anticipated rates at which crossing vessels might be expected for each of the areas under review. More specifically, the questions to be answered could be phrased as:

1) "At what rate might a vessel, travelling along a TSS lane within the areas of interest, be expected to encounter vessels crossing a TSS lane?"
2) "What is the expected vessel traffic rate travelling along the TSS lanes in the areas of interest?"

The first of these two questions speaks to the extent of the crossing issue in the areas, while the second is an assessment of the volume of traffic in the areas generally. The second question is slightly simpler to assess in our case, as the volume through the traffic lanes can be estimated from the simulated vessels track segments which enter a TSS lane and then exit without crossing the other TSS lane. The first question is somewhat trickier in that vessels crossing are only relevant hazards in situations where they are crossing in the vicinity of other vessels. Meshing specific times of crossing with the along-track transits of vessels, however, is a problem of complexity outside the scope of this analysis. In place of this ideal measure, we have estimated overall crossing rates in selected parts of the AOIs using the simulated traffic data. Using these rates, interactions might be inferred by experts using the combination of these rates and knowledge of the areas at hand. Estimation of lane crossings was performed by using a GIS to select a subset of vessel track segments from the overall datasets in each area that were considered to be crossing. From these subsets, and the time span of the data analysed, rates were computed. Specifics on the orientation of the vessel track segments within each area that were selected into the "along-track" and "crossing" groups are detailed by the respective study areas in the subsequent sections.

5.1 Singapore Strait Areas of Interest

Within the Singapore Strait region, the project stakeholders, Singapore MPA, identified two sub-areas of particular interest [15], illustrated in Figure 1. Because of the overall complexity of the Singapore region, analysis of vessel rates was constrained to these two "High Risk" areas. Vessels travelling through the TSS in the vicinity of these "High Risk" Areas of Interest in the Singapore Strait area were found to take one of four broad classes of routes. Vessels which did not cross traffic lanes were found to be travelling straight along the prescribed lanes, or exiting / entering the lanes to their right, as in Figure 62 and Figure 63.

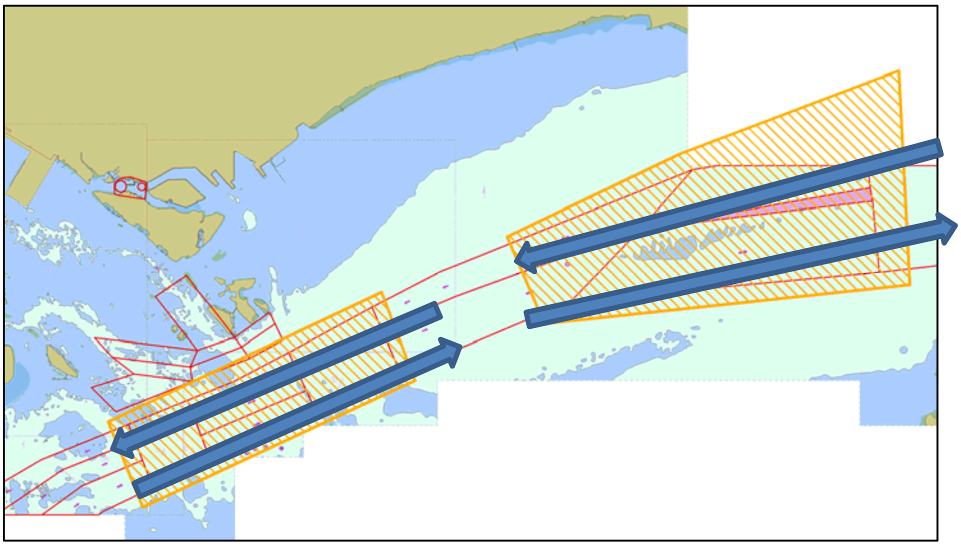

Figure 62 - Traffic Transiting Straight Through TSS

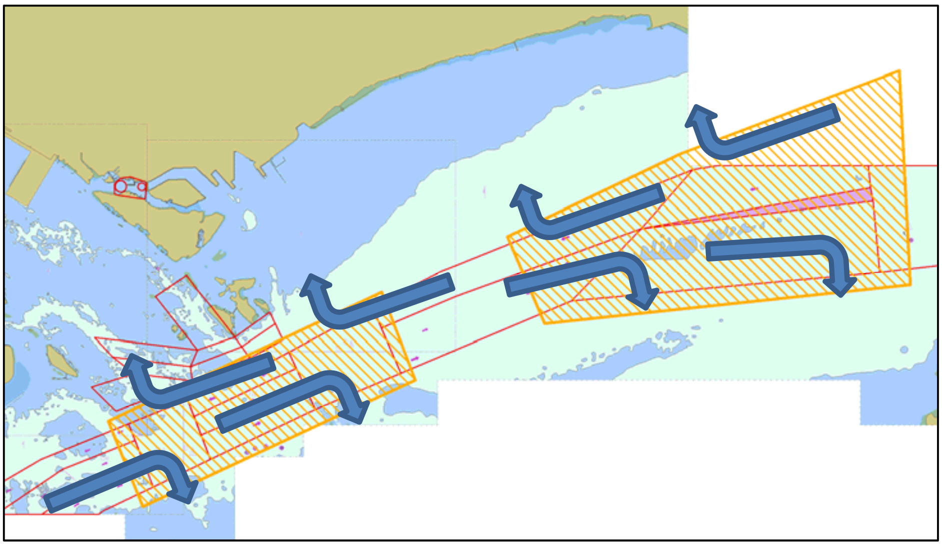

Figure 63 - Traffic Leaving (or entering) TSS Without Crossing Lanes

Vessels intending to cross a TSS are intended to do so either as a straight crossing, perpendicular to the traffic lanes, as in Figure 64, or as the result of a left turn while either leaving or entering a lane as in Figure 65. This pattern was noted to be present within the data.

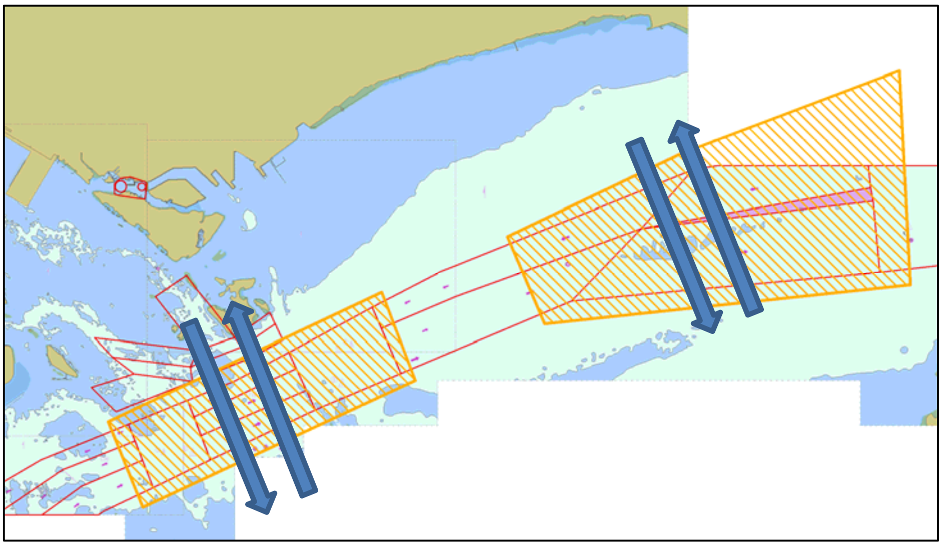

Figure 64 - Traffic Directly Crossing TSS

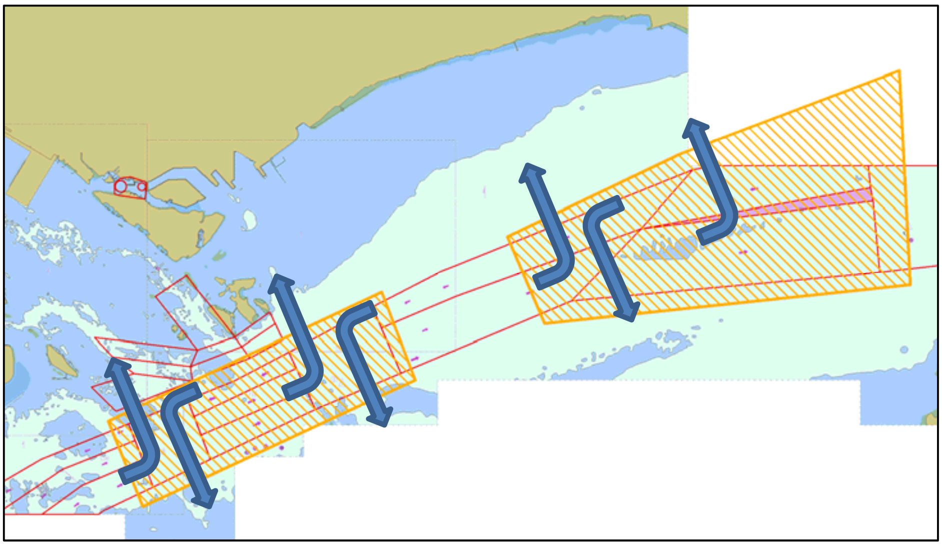

Figure 65 - Traffic leaving (or entering) TSS, Crossing Lane

These four cases roughly describe the spatial selections applied to the generated traffic segments in the Area of Interest using a GIS. By generating subsets of the overall data, sorted into these categorizations, it was possible to estimate rates of crossing and along-track traffic flow.

In the Easternmost of the two areas of critical interest the rates inferred from the data were as follows:

Table 13 - Singapore Strait TSS - Along Track and Crossing Rates - Easternmost Sub AOI

Action	Vessel Segments Noted (over 4 week sample)	Inferred Rate
Vessels directly crossing TSS	498	~18/d; 0.74/hr
Vessels departing lane and crossing TSS	1603	~57/d; 2.4/hr
Crossings, Total	2101	~75/d; 3.12/hr
Along-track movements within TSS (both directions combined)	7168	~256/d; ~10/hr
Vessels departing lane, not crossing TSS	2752	~98/d; ~4/hr
Outside TSS, but in area of interest (excluded from rates)	4337	

In the Westernmost of the two areas, the rates were:

Table 14 - Singapore Strait TSS - Along Track and Crossing Rates - Westermost Sub AOI

Action	Vessel Segments Noted (over 4 week sample)	Inferred Rate
Vessels directly crossing TSS	4814	~172/d; ~7.1/hr
Vessels departing lane and crossing TSS	1696	~60/d; ~2.5/hr
Crossings, Total	6510	~232.5/d; ~9.7/hr
Along-track movements within TSS (both directions combined)	5040	~180/d; ~7.5/hr
Vessels departing lane, not crossing TSS	1034	~37/d; ~1.5/hr
Outside TSS, but in area of interest (excluded from rates)	4340	

Generally, many more crossings are noted in the area nearer the harbour proper, with greater numbers of along-track traffic in the other area. A moderate difference was noted in the along-track rates between the two areas under consideration. Upon review of the adjacent traffic volumes in the density plots presented earlier, the most plausible accounting for this difference is that in the more congested (Easternmost) area, more traffic is transiting via the fairway, north of the TSS.

5.2 San Francisco Bay Area of Interest

Effectively no crossing events were noted in the TSS lanes on the approach to the San Francisco Bay area within the data sample analysed. This is most likely due to the very low volumes of traffic in the area. Within the precautionary area inside the Bay, however, measureable traffic volumes were found to be travelling along perpendicular courses. For the purposes of informing the bridge simulation in this study, some spot measurements of traffic volume were also evaluated at the most extreme points as suggested by the earlier density maps.

Table 15 - San Francisco Bay AOI - Measurements / Estimates of Traffic Rates

Measurement / Estimate	Vessel Segments Noted (over 4 week sample)	Inferred Rate
Spot Measurements:		
Mouth of Bay (East - West total)	1140	~40.7/day; ~1.7/hr
Alcatraz to Shore (East - West, South of Island)	2002	~72/day; ~3.0/hr
Alcatraz to Shore (East - West, North of Island)	2103	~75/day; ~3.1/hr
SF West to Treasure Island (East - West)	5163	~184/day; ~7.7/hr
Traffic Lane Measurements:		
Northwest Branch of TSS, North Lane	104	~3.7/day
Northwest Branch of TSS, South Lane	55	~2.0/day
Southwest Branch of TSS, North Lane	177	~6.3/day
Southwest Branch of TSS, South Lane	221	~7.9/day
South Branch of TSS, West Lane	30	~1.1/day
South Branch of TSS, East Lane	49	~1.8/day
Inner Precautionary Area:		
Tracks Running North - South	740	~26/day; ~1.1/hr
Tracks Approaching from East	1823	~65/day; ~2.7/hr

5.3 English Channel Area of Interest

The English Channel AOI is more easily compared to that of the Singapore Strait than the AOI for the San Francisco Bay, owing to the greater similarity of the former two in terms of TSS and traffic configuration (i.e. as international shipping routes). In the data analysed, however, the two aforementioned areas were found to differ in some characteristics of the observed traffic. More specifically, the traffic in the English Channel AOI was found to adhere more rigidly to the TSS lanes therein, with little lane departure noted. Because of this, it was much simpler to separate the data crossing the TSS from that travelling along the track. Crossings to the TSS were found to occur almost exclusively in the centre of the AOI, where the exclusion zone terminates, and in the precautionary area just north of the area where the two primary lanes touch. Ferry crossings were noted in the southern portion of this area, sometimes crossing the northernmost section of the exclusion zone. Traffic travelling southwest along the eastern branch of the TSS (within "West Hinder TSS") was noted to cross in the northern portion of this area via the established precautionary area in order to join the southbound lane of the primary TSS. Traffic heading north along the easternmost lane of the TSS was also found to make use of this precautionary area to head west toward the UK shore.

Vessel along-track rate estimates constructed in this area were limited to overall highest expected rates, which were noted to occur in the southern portions of both TSS lanes. In the sample reviewed, the northbound traffic lane was found to have 2560 vessel track segments over a period of 28 days, giving a rate of ~91 transits per day or ~3.8 per hour. In the opposing, southbound lane, 2334 vessel track segments over a period of 28 days, corresponding to a rate of ~83 transits per day or ~3.5 per hour.

In computing the crossing estimate, the bulk of the crossings were noted to occur between Dover and Calais or Dunkirk. The crossing count (bi-directional) was established as 4849 track segments per 28 days, working out to ~173 per day or ~7.2 per hour.

6 Discussion of Future Trends (Singapore)

To supplement the simulated traffic results, some work was undertaken in surveying expected trends particular to the Singapore Area Of Interest. In addition to providing supplemental information to the project stakeholders in the area of particular interest, knowledge about potential changes to the traffic environment may aid in determining the necessity of implementing the "3 green lights" signal, among other risk control measures.

Predictions regarding traffic volumes in the Singapore Strait region universally suggest an increase in the coming years. Disparities between reviewed documentation only exist regarding the extent of growth. Estimated rates of change range from 6.2% increase per year [16] to as high as 11.5% per year [17]. Of these estimates, the report based on the most current projections is that which suggests growth at 6.2% per year over a 10-year horizon.

It should be noted that traffic projections in the area are generally taken with an eye toward commerce and, as such, might be expected to influence some vessel types more so than others. In particular, tanker and cargo traffic might be expected to grow at the given rate, while passenger vessels might experience more modest growth. From among the vessel types considered in this study, tug and harbour service vessel traffic might be expected to increase to serve the additional commercial shipping traffic, however, constraints on port resources could moderate the growth to some degree. With these factors in mind, the effects of the most conservative (6.2% / year) growth estimate are applied to the traffic rates computed. Of these estimates, it is expected that increases in the along-track rate would be most accurate (along track traffic consisting primarily of commercial shipping vessels), while the increases in crossing rate are more likely to be over-estimates (due to the greater proportion of non-commercial shipping traffic {i.e. ferries}).

Table 16 shows the impact of extrapolating out to 2023 from the current along-track and crossing rates for both of the "High Risk Areas", assuming a yearly traffic increase of 6.2%. Given estimates on carrying capacity for the waterway ranging from 7 vessels per hour [18] (Straits of Malacca) to 29 - 51 vessels per hour [19] (Singapore Strait), the rates noted for along-track traffic flow appear to be approaching the capacity for the waterway over the next 10 years. With the primary lanes operating at or near capacity, the driver to avoid collisions between vessels in the lanes and those seeking to cross is magnified.

Table 16 - Estimates of Traffic Rate Increases - Singapore High Risk Areas

	Eastern High Risk Area		Western High Risk Area	
Year	Along Track (includes turns)	Crossing	Along Track (includes turns)	Crossing
2013	14.00	3.12	9.00	9.70
2014	14.87	3.31	9.56	10.30
2015	15.79	3.52	10.15	10.94
2016	16.77	3.74	10.78	11.62
2017	17.81	3.97	11.45	12.34
2018	18.91	4.21	12.16	13.10
2019	20.09	4.48	12.91	13.92
2020	21.33	4.75	13.71	14.78
2021	22.65	5.05	14.56	15.70
2022	24.06	5.36	15.47	16.67
2023	25.55	5.69	16.42	17.70

7 Incident Discussion

Historic data on collision incidents was collated for each of the three regions to add perspective to the traffic data and overall project in general. For the San Francisco Bay area, data were made available by the USCG via a subset of their MISLE database; however, for the other two regions collections of incidents were constructed from public domain information. In the Singapore Strait, a baseline set of incident reports was located within the Singapore MPA news release site [20], which was supplemented by media reports of incidents. Information regarding incidents in the English Channel was summarized from the UK MAIB site [21]. In all three of these incident sets, it should be noted that it is likely that some incidents have been omitted, in particular those which are of a less serious nature, those still under investigation, and any of a contentious nature to the parties involved.

In the Singapore Strait area, 13 collision incidents were found between the years 2012 and 2014, inclusive. A detailed accounting of the incident sources is included as Appendix 3D, while a more descriptive summary is included here as Table 17.

Table 17 - Identified Collision Incidents in Singapore Strait Area (2012 - 2014)

Year	Vessels	Study-Relevant Collision Details
2010	Laptev Sea; PWP 1	Overtaking vessel alters course
2012	MV Seeb; MT Kota Tenaga	Night condition
2012	Sunny Horizon; DL Salvia	Fairway collision
2013	BOSUN; SC3566	Fairway collision
2013	Oriental Pioneer; Atlantic Hero	Early morning light condition
2013	Beks Halil; Unknown small tanker	Overtaking at close quarters
2011	RHL Fidelitas; Voge Prestige	Crossing
2014	Lime Galaxy; Feihe	Ineffective bridge resource management under conditions
2014	NYK Themis; AZ Fuzhou	Early morning light condition; Fairway collision
2014	Hammonia Thracium; Zoey	In TSS Precautionary Area; Collision in lane crossing
2014	Lord Vishnu; Skua	In TSS Precautionary Area; Collision in lane crossing
2014	Ye Chi; Hisui	In TSS Precautionary Area; Collision in lane crossing
2014	Best Unity; Southern Explorer	Collision in anchorage

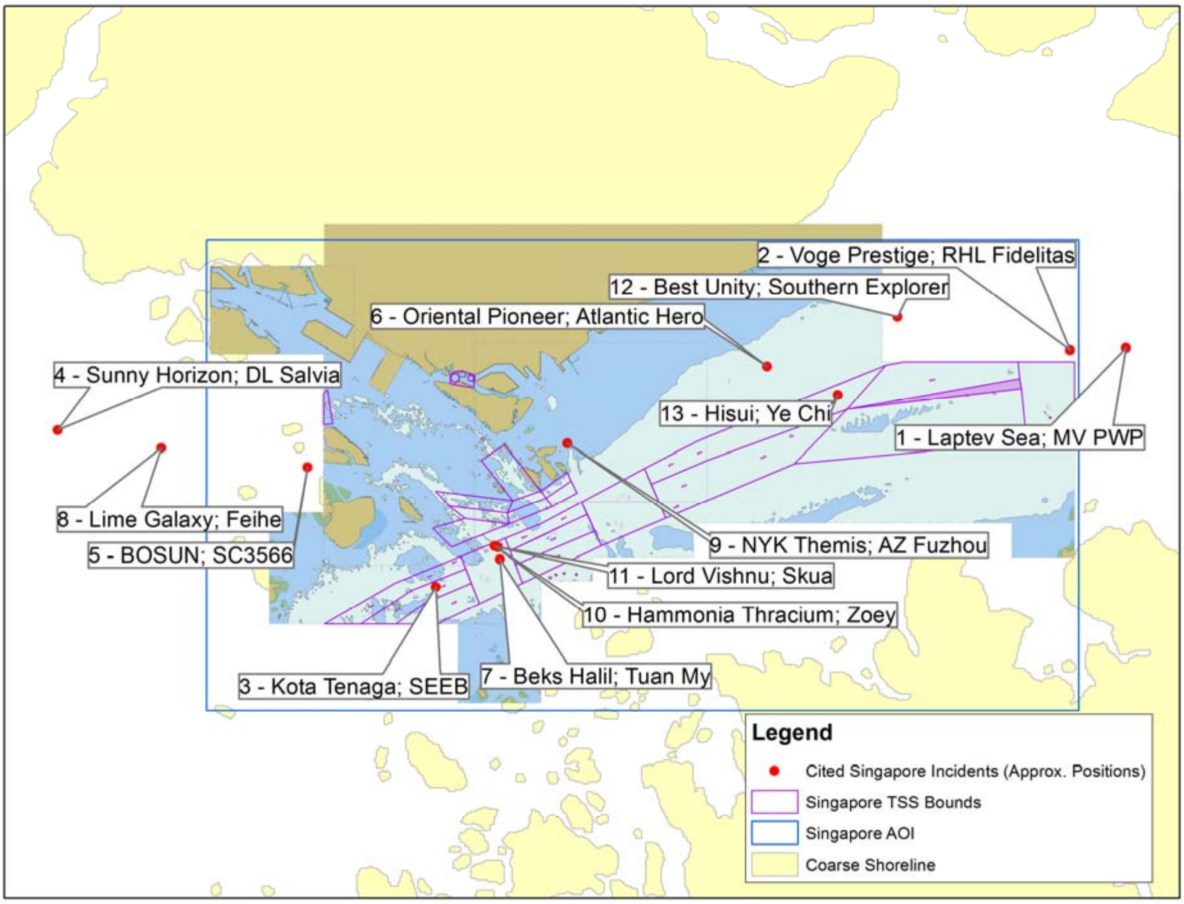

Figure 66 - Identified Collision Incidents in Singapore Area (2012-2014)

Within these collated incidents, 3 were noted to occur under limited lighting conditions, 6 were noted within traffic control areas (either fairway or TSS), and 3 were noted to be the precise type of incident for which the "3 green lights" traffic control measure is intended to aid in reducing (collision in TSS lane crossing). It should be mentioned that it was not noted in the incident synopses whether the vessels were carrying or operating the prescribed signal at the time of the incidents.

Significant collision incidents occurring in the relevant UK waters were found to be well documented and investigated by the UK MAIB [22]. A total of 10 were noted to fall in the English Channel / Dover Strait region, and are referenced in Appendix 3E, and described in the table below.

Table 18 - Identified Collision Incidents in English Channel Area of Interest (2000 – 2014)

Year	Vessels	Study-Relevant Collision Details
2000	Pasadena Universal; Nordheim	Dover Strait; Congestion in overtaking; Lack of proper intention assessment
2000	East Fern; Kinsale	Collision SW of Dover; Poor BRM attention for conditions
2001	Gudermes; Saint Jacques II	TSS crossing; Night visibility conditions; Bad crossing bearing
2001	Hampoel; Atlantic Mermaid	TSS overtaking; Night visibility conditions
2001	MV Sand Heron; FV Celtit	TSS crossing; Fishing vessel, w/ unclear intentions
2001	MV Ash; Dutch Aquamarine	Close overtaking in TSS under good visibility
2002	Diamant; Northern Merchant	Ro - pax and HSC collision; Poor visibility
2008	Scot Isles; Wadi Halfa	TSS crossing; Early morning light conditions; Watchkeeping failure
2013	Paula C; Barya Gayatri	Night conditions; In TSS
2014	Rickmers Dubai; Walcon Wizard	Overtaking in TSS; Morning light conditions

Of the collision incidents gathered, three were noted to involve TSS crossings, and all but 2 involved at least one factor of concern when considering implementation of the "three green lights" signal (attention, visibility, vessel intention assessment).

Despite no collision incidents in the San Francisco Bay Area having been analysed in detail by the NTSB [23], a total of 33 distinct events were retrieved from within the USCG MISLE database as falling within the SF Bay Area AOI, involving a total of 66 vessels over the time span 2002 - 2011. Summaries by year and type of collision are included in Table 19 for reference.

Table 19 - Collision Incidents in SF Bay AOI by Year (2002 - 2011)

Year	Collision incidents in San Fancisco Bay AOI
2002	5
2003	1
2004	3
2005	5
2006	3
2007	4
2008	2
2009	2
2010	5
2011	3
Total	33

Table 20 - Collision Incidents in SF Bay AOI by Collision Type (2002 - 2011)

Collision Type	Count
Crossing	4
Meeting	8
Overtaking	3
Other / Unspecified	18
Total	33

Because of the source for this incident information (USCG), it is believed that this dataset is more comprehensive and reliable than the data obtained for the other areas due to active curation by the USCG. Additionally, it appears that the dataset includes vessels at the smaller end of the size spectrum, believed to be omitted from other regions. The combination of these two factors is believed to account for the relatively large volume of incidents noted.

It is worthy of note that despite having relatively low traffic volumes in comparison to the other two regions, there are still a measurable quantity of collision incidents over the years surveyed. Within this dataset, crossings are also noted (4 of 33 incidents), though no particulars are provided as to the nature of the crossing encounters (e.g. in traffic lane or constricted navigation vs open water).

8 Conclusions

Three areas in total were considered for traffic analysis as part of the HAZID component of the Singapore MPA solicited FSA in consideration of the "three green lights" measure: the Singapore Strait, the San Francisco Bay Area (including TSS approach to the bay), and the English Channel in the vicinity of the Dover to Calais crossing.

Traffic data in the form of AIS position reports were processed into simulated vessel tracks. Overall, the Singapore area was found to have the highest traffic levels in terms of vessel track segment counts, as well as vessel time within the area of interest, though a greater quantity of vessel travel distance was noted for the English Channel area. If the results by volume were normalized by area, however, the Singapore Strait would have the highest traffic overall in all categories of measurement.

The simulated vessel tracks were plotted in gridded form using GIS tools in order to display the areas of highest density in each of the three regions and to identify areas in which traffic is most likely to meet at crossing. Particular note was made where crossings could be expected to occur within Traffic Separation Schemes. Generally, passenger vessel transits (i.e. ferries) were found to be the traffic type most likely to be transiting directly across primary traffic lanes within TSSs.

Rates of along-track and across-track vessel occurrence were computed for selected portions of all three areas of interest. Efforts were made to establish rates meaningful to the HAZID process as well as the bridge simulation exercise. As expected from the overall traffic data evaluation, the Singapore area had the highest rates of traffic flow among the three areas, followed by the English Channel area and finally the San Francisco Bay area. Estimates of potential future flow rates were assessed for the Singapore area, based on projections from literature. The results of these estimates suggest that the route may be reaching its maximum along-track throughput over the next decade, further reinforcing that measures may be required to ensure the safety where vessels may be crossing this extremely busy waterway.

Collision incidents were surveyed over the recent past for the three areas under consideration. In all three areas, collisions were noted to have occurred during crossing situations. In the Singapore and English Channel areas, it was also possible to identify several factors among the incidents which may be mitigated in some cases by the "three green lights" measure. Factors noted include darkness / limited visibility and unknown vessel intention while present within a TSS.

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23. https://www.ntsb.gov/investigations/reports_marine.html

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Appendix 3A - Table of AIS Message Types - From USCG Navcen

Source: http://www.navcen.uscg.gov/?pageName=AISMessages

Message ID	Name	Description	Priority	Access scheme	Communication state	M/B
1	Position report	Scheduled position report; Class A shipborne mobile equipment	1	SOTDMA, RATDMA, ITDMA	SOTDMA	M
2	Position report	Assigned scheduled position report; Class A shipborne mobile equipment	1	SOTDMA	SOTDMA	M
3	Position report	Special position report, response to interrogation; Class A shipborne mobile equipment	1	RATDMA	ITDMA	M
4	Base station report	Position, UTC, date and current slot number of base station	1	FATDMA, RATDMA	SOTDMA	B
5	Static and voyage related data	Scheduled static and voyage related vessel data report; Class A shipborne mobile equipment	4	RATDMA, ITDMA	N/A	M
6	Binary addressed message	Binary data for addressed communication	4	RATDMA, FATDMA, ITDMA	N/A	M/B
7	Binary acknowledgement	Acknowledgement of received addressed binary data	1	RATDMA, FATDMA, ITDMA	N/A	M/B
8	Binary broadcast message	Binary data for broadcast communication	4	RATDMA, FATDMA, ITDMA	N/A	M/B
9	Standard SAR aircraft position report	Position report for airborne stations involved in SAR operations only	1	SOTDMA, RATDMA, ITDMA	SOTDMA ITDMA	M
10	UTC/date inquiry	Request UTC and date	3	RATDMA, FATDMA, ITDMA	N/A	M/B
11	UTC/date response	Current UTC and date if available	3	RATDMA, ITDMA	SOTDMA	M
12	Addressed safety related message	Safety related data for addressed communication	2	RATDMA, FATDMA, ITDMA	N/A	M/B
13	Safety related acknowledgement	Acknowledgement of received addressed safety related message	1	RATDMA, FATDMA, ITDMA	N/A	M/B
14	Safety related broadcast message	Safety related data for broadcast communication	2	RATDMA, FATDMA, ITDMA	N/A	M/B
15	Interrogation	Request for a specific message type can result in multiple responses from one or several stations	3	RATDMA, FATDMA, ITDMA	N/A	M/B
16	Assignment mode command	Assignment of a specific reportbehaviour by competent authority using a Base station	1	RATDMA, FATDMA	N/A	B

Message ID	Name	Description	Priority	Access scheme	Communication state	M/B
17	DGNSS broadcast binary message	DGNSS corrections provided by a base station	2	FATDMA, RATDMA	N/A	B
18	Standard Class B equipment position report	Standard position report for Class B shipborne mobile equipment to be used instead of Messages 1, 2, 3	1	SOTDMA, ITDMA, CSTDMA	SOTDMA, ITDMA	M
19	Extended Class B equipment position report	No longer required. Extended position report for Class B shipborne mobile equipment; contains additional static information	1	ITDMA	N/A	M
20	Data link management message	Reserve slots for Base station(s)	1	FATDMA, RATDMA	N/A	B
21	Aids-to-navigation report	Position and status report for aids-to-navigation	1	FATDMA, RATDMA	N/A	M/B
22	Channel management	Management of channels and transceiver modes by a Base station	1	FATDMA, RATDMA	N/A	B
23	Group assignment command	Assignment of a specific reportbehaviour by competent authority using a Base station to a specific group of mobiles	1	FATDMA, RATDMA	N/A	B
24	Static data report	Additional data assigned to an MMSI Part A: Name Part B: Static Data	4	RATDMA, ITDMA, CSTDMA, F ATDMA	N/A	M/B
25	Single slot binarymessage	Short unscheduled binary data transmission Broadcast or addressed	4	RATDMA, ITDMA, CSTDMA, F ATDMA	N/A	M/B
26	Multiple slot binary message with Communications State	Scheduled binary data transmission Broadcast or addressed	4	SOTDMA, RATDMA, ITDMA, FATDMA	SOTDMA, ITDMA	M/B
27	Position report for long range applications	Class A and Class B "SO" shipborne mobile equipment outside base station coverage	1	MSSA	N/A	M
28-63	Undefined; Reserved for future use	N/A	N/A	N/A	N/A	M

Appendix 3B - Table of AIS Navigation Status Indicators - Compiled from USCG Navcen

Source: http://www.navcen.uscg.gov/?pageName=AISMessagesA

Navigational Status Value	Description
0	under way using engine
1	at anchor
2	not under command
3	restricted maneuverability
4	constrained by her draught
5	moored
6	aground
7	engaged in fishing
8	under way sailing
9	reserved for future amendment of navigational status for ships carrying DG, HS, or MP, or IMO hazard or pollutant category C, high speed craft (HSC),
10	reserved for future amendment of navigational status for ships carrying dangerous goods (DG), harmful substances (HS) or marine pollutants (MP), or IMO hazard or pollutant category A, wing in ground (WIG)
11	power-driven vessel towing astern (regional use)
12	power-driven vessel pushing ahead or towing alongside (regional use)
13	reserved for future use
14	AIS-SART (active), MOB-AIS, EPIRB-AIS
15	default, undefined (also used by AIS-SART, MOB-AIS and EPIRB-AIS under test)

Appendix 3C - AIS Vessel Types - Compiled from USCG Navcen

Source: http://www.navcen.uscg.gov/?pageName=AISMessagesAStatic

General vessel types

Vessel Type Code	Vessel Type Description
1X	Reserved for future use
2X	Wing in Ground
30	Fishing vessel
31	Towing vessel
32	Towing and length of the tow exceeds 200 m or breadth exceeds 25 m
33	Vessel engaged in dredging or underwater operations
34	Vessel engaged in diving operations
35	Vessel engaged in military operations
36	Sailing vessel
37	Pleasure craft
38	Reserved for future use
39	Reserved for future use
4X	High speed craft
50	Pilot vessel
51	Search and rescue vessels
52	Tugs
53	Port tenders
54	Vessels with anti-pollution facilities or equipment
55	Law enforcement vessels
56	Spare - for assignments to local vessels
57	Spare - for assignments to local vessels
58	Medical transports (as defined in the 1949 Geneva Conventions and Additional Protocols)
59	Ships and aircraft of States not parties to an armed conflict
6X	Passenger ships
7X	Cargo ships

Vessel Type Code	Vessel Type Description
8X	Tanker(s)
9X	Other types of ship

Vessel Subtypes for vessel type codes noted with "X" above

Values for X	Subtype Description
0	All ships of this type
1	Carrying dangerous goods, hazardous substances, marine pollutants, IMO hazard or pollutant category X
2	Carrying dangerous goods, hazardous substances, marine pollutants, IMO hazard or pollutant category Y
3	Carrying dangerous goods, hazardous substances, marine pollutants, IMO hazard or pollutant category Z
4	Carrying dangerous goods, hazardous substances, marine pollutants, IMO hazard or pollutant category OS
5	Reserved for future use
6	Reserved for future use
7	Reserved for future use
8	Reserved for future use
9	No additional information

Appendix 3D - Incident References, Singapore Region

Year	Vessels	Source(s)
2010	Laptev Sea; PWP 1	http://coordination-maree-noire.eu/spip.php?breve610&lang=en
2011	RHL Fidelitas; Voge Prestige	http://www.wkwebster.com/content/cc-world.asp
2012	MV Seeb; MT Kota Tenaga	http://mti.gov.mt/en/Document%20Repository/MSIU%20Documents/Investigations%202012/MV%20Seeb_Final%20Safety%20Investigation%20Report.pdf
2012	Sunny Horizon; DL Salvia	http://www.mpa.gov.sg/sites/global_navigation/news_center/mpa_news/mpa_news_detail.page?filename=nr120909.xml
2013	BOSUN; SC3566	http://www.mpa.gov.sg/sites/global_navigation/news_center/mpa_news/mpa_news_detail.page?filename=nr130313.xml
2013	Oriental Pioneer; Atlantic Hero	http://www.mpa.gov.sg/sites/global_navigation/news_center/mpa_news/mpa_news_detail.page?filename=nr130702a.xml http://ens-newswire.com/2013/07/05/bulk-carrier-collision-spills-oil-in-singapore-strait/
2013	Beks Halil; Tuan My	http://officerofthewatch.com/2013/03/05/bulk-carrier-and-cargo-ship-collide-in-the-straits-of-singapore/
2014	Lime Galaxy; Feihe	http://www.mpa.gov.sg/sites/global_navigation/news_center/mpa_news/mpa_news_detail.page?filename=nr140129.xml http://www.ihsmaritime360.com/article/11820/ship-masters-should-check-conditions-in-singapore-straits http://www.platts.com/latest-news/shipping/rotterdam/mpa-issues-findings-of-investigation-into-vessel-26799131
2014	NYK Themis; AZ Fuzhou	http://shipandbunker.com/news/apac/887979-second-collision-causes-another-bunker-spill-in-singapore
2014	Hammonia Thracium; Zoey	http://www.mpa.gov.sg/sites/global_navigation/news_center/mpa_news/mpa_news_detail.page?filename=nr140210.xml http://shipandbunker.com/news/apac/937706-singapore-3rd-bunker-spill-in-13-days-after-another-vessel-collision http://www.cm-soms.com/uploads/1/21/TTEG%2039-5-2-3%20Marine%20Casualty%20Affecting%20Traffic%20Movement,%20Singapore.pdf
2014	Lord Vishnu; Skua	http://www.cm-soms.com/uploads/1/21/TTEG%2039-5-2-3%20Marine%20Casualty%20Affecting%20Traffic%20Movement,%20Singapore.pdf
2014	Ye Chi; Hisui	http://www.cm-soms.com/uploads/1/21/TTEG%2039-5-2-3%20Marine%20Casualty%20Affecting%20Traffic%20Movement,%20Singapore.pdf

Year	Vessels	Source(s)
2014	Best Unity; Southern Explorer	http://www.vesselfinder.com/news/2344-Bulk-carrier-and-cargo-ship-collide-in-the-Singapore-Straits http://www.maritime-executive.com/article/Bulk-Carriers-Collide-in-Singapore-2014-09-17

Appendix 3E - Incident References, English Channel Region

Year	Vessels	Source(s)
2000	Pasadena Universal; Nordheim	http://www.maib.gov.uk/publications/investigation_reports/2000/pasadena_universal_nordheim.cfm
2000	East Fern; Kinsale	http://www.maib.gov.uk/cms_resources.cfm?file=/eastfern-kinsale.pdf
2001	Gudermes; Saint Jacques II	http://www.maib.gov.uk/publications/investigation_reports/2002/gudermes_and_saint_jacques.cfm
2001	Hampoel; Atlantic Mermaid	http://www.maib.gov.uk/publications/investigation_reports/2002/hampoel_and_atlantic_mermaid.cfm http://www.maib.gov.uk/cms_resources.cfm?file=/atlantic-mermaid-and-Hampoel.pdf
2001	MV Sand Heron; FV Celtit	http://www.maib.gov.uk/publications/investigation_reports/2002/mv_sand_heron_and_fv_celtit.cfm
2001	MV Ash; Dutch Aquamarine	http://www.maib.gov.uk/publications/investigation_reports/2003/ash_and_dutch_aquamarine.cfm http://www.maib.gov.uk/cms_resources.cfm?file=/ash-and-dutch-aquamarine.pdf
2002	Diamant; Northern Merchant	http://www.maib.gov.uk/publications/investigation_reports/2003/diamant_northern_merchant.cfm http://www.maib.gov.uk/cms_resources.cfm?file=/diamant-northern-merchant.pdf
2008	Scot Isles; Wadi Halfa	http://www.maib.gov.uk/publications/investigation_reports/2009/scot_isles__wadi_halfa.cfm http://www.maib.gov.uk/cms_resources.cfm?file=/ScotIslesWadiHalfaReport.pdf
2013	Paula C; Barya Gayatri	http://www.maib.gov.uk/publications/investigation_reports/2014/paula_c_and_darya_gayatri.cfm
2014	Rickmers Dubai; Walcon Wizard	http://www.maib.gov.uk/publications/investigation_reports/2014/rickmers_dubai__kingston__walcon_wizard.cfm

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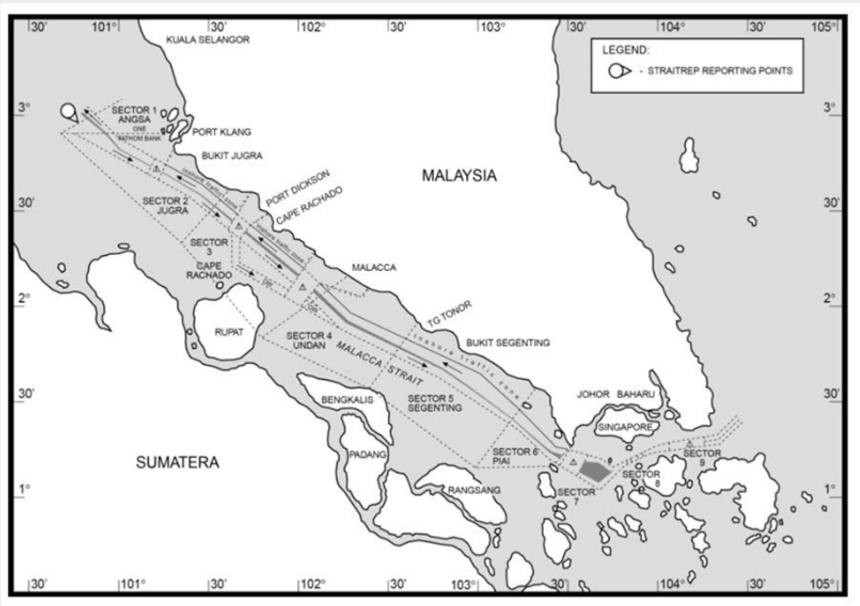
FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait

Part 4: Simulation of 3 Green Lights Night Signal

February 20, 2015



Summary

FSA for Vessels Crossing TSS and Precautionary Areas in Singapore Strait

Part 4 – Simulation of 3 Green Lights Night Signal

Technical Report No.:	Revision:	Date:
TR- SNG 1404102/04	1	20 February 2015

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Executive Summary

This study was undertaken as part of the formal safety assessment (FSA) for the use of three green lights night signal for vessels crossing the traffic separation scheme (TSS) and precautionary areas in the Singapore Strait. The main objective of the study presented in this report was to evaluate if the three green lights night signal are beneficial to identifying vessels that are intending to cross or are currently crossing the traffic separation scheme. This was achieved by testing the ability of lookouts to identify crossing vessels in a traffic separation scheme (TSS) using the new combination of navigation lights as compared with those using only traditional navigation lights. This report informs FSA Step 3 - Risk control options.

The ship simulations were conducted at the Center for Marine Simulation (CMS) of the Marine Institute of Memorial University in St. John's, Newfoundland and Labrador. For this study, CMS made available their full-mission, full-motion, bridge simulator and a tug visual simulator. The Full Motion Ships Bridge simulator utilizes Kongsberg Maritime's industry leading Polaris Ship Bridge simulator software that is certified by DNV to Class A standards for full mission ship simulators. The tug simulator is capable of simulating a 6 DOF hydrodynamic model and thus realistically interacts with the vessel to which it is attached.

The simulation plan was designed to determine, at a basic level, whether there are benefits to using the three green lights night signal. Simple sets of experiments were carried out to investigate any differences in the correct identification of crossing vessels by a set of Lookouts, for vessels with or without the three green light night signal. No attempt was made to provide complex situations and navigational tasks in order not to confound the results of the study, and to enable a reasonable number of simulations to be carried out within the 3 day simulation window.

Using ship simulators four persons were assigned the task of being Lookouts at night. The Lookouts were presented with a number of crossing vessels. The crossing vessels were all of the same size, physical and visual characteristics in every run excepting that some exhibited normal navigation lights indicative of a power driven vessel and others additionally exhibited the three all-round green lights in a vertical line the proposed navigation lights). It was decided to use vessels of the same size and characteristics because introducing different sizes and types of vessels could confound the results.

Lookouts were instructed that every crossing vessel identified will be presumed to be crossing the traffic separation scheme. The Lookouts were given a timer which they used to indicate the time they first noticed the navigation lights. This was compared to the control time to identify how long after initial presentation of the target the Lookout was able to observe the lights. The Lookouts also orally reported to the Observer what the vessel was doing. The report consisted of three elements:

- Where they saw the ship (port, starboard, how many points off);
- Whether the ship is crossing from starboard to port or port to starboard; and,
- If the ship is exhibiting the normal navigation lights or the 3 green lights.

Five physical and environmental conditions were considered in the simulation:

- Clear Visibility / Multiple Ships / Background Lights – San Francisco
- Clear Visibility / Single Ship / Background Lights – San Francisco
- Clear Visibility / Multiple Ships / No Background Lights – English Channel
- Clear Visibility / Single Ship / No Background Lights – English Channel
- Degraded Visibility / Multiple Ships / Background Lights - Singapore

Conditions 1 and 2 were located in the San Francisco Bay area and provided scenarios with very bright background lights; Conditions 3 and 4 were located in the English Channel and provided scenarios with no background lights; and finally, Condition 5 was located in the Singapore Strait, and provided scenarios with degraded visibility and background lights. Lighting conditions were made as close to reality as possible in the simulators.

Sixty simulation runs were carried out during which a total of 600 targets (crossing vessels), including 300 that displayed the three green lights night signal, and 300 that did not, were presented to the Lookouts. Three main measures were used to assess benefit of using the three green lights versus not using them (those with only the normal lights), namely, (a) the percentage of targets that were correctly identified (correct lights and correct direction of the crossing vessel); (b) percentage of vessels with green or normal lights not detected; and (c) time it takes to identify the target.

It was observed that for vessels displaying the three green lights, the Lookouts were able to provide accurate information for 88% of the time, compared to 85% of the time for vessels not displaying the three green lights night signal, and 86% for all targets. There was thus a marginal improvement in the correct identification of targets when the vessels displayed the three green lights.

It was also observed that only 5% of targets displaying the three green lights were not detected by the Lookouts, compared to 10% of targets not displaying the three green lights and 8% overall. Although the differences in these percentages are small and may well be within the margin of error, the results do indicate a potential improvement in the detection of crossing vessels that displayed the three green lights.

On the average, for vessels displaying the three green lights night signal, it took the Lookouts 23 s to detect the vessel after the vessel first appeared, compared to 28 s for vessels not displaying the three green lights, and 26 s overall. Although this time difference would appear to be rather small in absolute value, it should be borne in mind that the task in the experiment had been greatly simplified by the fact that all targets were known to be crossing vessels, in order to reduce the amount of confounding factors. Regardless, the simple tests conducted in this simulation exercise have demonstrated an approximately 18% improvement in the time it took the Lookout to correctly detect and identify the crossing vessels, if the vessels displayed the three green lights night signal. Additional support on the utility of the new navigation light was obtained through questionnaires administered by the MPA on vessels operating live within the vicinity of crossing vessels on an on-going basis in the Singapore Strait, as described in Part 1: Main Report.

The Lookouts also identified a number of non-crossing vessels as crossing vessels. Even though the experiment had been greatly simplified, there were still uncertainties as to the intents of vessels in the environment.

The influence of the physical and environmental conditions on the results was investigated. Approximately, 89% of targets presented under each condition were correctly identified, except Condition 1 (Multiple Ships in San Francisco, with Background Lights), for which the average correct detection rate was 78%. The overall average rate of vessels not detected was also highest at 12% for Condition 1. It would appear that this condition (multiple ships with background lights) posed the most difficulty to the Lookouts. There was little difference in the correct detection rates for vessels/ target displaying or not displaying the three green lights (77% vs 78%). The rates of vessels not detected were also similar (12% for both light displaying scenarios). For this condition, the only difference was in the time it took to detect and identify the targets - 34 s for vessels displaying green lights, compared to 40 s for targets not displaying the three green lights, indicating a 15% improvement in detection time with the use of the three green light signal.

For Condition 2 (Single Ship in San Francisco, with Background Lights), the benefit of the three green lights in correctly detecting the targets was more pronounced as follows:

(a) 95% detection rate for vessels displaying the three green lights versus 82% for vessels not displaying the green lights; and
(b) 3% non-detection rate for vessels displaying the three green lights versus 15% for vessels not displaying the green lights;

However, the average time for detection was higher for targets with the three green lights by 17% for this condition only.

For Condition 3 (multiple ships, with no background lights in the English Channel), the detection rates for targets with and without the three green lights were very similar: 88% for vessels with the three green lights and 90% for vessels without the three green lights. The rates of vessels not detected were also very

similar, at 3% and 5%, respectively for vessels displaying and not displaying the three green lights. The significant benefit of the three green lights was shown in the time it took the Lookouts to correctly identify the targets, with a 26% reduction in the detection time recorded for targets displaying the three green lights.

For Condition 4 (single ship, with no background lights in the English Channel), the detection rates for targets with and without the three green lights were 90% vs 85%; the corresponding rates of vessels not detected were 5% vs 12%; and the reduction in the time for identifying vessels with the green lights over those without was 27%.

For Condition 5 (multiple ships with degraded visibility with background lights in the Singapore Strait), the detection rates for targets with and without the three green lights were 88% vs 90%; the rates of vessels not detected were 3% vs 5%; and the reduction in the time for identifying vessels with the green lights over those without was 23%.

The use of the three green lights provided the highest percentage of vessel detection for Condition 2 (Single Ship in San Francisco Bay with Background lights), and least for Condition 1 (Multiple Ships in San Francisco Bay with Background lights). The level of detection for all other conditions (Conditions 3 to 5) appeared to be similar. The the number of vessels not detected is generally lower with the use of the three green lights. For vessels not displaying the three green lights, the highest percentage of vessels not detected was highest for the single ship scenarios (Conditions 2 and 4).

The San Francisco scenarios with background lights (Conditions 1 and 2) required the most time to detect, with the multiple ship scenarios being the highest. The average detection times for Condition 3 (Multiple Ship in English Channel without background lights) and Condition 5 (Multiple Ships in Degraded Visibility in Singapore Straight) were very similar. Condition 4 (Single Ship in with no background lights in English Channel) required the least amount of time for correct detection and identification. In all cases, the corresponding time for vessels displaying the three green lights was lower than that for vessels without the three green lights, except for Condition 2 where a slightly higher detection time was noticed.

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GLOSSARY AND ACRONYMS

FSA	Formal Safety Assessment
IMO	International Maritime Organization
LRA	Lloyd's Register Asia
MPA	Maritime and Port Authority of Singapore
TSS	Traffic Separation Scheme

1. Introduction

1.1 Background

This document is Part 4 of the overall report on the formal safety assessment (FSA) for the use of three green lights night signal for vessels crossing the traffic separation scheme (TSS) and precautionary areas in the Singapore Strait. The document provides details of the simulations carried out in a full mission bridge simulator to assess the benefit of the three green lights night signal, undertaken as part of the FSA. The FSA methodology [1] comprises a five step process involving:
(1) Identification of hazards;
(2) Risk analysis;
(3) Risk control options;
(4) Cost benefit assessment; and
(5) Recommendations for decision making.

This report informs Step 3.

1.2 Objectives and Scope

In traffic separation schemes, where there are high densities of background lights, navigation lights from anchorages and high traffic densities, it can be difficult to pick out the navigation lights of vessels crossing the traffic separation scheme. The purpose of this simulation study was to evaluate if the three green lights night signal are beneficial to identifying vessels that are intending to cross or are currently crossing the traffic separation scheme. This was achieved by testing the ability of lookouts to identify crossing vessels in a traffic separation scheme (TSS) using a new combination of navigation lights as compared with those using only traditional navigation lights.

2. Description of the Simulation Equipment

2.1 Facilities

The ship simulations were conducted at the Center for Marine Simulation (CMS) of the Marin Institute of Memorial University in St. John's, Newfoundland. The CMS provides a comprehensive suite of maritime simulators in Canada. CMS facilities include: a full mission ship bridge simulator mounted on an aviation motion base; a full mission ballast control room simulator with motion base; a full mission propulsion plant simulator with audio system; an electronic navigation simulator; three dynamic positioning simulators; two remotely operated vehicle (ROV) simulators; a liquid cargo simulator; a process control simulator; a Force Technology fast-time simulator; a lifeboat launching simulator; an on-line navigation instruments simulator, an electronic chart display and information system simulator, a global maritime distress safety system simulator, and a versatile tug simulator.

For this study, CMS made available their full mission full motion bridge simulator and a tug visual simulator. This made it possible to collect twice the amount of data that would have been collected with the use of only one simulator. Figure 1 shows pictures of the full-mission, full-motion bridge and tug visual simulators used in the study area. The Full Motion Ships Bridge simulator utilizes Kongsberg Maritime's industry leading Polaris Ship Bridge simulator software. Using advanced numerical models for environmental forces, vessels, and sea states this simulation engine when combined with high fidelity visual graphics can represent any marine transportation scenario including ship manoeuvring, voyage or route studies, emergency situations, or risk assessments. The Polaris ship simulator system at CMS is certified by DNV to Class A standards for full mission ship simulators.

Figure 1 Full-mission, full-motion bridge simulator

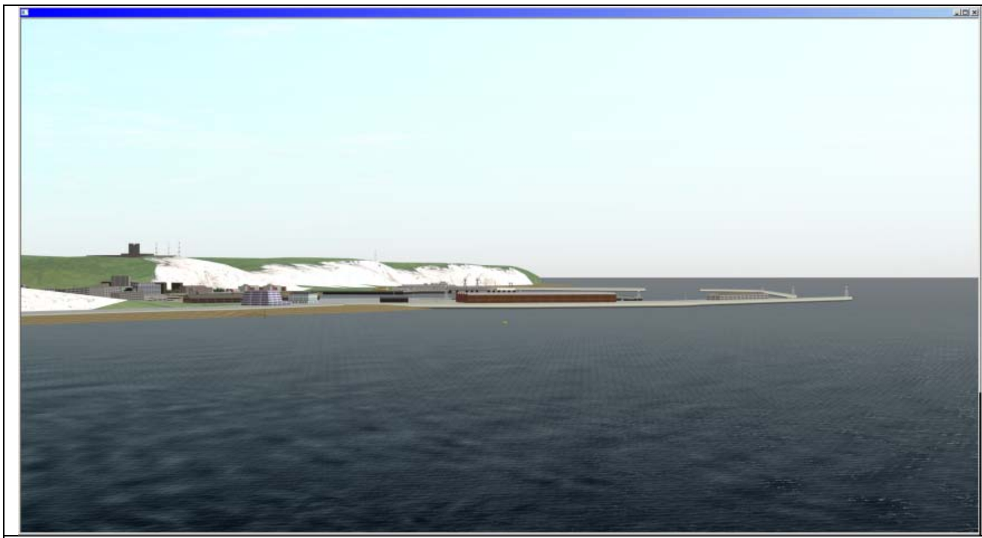
CMS's tug simulator is capable of simulating a 6 DOF hydrodynamic math model and thus realistically interact with the vessel to which it is attached (e.g. hawser forces are exerted on both the vessel and the tug). The tug Instructor Station allows the instructor to monitor and control aspects of the simulator such as tug position, hawser angle/tension, and propulsion system settings.

The tug simulator has a much narrower field of view. The Lookout can stand in one spot and see all of the screens and easily scan the whole field. On the full mission bridge the candidate has more windows to deal with as well as a much larger physical space. They were more inclined to be walking around to see the full field. Also, as the tug has LCD screens the contrast is very good and picking out shadows against light is easier. Furthermore, the tug simulator had no course and speed indicator that the Lookout could use to assess if movement of lights may be due to the change in course or speed of own ship. The Lookouts only had visuals to make all assessments. This was not the case for the full mission bridge. Blind sectors in the full mission bridge can be seen around by the lookout moving around, whereas the blind sector in the tug simulator cannot be seen around by moving and remains truly a blind sector. In order to determine if the differences in the simulator environments affected the results in any significant way, the data obtained from the two simulators were assessed separately.

2.2 Geographic Databases

A geographic database is a collection of various data sets, which are used to generate a number of simulation files required for the navigation simulators. All of these files are integrated by the simulation system when loading an exercise, which interact in the form of visuals, motion, ship models, and navigation systems. Environmental effects such as wind, tide, current, and precipitation are maintained through the instructor station by the instructor, and can be stored within an exercise for easy recall of those conditions. These elements influence ship motion and navigation systems appropriately. The visual databases are generated by constructing terrain features and cultural objects from within the 3D development software. Each ship type has associated 3D visual representations, which can be viewed from any angle and from any distance, and will show the correct perspective. The system contains prototypes of all standard navigation aids (buoys, lights, etc.) and accepts new designs into its library.

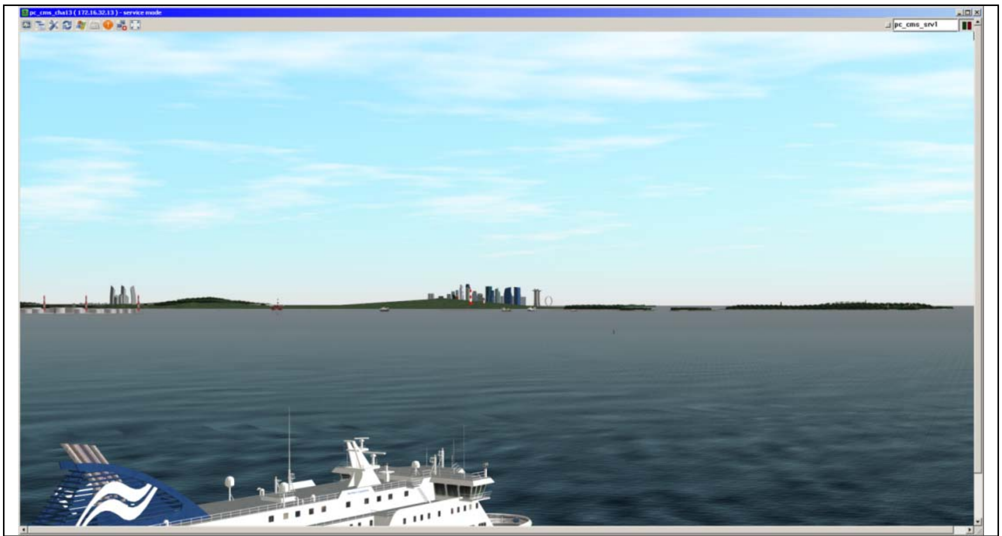
The geographical data bases for Singapore Strait, the English Channel and San Francisco Bay available in the CMS library, were refined/ modified to suit the requirements of this study. The views of the three areas as seen from the simulators are shown in Figure 2 to Figure 4. Note that only the night views were used in the study. The day views are shown for illustration purposes; to demonstrate that the cultural objects in the simulation models were close to reality. In addition to the Singapore Strait, which had background lights, the English Channel and San Francisco Bay were studied. The English Channel provided scenarios with no background lights, and the San Francisco Bay area provided additional scenarios with very bright background lights.



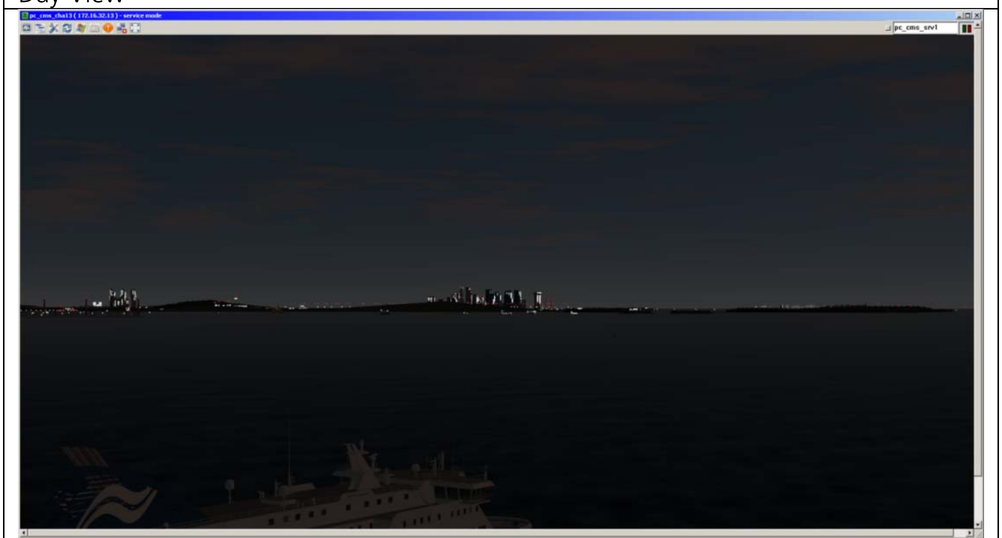
Day View

Night View

Figure 2 Day and Night Views of English Channel



Day View



Night View

Figure 3 Day and Night Views of Singapore Strait

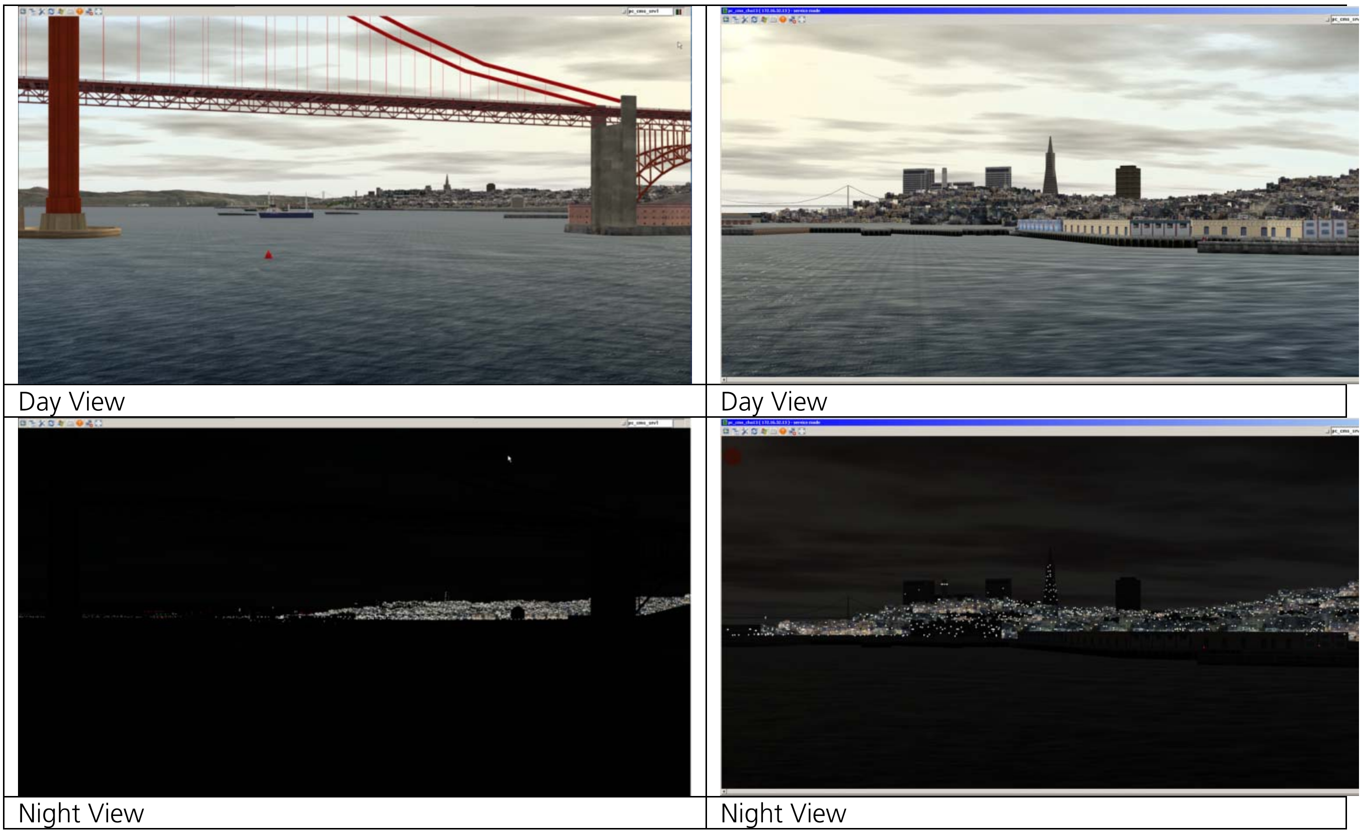


Figure 4 Day and Night Views of San Francisco Bay

3. Methodology

The simulation exercise was carried out at the facilities of the Center for Marine Simulation (CMS) in St John's, Newfoundland, on November 18-20, 2014.

3.1 Study Team and Attendance

The team members participating in the study are listed in **Table 1**.

Table 1: Study Team Members

Name	Organization	Role/ Position	E-mail Address
Stephen Dubuc	Center for Marine Simulation, Marine Institute of Memorial University (CMS)	Instructor	stephendubuc@hotmail.com
Capt. Jack Gallagher	Hammurabi Consulting	Facilitator, Recorder	jack@hammurabi.ca
Tamunoiyala Koko	LRA	Recorder	Tamunoiyala.koko@lr.org
Douglas Owen	LRA	HF, SME; Design of Simulation Plan	Douglas.owen@lr.org
4 Lookouts	CMS	Lookout	

3.2 Approach

The simulation plan was designed to determine, at a basic level, the benefits of the use of three green lights night signal. Simple sets of experiments were carried out to investigate any differences in the correct identification of crossing vessels by a set of Lookouts, if the vessels displayed the three green light night signal or not. No attempt was made to provide complex situations and navigational tasks in order not to confound the results of the study, and to enable a reasonable number of simulations to be carried out within the 3 day simulation window.

Using visual simulators four persons were assigned the task of being Lookouts at night. The Lookouts were presented with a number of crossing vessels. The crossing vessels were all of the same size, physical and visual characteristics in every run excepting that some exhibited normal navigation lights indicative of a power driven vessel and others additionally exhibited the three all-round green lights in a vertical line. It was decided to use vessels of the same size and characteristics because introducing different sizes and types of vessels could confound the results by introducing other visual features that affect the salience of the vessel independent of the navigation lights (e.g. size of the vessel in the visual field).

Each Lookout tested individually to avoid them taking cues from the actions of other Lookouts. Lookouts were in general stationed near the vessel center to give the best unobstructed view to port and starboard but were free to move about as they determined best suited their lookout task.

A normal navigational Lookout is tasked with reporting all material objects or lights as they become material. This means that Lookouts are expected to observe and make a determination if the light or object is necessary to report to the officer of the watch. In many cases this involves observing a ship for some time after first sighting in order to determine the intent or condition of a vessel such as whether it is crossing, overtaking, end on, constrained by draft etc. As this is a human factors study the Lookout tasks were modified somewhat to suit the experiment.

In the experiment, Lookouts were given the task to identify crossing vessels, indicating whether the crossing vessel was displaying the 3 green lights night signal or normal navigation lights. Lookouts were instructed that every crossing vessel identified will be presumed to be crossing the traffic separation scheme. The Lookouts were also required to record the time when they first noticed the navigation lights, by clicking the mouse of a computer on which a timer program had been loaded for the exercise. The computer timer program recorded the time each time the mouse is clicked from the start of the simulation. The time recorded by the Lookout was compared to the control time (from the simulation program) to identify how long after initial presentation of the target the Lookout was able to observe the lights. The Lookouts also orally reported to the Observer what the vessel was doing. The report consisted of three elements:

1. Where they saw the ship (port, starboard, how many points off);
2. If the ship is a crossing vessel and whether crossing port to starboard or starboard to port; and
3. If the ship is exhibiting the normal navigation lights or the 3 green lights.

The Lookouts were instructed to report to the observer only when they have figured out what the vessel is doing i.e. is it a crossing vessel. The report to the Observer is similar to the report a Lookout would make to the officer of the watch. The Observer made sure the three pieces of information were provided each time the mouse was clicked by the Lookout.

The crossing vessels appeared at a distance of between 4.5 and 5.5 nautical miles and presented lights appropriate for that distance. The relative speed of the ship the Lookout is on and the crossing vessels was approximately 30 knots, with both ships always in motion. This is a realistic closing speed and large enough that changes in aspect become readily available.

All crossing vessels were presented in the arcs from 15 degrees from the bow to 75 degrees from the bow on each side of the ship. This ensured that Lookouts were not trying to keep a 360 degree lookout and that both simulators used offered an identical presentation.

Vessels were only presented to the lookouts for 60 seconds. This interval was long enough to make a sighting and determination but short enough that some targets may be missed. The target may be missed altogether or may be seen but insufficient time to assess whether it is crossing or not.

Also by having the vessel presented for only 60 seconds the Lookout would not have to be concerned as to whether a close quarters or collision situation is developing as this was not of interest to the objectives of the experiment. The Lookouts were instructed to not be concerned with targets that disappear as they will not reappear closer or present any future threat to their ship.

Each condition run lasted between 15 and 20 minutes and the Lookouts were not aware of the number of crossing vessels that were presented.

3.3 Simulation Runs

Five physical and environmental conditions, as listed in Table 2 were considered in the simulations. Conditions 1 and 2 were located in the San Francisco Bay area, Conditions 3 and 4 were located in the English Channel, and Condition 5 was located in the Singapore Strait.

Table 2: List of Simulation Conditions

Condition No.	Description of Condition (Location, Physical and Environmental Conditions)
1	Clear Visibility / Multiple Ships / Background Lights – San Francisco
2	Clear Visibility / Single Ship / Background Lights – San Francisco
3	Clear Visibility / Multiple Ships / No Background Lights – English Channel
4	Clear Visibility / Single Ship / No Background Lights – English Channel
5	Degraded Visibility / Multiple Ships / Background Lights - Singapore

A total of 60 simulation runs were carried out over a three day period in the two simulators, that is, 10 identical simulation runs per day in each simulator.

The presentation order of the ships with either normal or additional navigation lights was counterbalanced across the trials. For the first 10 runs (Day 1) the exact same ships were presented in the exact same times and locations for each of the five conditions. For the second 10 runs (Day 2) the order and location in which the ships were presented was altered so that lookouts could not "learn" or remember what was presented during the trial the previous day. Similarly the order was changed again for the last 10 runs (Day 3). The simulations seek to answer the following questions:

1. Are ships with the additional suite of navigation lights detected more often when compared to ships with just the normal navigation lights?
2. Does the new suite of navigation lights reduce the time taken to detect the ship, and assess the aspect / intent of the ship?

In the conditions where there are multiple ships the simulation was run for a few minutes for the lookout to become accustomed to the ships in view prior to introducing crossing vessels. For these cases, there were several other ships in view in addition to the crossing vessel. The order in which the candidates viewed the various scenarios was randomized to insure that results were not skewed by the improved skill of the observers over the test period.

The interval between vessels was also randomized, between 20 and 90 seconds. Each run had 10 crossing vessels, which were randomly fitted with the new suite of lights so that 50% had each configuration. As stated in Section 3.2, the Lookouts were not informed on the number of crossing vessels in each run, until after the whole exercise.

To ensure anonymity of the study results, the Lookouts will be designated as Lookout A, B, C and D, in no particular order. On each day, two Lookouts are assigned to one simulator, and the Lookouts undertake their duties alternately, as per the schedule in **Table 3**. The order of the simulation conditions was also randomized as shown in **Table 4**.

Table 3: Schedule of Lookouts in Simulators

Day	Lookouts Assigned to Specified Simulator (Alternately, One at a Time)	
	Full Mission Bridge	Tug Simulator
1	A & B	C & D
2	B & C	A & D
3	C & D	A & B

Table 4: Order of Simulation Conditions

Day	Run Nos.	Simulation Conditions									
1	1 - 10	1	3	2	4	5	2	3	5	4	1
2	11 - 20	4	1	5	5	3	2	1	4	2	3
3	21 - 30	3	4	4	3	2	5	5	1	1	2

A total of 600 targets were presented to the Lookouts of which 300 displayed the three green lights night signal, and 300 did not. This provides a reasonably large data size from which to derive statistically significant results, when assessing the overall results. Similarly, reasonably large data sets are available when assessing the influence of the individual simulation condition, simulator or Lookout, as shown in **Table 5**.

Table 5: No. of Targets in Simulations

Data Set	Number of Targets		
	With Green Lights	Without Green Lights	Total
Overall	300	300	600

Each Simulation Condition	60	60	120
Each Simulator	150	150	300
Each Lookout	75	75	150

Some of the Lookouts were not familiar with the simulation environment. To this end, a familiarization run was undertaken on the full mission bridge with everyone. After running for a while several ships were introduced to allow participants to see what they would be picking out. This was a very helpful run as it reduced the participants' anxiety and made them much more comfortable with the task.

Three main measures were used to assess benefit of using the three green lights versus not using them (those with only the normal lights), namely, (a) the percentage of targets that were correctly identified (correct lights and correct direction of the crossing vessel); (b) percentage of vessels with green or normal lights not detected; and (c) time it takes to identify the target.

3.4 Recording of Data

A simple computer program that uses the computer's clock was developed for purposes of recording the time when Lookouts observed the targets. The program was loaded on a lap top computer and the Lookouts recorded the times by clicking the mouse, first at the beginning of each run, and at the times when the targets were observed. The computer program recorded the time stamps at each mouse click, and computed the cumulative time from start of each run, as well as the elapsed time between successive clicks. A typical time stamp record from one of the runs is show in Figure 5. A new file was created for each run, to reinitialize the starting time for each run to zero.

19/11/2014 8:21:18 AM	0	0	Laptop2
19/11/2014 8:23:15 AM	117.6866	117.6866	Laptop2
19/11/2014 8:24:55 AM	217.0276	99.34097	Laptop2
19/11/2014 8:26:14 AM	296.0573	79.02974	Laptop2
19/11/2014 8:27:41 AM	383.1835	87.12615	Laptop2
19/11/2014 8:29:31 AM	492.8985	109.715	Laptop2
19/11/2014 8:31:01 AM	583.5502	90.65176	Laptop2
19/11/2014 8:33:27 AM	729.8941	146.3439	Laptop2
19/11/2014 8:35:29 AM	851.0907	121.1966	Laptop2
19/11/2014 8:36:59 AM	941.0561	89.96536	Laptop2
19/11/2014 8:38:26 AM	1028.057	87.00135	Laptop2

Figure 5 Typical Time Stamp Record for a Run

The form used to collect the data is shown in Appendix 4B. Details of all of the 60 simulation runs are provided in Appendix 4C.

3.5 End of Simulation Debrief

A debrief meeting of was held at end of all of the simulations. During the debrief, the Lookouts were informed that there were exactly 10 crossing vessels in each run. The Lookouts were also requested to fill out the debrief form shown in Appendix 4B, to record their general impressions regarding the exercise. Further discussions were also held by the whole simulation team and recorded at this meeting. The purpose of these discussions was to get the Lookouts' perspective on the experiments and to provide lessons learned.

4. Results and Discussion

4.1 Overall Results

Overall, 600 targets (300 with the three green lights night signal, and 300 without) were presented. Column 2 of the table shows the accuracy of detection (Lookouts able to detect correct light and correct crossing direction), for all targets with and without the green lights, and overall. It can be seen that for vessels displaying the three green lights, the Lookouts were able to provide accurate information for 88% of the time, compared to 85% of the time for vessels not displaying the three green lights night signal, and 86% for all targets. There was thus a marginal improvement in the correct identification of targets when the vessels displayed the three green lights.

Table 6 provides a summary of the extent to which the Lookouts were able to identify the targets that were presented to them.

Table 6: Summary of Overall Results

Three Green Lights (1)	Vessel Detected			Vessel Not Detected (5)	Average Correct Detection Time (s) (6)	Non-Crossing Vessels Detected (7)
	Correct Lights Correct Directions (2)	Correct Lights Incorrect Directions (3)	Incorrect Lights (4)			
Y	88%	3%	4%	5%	23	18
N	85%	2%	3%	10%	28	
Overall	86%	3%	4%	8%	26	

Column 3 of the table shows the percentages of targets for which the Lookouts correctly identified the type of lights displayed by the target, but incorrectly determined the crossing direction. These percentages were generally small: 3% for vessels with green lights; 2% for vessels without the green lights; and 3% overall.

Column 4 of the table shows the percentages of targets for which the Lookouts incorrectly identified the type of lights displayed by the target. Again, these percentages were generally small: 4% for vessels with green lights; 3% for vessels without the green lights; and 4% overall.

Column 5 of the table shows the percentages of targets that were not detected by the Lookouts. It can be seen that only 5% of targets displaying the three green lights were not detected by the Lookouts, compared to 10% of targets not displaying the three green lights and 8% overall. Although the differences in these percentages are small and may well be within the margin of error, the results do indicate a potential improvement in the detection of crossing vessels that displayed the three green lights.

Column 6 of the table shows the average times it took to correctly detect and identify crossing directions of the targets. On average, for vessels displaying the three green lights night signal, it took the Lookouts 23 s to detect the vessel after the vessel first appeared, compared to 28 s for vessels not displaying the three green lights, and 26 s overall. The time difference for vessels with 3 green lights versus those without would appear to be rather small in absolute value. However, it should be borne in mind that the task in the experiment had been simplified by the fact that all targets were known to be crossing vessels, in order to reduce the amount of confounding factors. Regardless, the simple tests conducted in this simulation exercise have demonstrated an approximately 18% improvement in the time it took the Lookout to correctly detect and identify the crossing vessels, if the vessels displayed the three green lights night signal. Additional support on the utility of the new navigation light was obtained through questionaires administered by the MPA on vessels operating live within the vicinity of crossing vessels in the Singapore Strait on an on-going basis, as described in Part 1: Main Report.

Finally, in Column 7 of the table, total number of non-crossing vessels that were identified as crossing vessels is presented. Even though the experiment had been greatly simplified, there were still uncertainties as to the intents of vessels in the environment.

In the following sections, the influences that various factors such as the simulation conditions, type of the simulators, the Lookouts themselves, and experience, have on the results are discussed.

4.2 Influence of Simulation Conditions

Table 7 presents the results for each of the five simulation conditions. The conditions were described in Table 2. Recall that the Conditions 1 and 2 were in the San Fricisco Bay area, with Condition 1 having multiple ships and Condition 2 having a single ship, and both with background lights and clear visibility. Similarly, Conditions 2 and 3 were in the English Channel, with Condition 3 having multiple ships and Condition 4 having a single ship, and both without background lights and clear visibility. Condition 5 was in the Singapore Strait with multiple ships, background lights and degraded visibility.

Table 7: Simulation Results for Various Simulation Conditions

Condition (1)	Three Green Lights (2)	Vessel Detected: Correct Lights Correct Directions (3)	Vessel Detected: Correct Lights Incorrect Directions (4)	Vessel Detected: Incorrect Lights (5)	Vessel Not Detected (6)	Average Correct Detection Time (s) (7)	Non-Crossing Vessels Detected (8)
1	Y	77%	3%	8%	12%	34	2
	N	78%	2%	8%	12%	40	
	Overall	78%	3%	8%	12%	37	
2	Y	95%	0%	2%	3%	28	0
	N	82%	2%	2%	15%	24	
	Overall	88%	1%	2%	9%	26	
3	Y	88%	5%	3%	3%	20	10
	N	90%	5%	0%	5%	27	
	Overall	89%	5%	2%	4%	23	
4	Y	90%	5%	0%	5%	16	3
	N	85%	2%	2%	12%	22	
	Overall	88%	3%	1%	8%	19	
5	Y	88%	2%	7%	3%	20	3
	N	90%	2%	3%	5%	26	
	Overall	89%	2%	5%	4%	23	

For each condition, a total of 120 targets (60 with the three green lights night signal, and 60 without) were presented. Overall, approximately 89% of all targets were correctly identified for all conditions, except Condition 1 (Multiple Ships in San Francisco, with Background Lights), for which the average correct detection rate was 78% (see Column 3 of the table). It is not clear why the detection rate for Condition 1 was much lower than the rates for the other conditions. The overall average rate of vessels not detected was also highest at 12% for Condition 1. It would appear that this condition (multiple ships with background lights) posed the most difficulty to the Lookouts, and should be given careful consideration. A further look at this condition indicates that there is little difference in the correct detection rates for vessels/ target displaying or not displaying the three green lights (77% vs 78%). The rates of vessels not detected were also similar (12% for both light displaying scenarios). For this condition, the only difference was in the time it took to detect and identify the targets. The average time for identifying targets displaying the three green lights was 34 s compared to 40 s for targets not displaying the three green lights. Again, as discussed previously, this time difference is rather small. However, the results to indicate a 15% improvement in detection time with the use of the three green lights signal.

For Condition 2 (Single Ship in San Francisco, with Background Lights), the benefit of the three green lights in correctly detecting the targets was more pronounced as follows:

(a) 95% detection rate for vessels displaying the three green lights versus 82% for vessels not displaying the green lights; and
(b) 3% non-detection rate for vessels displaying the three green lights versus 15% for vessels not displaying the green lights;

However, the average time for detection was higher for targets with the three green lights by 17% for this condition only.

Consider the cases with no background lights in the English Channel (Conditions 3 and 4). For the multiple ship condition, the detection rates for targets with and without the three green lights were very similar: 88% for vessels with the three green lights and 90% for vessels without the three green lights. The rates of vessels not detected were also very similar, at 3% and 5%, respectively for vessels displaying and not displaying the three green lights. The significant benefit of the three green lights was shown in the time it took the Lookouts to correctly identify the targets, with a 26% reduction in the detection time recorded for targets displaying the three green lights. Similar results were also observed for the single ship condition, with the differences (benefits) being more pronounced for this case. For the single ship condition, the detection rates for targets with and without the three green lights were 90% vs 85%; the corresponding rates of vessels not detected were 5% vs 12%; and the reduction in the time for identifying vessels with the green lights over those without was 27%. The greater benefit for the single ship condition might be due to lesser distraction due to absence of other vessels in the vicinity.

Consider the case of degraded visibility with background lights in the Singapore Strait (Condition 5). The detection rates for targets with and without the three green lights were very similar: 88% for vessels with the three green lights and 90% for vessels without the three green lights. The rates of vessels not detected were also very similar, at 3% and 5%, respectively for vessels displaying and not displaying the three green lights. However, a slightly higher percentage of the green light signals were incorrectly detected than no green lights (7% versus 3 %). Overall, the a significant benefit of the three green lights was shown in the time it took the Lookouts to correctly identify the targets, with a 23% reduction in the detection time recorded for targets displaying the three green lights.

Figure 6 to Figure 8 presents the results graphically for quick comparison of the various conditions. Figure 6 compares the percentage of vessels detected correctly (correct lights, correct direction) under the various conditions. It can be seen that the use of the three green lights night sign provided the highest percentage of vessel detection for Condition 2 (Single Ship in San Francisco Bay with Background lights), and least for Condition 1 (Multiple Ships in San Francisco Bay with Background lights). The level of detection for all other conditions (Conditions 3 to 5) appeared to be similar.

Figure 7 compares the percentage of vessels not detected under the various conditions. It is seen that the number of vessels not detected is generally lower with the use of the three green lights. Without the use of the three green lights, the highest percentage of vessels not detected was highest for the single ship scenarios (Conditions 2 and 4), and this was regardless of the presence or absence of background lights.

Figure 8 compares the average amounts of time it took the Lookouts to correctly detect the targets under various simulation conditions. The San Francisco scenarios with background lights (Conditions 1 and 2) required the most time to detect, with the multiple ship scenarios being the highest. The average detection times for Condition 3 (Multiple Ship in English Channel without background lights) and Condition 5 (Multiple Ships in Degraded Visibility in Singapore Straight) were very similar. Condition 4 (Single Ship in with no background lights in English Channel) required the least amount of time for correct detection and identification. In all cases, the corresponding time for vessels displaying the three green lights was lower than that for vessels without the three green lights, except for Condition 2 where a slightly higher detection time was noticed.

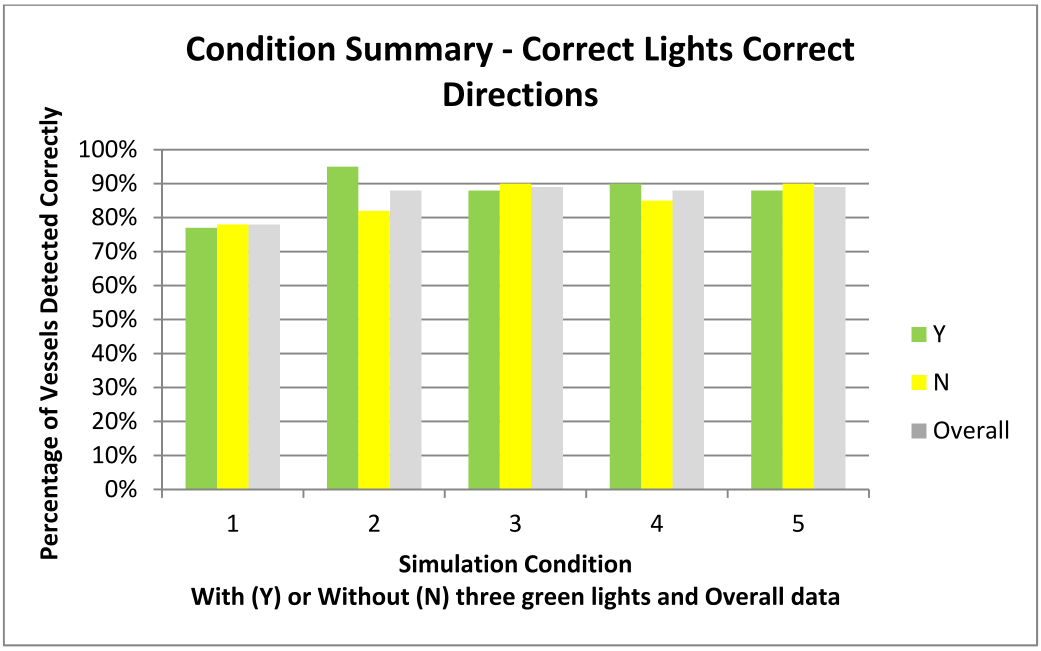


Figure 6 Percentage of Vessels Detected Correctly by Various Lookouts

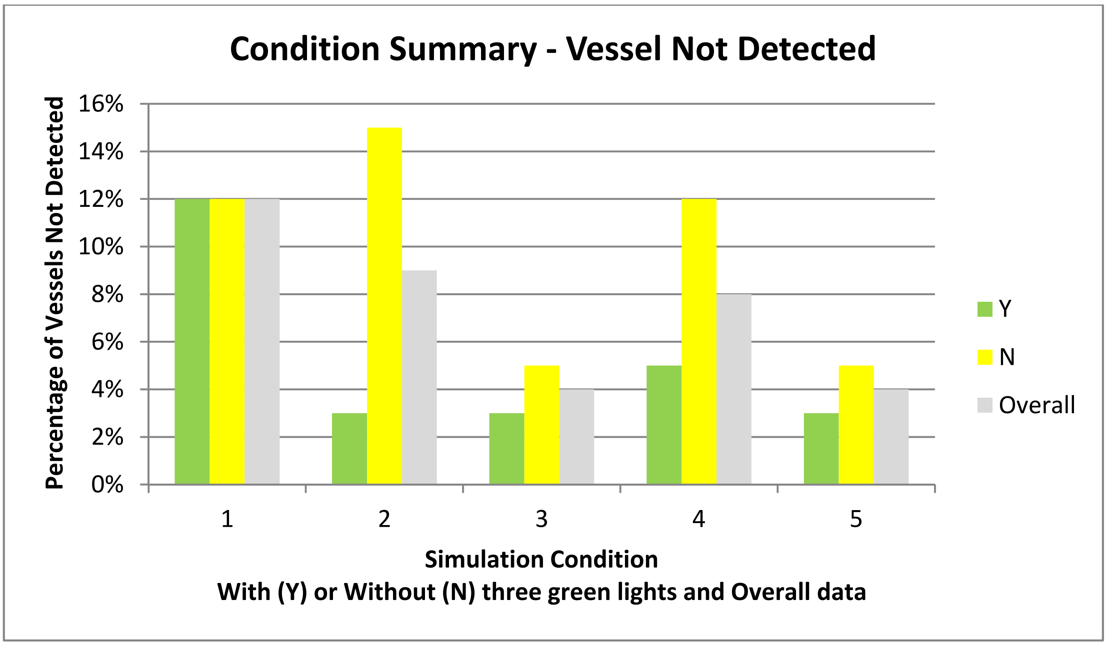


Figure 7 Percentage of Vessels Not Detected Under Various Simulation Conditions

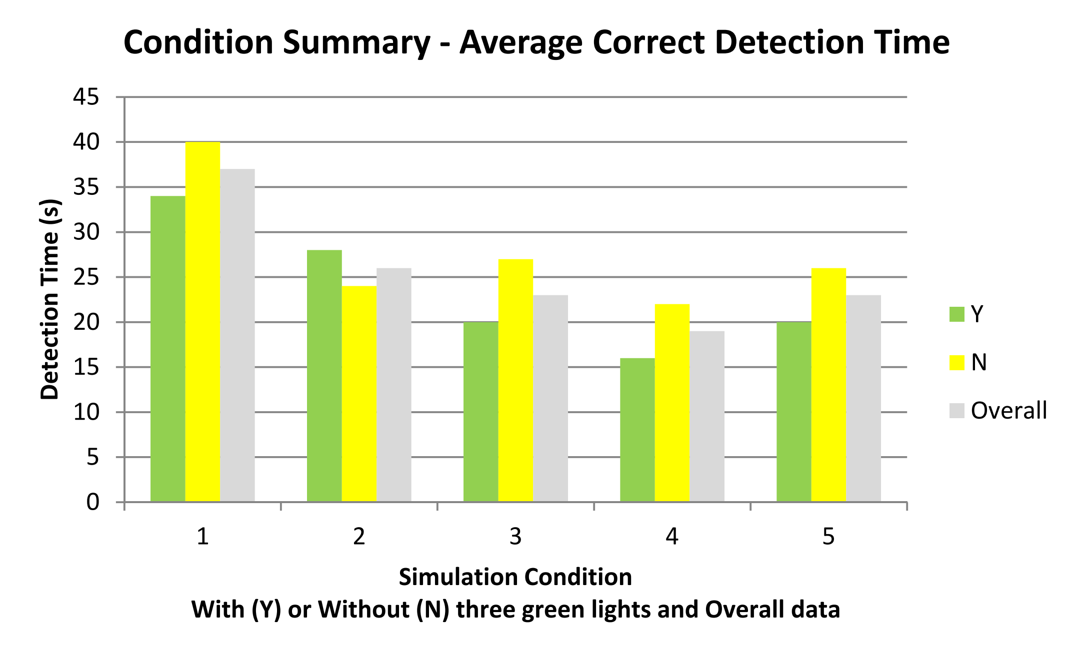


Figure 8: Average Time for Correct Identification of Vessels Under Various Simulation Conditions

4.3 Influence of Simulator

As two simulators were used for the exercise, it was important to determine if this had any significant influence on the results. Table 8 presents the results from each of the two simulators.

Table 8: Simulation Results from the Two Simulators

Simulator	Three Green Lights	Vessel Detected			Vessel Not Detected	Average Correct Detection Time (s)	Non-Crossing Vessels Detected
		Correct Lights Correct Directions	Correct Lights Incorrect Directions	Incorrect Lights			
Tug	Y	85%	3%	5%	7%	20	12
	N	83%	2%	3%	13%	24	
	Overall	84%	3%	4%	10%	28	
F/M	Y	91%	3%	3%	3%	26	6
	N	87%	3%	3%	7%	31	
	Overall	89%	3%	3%	5%	29	

In each simulator, a total of 300 targets (150 with the three green lights night signal, and 150 without) were presented. Overall, approximately 89% of all targets were correctly identified in the full mission bridge simulator, compared to 84% for the tug simulator. Also, the overall, approximately 5% of targets were not detected in the full mission bridge simulator, compared to 10% for targets in the tug simulator. This represented only 5% differences in the rates for correct detection, and non-detection of vessels, respectively, with the full mission bridge simulator detected and incorrect lights detected were very similar for both simulators. The average times to detect the targets were also similar for both simulators. This suggests that even though there were slight differences in the results obtained from both simulators, the use of two simulators did not affect the results in any significant way.

4.4 Influence of Lookout

The influence of the Lookouts on the results was also investigated. Table 9 summarizes the results obtained by the four Lookouts.

Table 9: Simulation Results from the Each Lookout

Lookout	Three Green Lights	Vessel Detected			Vessel Not Detected	Average Correct Detection Time (s)	Non-Crossing Vessels Detected
		Correct Lights Correct Directions	Correct Lights Incorrect Directions	Incorrect Lights			
A	Y	77%	4%	8%	11%	22	14
	N	80%	3%	7%	11%	31	
	Overall	79%	3%	7%	11%	27	
B	Y	93%	3%	1%	3%	22	3
	N	85%	4%	3%	8%	26	
	Overall	89%	3%	2%	5%	24	
C	Y	83%	4%	7%	7%	29	0
	N	88%	1%	3%	8%	32	
	Overall	85%	3%	5%	7%	31	
D	Y	97%	1%	0%	1%	20	1
	N	87%	1%	0%	12%	21	
	Overall	92%	1%	0%	7%	21	

Each Lookout was presented with a total of 150 targets (75 with the three green lights night signal, and 75 without).

Overall, the percentage of targets correctly identified varied from 79% to 92%. As shown in Figure 9, the variability in the percentages were low. Lookouts A and C observed almost similar percentages of the target, just as for Lookouts B and D.

The average percentages of all vessels not detected by the Lookouts varied from 5% to 11% (see Figure 10). However, there appeared to be a larger variability for the percentages of targets with green lights that were not detected. On the other hand, as shown in Figure 11, the spread of detection times recorded by the Lookouts was also not significant.

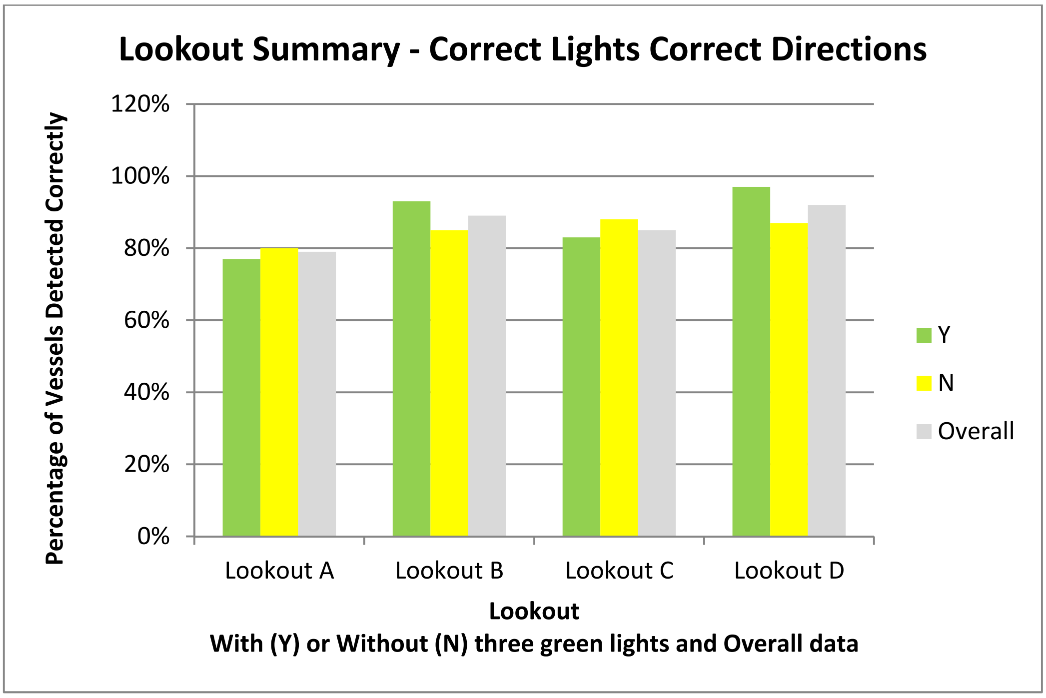


Figure 9 Percentage of Vessels Detected Correctly by Various Lookouts

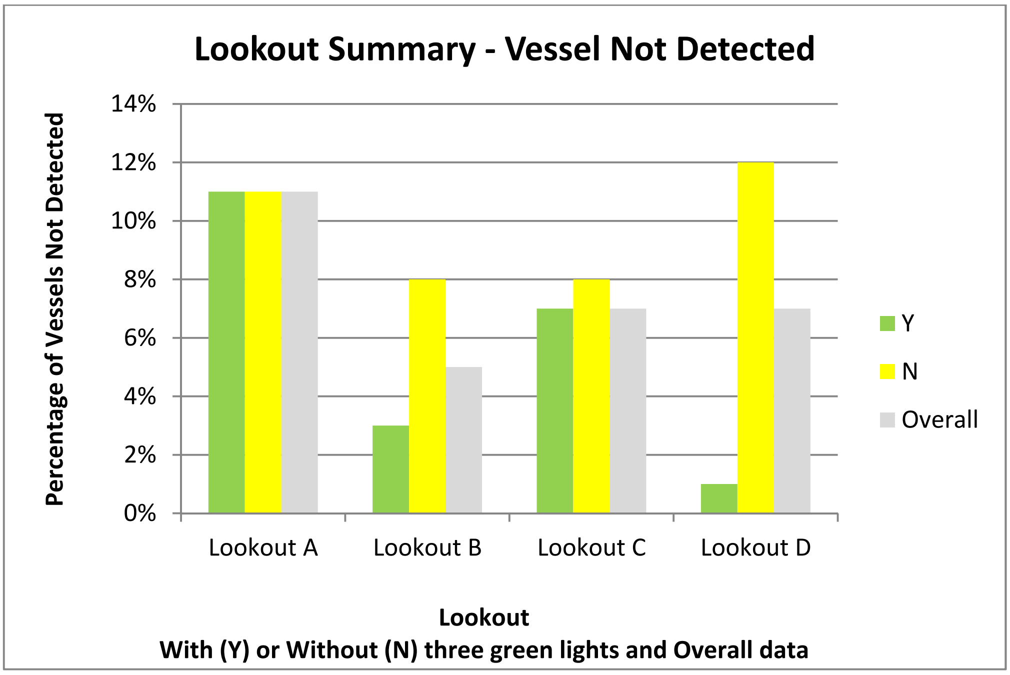


Figure 10 Percentage of Vessels Not Detected by Various Lookouts

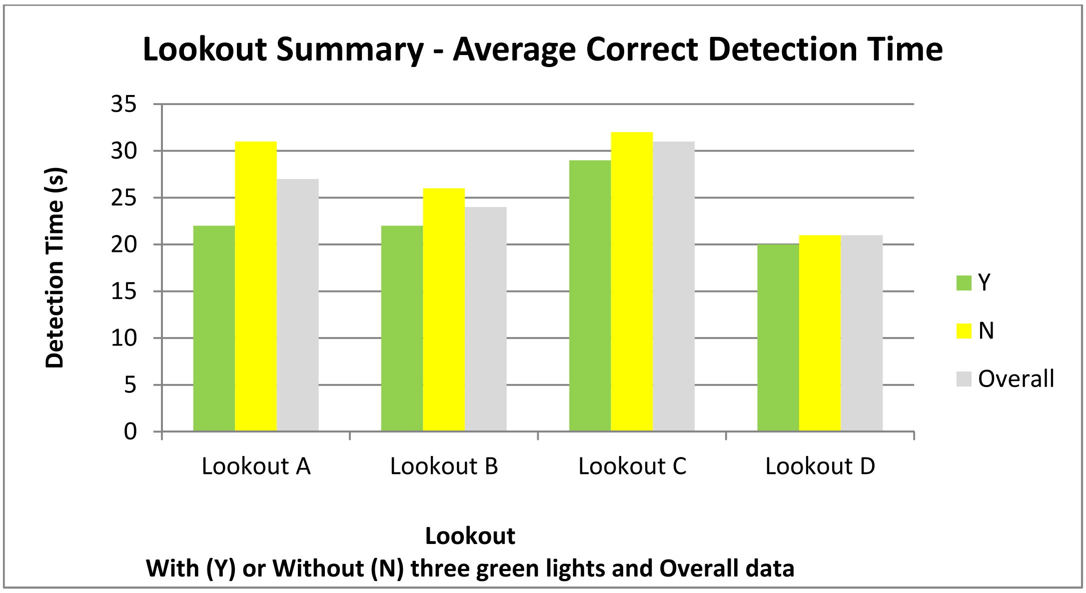


Figure 11: Average Time for Correct Identification of Vessels by Various Lookouts

4.5 Influence of Time Spent on Simulator

The results obtained from each day of simulation were also compiled to investigate the influence of the time spent by Lookouts in the simulators. Overall there were 200 targets (100 with three green lights, and 100 without) assessed on each simulation day. Table 10 summarizes the results obtained on each simulation day, and the highlights are summarized below:

- The percentage of vessels correctly detected remained fairly constant from Day 1 to Day 2 and increased slightly from Day 2 to Day 3
- The percentages of vessels not detected reduced slightly from Day 1 to Day 3
- The average time to correctly detect targets also reduced slightly from Day 1 to Day 3.

Overall, the expected trend of the results due to experience gained with the process was observed. However, the differences in results between the days were not significant enough to impact the quality of the overall results.

Table 10: Simulation Results from the Each Simulation Day

Day	Three Green Lights	Vessel Detected			Vessel Not Detected	Average Correct Detection Time (s)	Non-Crossing Vessels Detected
		Correct Lights Correct Directions	Correct Lights Incorrect Directions	Incorrect Lights			
1	Y	85%	3%	5%	7%	30	4
	N	83%	3%	1%	13%	33	
	Overall	84%	3%	3%	10%	31	
2	Y	83%	4%	7%	6%	22	7
	N	83%	3%	6%	8%	30	
	Overall	83%	4%	7%	7%	26	
3	Y	95%	2%	0%	3%	19	7
	N	89%	1%	2%	8%	21	
	Overall	92%	2%	1%	6%	20	

4.6 End of Simulation Debrief

At the end of the simulation exercise, the Lookouts were asked to record their general impressions regarding the simulation exercise as a whole and the benefit of the use of the three green lights. Their responses are summarized in **Table 11**. In the table, each bullet in the last column corresponds to the response of a Lookout to the corresponding question or issue in the second column.

Table 11: Responses of Lookouts at Debrief Meeting

Item #	Issue/ Question	Lookouts' Response
1	What is your general impression respecting the use of the three green lights versus the normal navigation lights?	• 3 green lights is effective for quick identification of a crossing target • In areas without background lights, made little difference. Much more useful when background lights were present • In my perspective I think it will make the lookouts' job better/ easier. It is a lot easier to see them than the normal • I believe they should be implemented as they provide an easy assessment of the situation and allow for faster sightings of vessels
2	Rating the utility of the lights on a scale of 1 – 100 where 100 is remarkably improves the identification and intent of vessels and 1 remarkably confuses the identification and intention of vessels and 50 is neutral.	• Lookout A: 80 • Lookout B: 80 • Lookout C: 100 • Lookout D: 85 Average: 86.25
3	Do you feel that the lights had the same utility in each location?	• No. The farther the distance, the more difficult to differentiate the green from the white lights • No, unnecessary in open areas with no background lights (English Channel) • Yes, the lights were clear and quite easy to see • Yes. However, were far more helpful when background light is present
4	Do you feel that the lights had the same utility in good versus poor visibility?	• More difficult to detect the green during periods of reduced visibility • More difficult to interpret in restricted visibility, regardless made masthead more visible • Yes • Neither agree nor disagree
5	Did the lights help with identification of vessels alone? Intent of vessels alone? Or both?	• The lights assist in quick recognition of a crossing situation • Yes, in heavy background and restricted visibility, lights improved both identification and intent • Both, overall great indication • Both
6	Any other Comments?	• The use of 3 green mast head lights is a useful and simple improvement to navigation during restricted / reduced visibility • None • If brought into place, will prevent a lot of collisions/ accidents • None

The main highlights of the Lookout responses are summarized below:

- In general, all of the Lookouts felt that the three green lights night signal was effective for identification of a target and provided easier and quicker assessment of a situation
- The three green light night signal were more effective for cases with background lights
- There was no difference between the green lights and normal signals for cases with no background lights
- Some of the Lookouts felt that the lights were more difficult to interpret in reduced visibility
- On a scale of 0 to 100, the Lookouts gave an average rating of the utility of the lights at 86. Recall that the percentage of vessels that were detected by the Lookouts during the simulation was also 86%. It is interesting that the qualitative assessment of the utility of the lights by the Lookouts matched the results from the experiment. This may be coincidental, but it tends to support the validity of the personal views of the Lookouts as summarized above.

4.7 Limitations and Uncertainty Analysis

Limitations and issues that arose during the exercise and how these were dealt with are discussed below.

When ships appear at a simulated distance of approximately 5 miles, the lights often "pop" up and make it easier to see. This was not quite like a light appearing over the horizon and eventually coming into view as it would on a ship. Additionally if the Lookout was lucky with their scanning timing they could sometimes see the hull of the ship appear against the background lights and then the navigation lights appear.

One candidate observed that the task was simplified as they knew when they sighted a ship they could follow it until it disappeared and then another one would appear about a minute later. This allowed times for relaxation (when ship present) and increased vigilance (when ship has been gone for 30 or more seconds). This may explain some of the variabilities observed in the results by Lookout.

The initial simulation plan called for double clicking of the timer: once when the Lookout saw the target, and another time when the Lookout had correctly identified the target as a crossing vessel. During the first day of the exercise (runs 1-10), it quickly became obvious that the double clicking was not important as the Lookouts knew that every vessel they observed was a crossing vessel. This meant that the second click was redundant. The Lookouts were advised beginning at run 11 to only click once.

All targets are moving at speeds of 15 to 20 knots which makes a good relative motion. It was pointed out that picking out against background lights with lower vessels speeds could still be very difficult.

The influence of variability (standard deviations) of the test results was studied by performing simple t-statistics on the overall results and data sets for each of the five conditions. The goal was to determine the confidence levels for which the following hypotheses were valid:

1. Time to detect vessels with green lights is less than without green lights night signal
2. Vessels with three green lights could be correctly detected at greater rate than without three green lights

Table 12 summarizes the results. Overall, there is 98% confidence that the time to detect vessels with the three green lights is less that the time to detect vessels without the three green lights. The confidence levels for the individual simulation conditions, except Condition 2, were lower, and at least 80%. Recall that the sample sizes for the overall data sets were approximately five times larger than those for the individual simulation conditions. This could account for why the confidence levels for the individual simulation conditions were lower than overall. Unfortunately, the hypothesis was violated for Condition 2 (Single Ship / Background Lights – San Francisco). On the question of correct detection (correct lights and correct crossing direction) only the overall case was investigated and the level of confidence for acceptance of the hypothesis was 79%. Overall, the results of the study provide reasonable confidence on the utility of the three green light night signal. Additional support on the utility of the new navigation light was obtained through questionnaires administered by the MPA on vessels operating live within the vicinity of crossing vessels on an on-going basis in the Singapore Strait, as described in Part 1: Main Report.

Table 12: Confidence Levels for Acceptance of Hypotheses

Hypothesis	Condition	Confidence Level for Acceptance of Hypothesis
Time to detect vessels with green lights is less than without green lights night signal	Overall	98%
	Condition 1	80%
	Condition 2	Violated
	Condition 3	95%
	Condition 4	90%
	Condition 5	90%
Vessels with three green lights could be correctly detected at greater rate than without three green lights	Overall	79%

5. Summary and Conclusions

This study was undertaken as part of the formal safety assessment (FSA) for the use of three green lights night signal for vessels crossing the traffic separation scheme (TSS) and precautionary areas in the Singapore Strait. The main objective of the study presented in this report was to evaluate if the three green lights night signal are beneficial to identifying vessels that are intending to cross or are currently crossing the traffic separation scheme. This was achieved by testing the ability of lookouts to identify crossing vessels in a traffic separation scheme (TSS) using the new combination of navigation lights as compared with those using only traditional navigation lights. This report informs FSA Step 3 - Risk control options.

The ship simulations were conducted at the Center for Marine Simulation (CMS) of the Marin Institute of Memorial University in St. John's, Newfoundland. For this study, CMS made available their full mission full motion bridge simulator and a tug visual simulator. The simulation plan was designed to determine, at a basic level, the benefits of the use of three green lights night signal. Simple sets of experiments were carried out to investigate any differences in the correct identification of crossing vessels by a set of Lookouts, for vessels with or without the three green light night signal. No attempt was made to provide complex situations and navigational tasks in order not to confound the results of the study, and to enable a reasonable number of simulations to be carried out within the 3 day simulation window.

Using ship simulators four Lookouts were presented with a number of crossing vessels. The Lookouts were given a timer which they used to indicate the time they first noticed the navigation lights. This was compared to the control time to identify how long after initial presentation of the target the Lookout was able to observe the lights. The Lookouts also orally reported to the Observer what the vessel was doing. The report consisted of three elements:

1. Where they saw the ship (port, starboard, how many points off); and
2. Whether crossing port to starboard or starboard to port
3. If the ship is exhibiting the normal navigation lights or the 3 green lights.

Five physical and environmental conditions were considered in the simulation:

1. Clear Visibility / Multiple Ships / Background Lights – San Francisco
2. Clear Visibility / Single Ship / Background Lights – San Francisco
3. Clear Visibility / Multiple Ships / No Background Lights – English Channel
4. Clear Visibility / Single Ship / No Background Lights – English Channel
5. Degraded Visibility / Multiple Ships / Background Lights - Singapore

Conditions 1 and 2 were located in the San Francisco Bay area and provided scenarios with very bright background lights; Conditions 3 and 4 were located in the English Channel and provided scenarios with no background lights; and finally, Condition 5 was located in the Singapore Strait, and provided scenarios with degraded visibility and background lights.

Sixty simulation runs were carried out during which a total of 600 targets (crossing vessels), including 300 that displayed the three green lights night signal, and 300 that did not, were presented to the Lookouts. Three main measures were used to assess benefit of using the three green lights versus not using them (those with only the normal lights), namely, (a) the percentage of targets that were correctly identified (correct lights and correct direction of the crossing vessel); (b) percentage of vessels with green or normal lights not detected; and (c) time it takes to identify the target.

Based on the results of the simulation exercise, and opinions expressed by the Lookouts that participated in the simulations, the following conclusions can be made:

- The three green lights night signal was effective for identification of a target and provided easier and quicker assessment of a situation
- On the average the 86% of targets displaying the three green lights were correctly identified, compared with 83% for targets not displaying the three green lights night signal.
- In general, the rate of vessels not detected was lower for vessels displaying the three green lights night signal, than that not displaying the signal.

- On the average, there is greater than 20% improvement in the time it took the Lookouts to identify targets displaying the three green lights night signal than those not displaying the lights.
- The three green lights night signal was more effective for cases with background lights.
- There was little difference between the green lights and normal signals for cases with no background lights

There was considerable variability in the detection times recorded, such that the standard deviations of the detection times for targets with and without the three green lights were of the order of the respective mean values. As a result, the differences in the detection times may well be within the margins of error. The mean values were used to establish the trends in the detection times presented in the analysis.

The observed small improvements in the detection times for ships displaying the 3 green lights could be beneficial in real life, especially, in a developing dynamic environment where the bridge personnel are required to perform several tasks simultaneously or in a short time period. Observing a crossing vessel quickly, and knowing the intent of the crossing vessel, can assist the bridge personnel to improve their situational awareness and hence reduce potential collision incidents that could arise from such causes.

6. References

1. Revised Guidelines for the Formal Safety Assessment, MSC-MEPC.2/Circ.12, IMO, 2013

7. Appendix 4A: Brief Resumes of Participants

Name	Organization	Present Position	Brief Resume
Stephen Dubuc	CMS	Instructor	Master Mariner. Over 15 years seagoing experience on vessels such as container ships, Ro-Ro, general cargo, tankers, LNG, DSV, cable, construction, semi-submersibles, drill ship. Over 7 years as Senior Officer.
Capt. Jack Gallagher	Hammurabi Consulting	Owner & Principal	Master Marine Certificate of Competence, over 35 years marine experience. Previously worked for Canadian Coast Guard rising to Director of Operations Maritime Provinces. Current Owner and Principal of Hammurabi Consulting, focusing on navigation and other marine risks.
Tamunoiyala Koko	LRA	Team Leader, Reliability & Risk	PhD structural mechanics. 25 years' engineering experience. Expert in risk assessment methodologies. Technical lead and facilitation of risk assessments for marine vessel designs and operations
Doug Owen	LRA	Principal Consultant, Human Factors	MA in Psychology / Human Factors and Cognitive Ergonomics. Over 15 years' ergonomics and human factors experience across a range of safety critical industries, having worked in New Zealand, Italy and the UK and is a Visiting Fellow of Cranfield University, School of Engineering, UK.
4 Lookouts	CMS	Instructor	Not Identified to preserve anonymity of the results

8. Appendix 4B: Observer Record and End of Simulation Debrief Forms

Observer Record Forms **Run #** _______ Simulator F/M – Tug **Lookout Name:**_______________

Target	Report of Lookout Degrees or Point Port/Starboard	Port to Starboard	Starboard to Port	Special Lights Yes/No

Comments:

____

____

____

End of Simulations Debrief

Lookout Name:_______________

Item #	Issue/ Question	Lookout's Response
1	What is your general impression respecting the use of the three green lights versus the normal navigation lights?	
2	Rating the utility of the lights on a scale of 1 – 100 where 100 is remarkably improves the identification and intent of vessels and 1 remarkably confuses the identification and intention of vessels and 50 is neutral.	
3	Do you feel that the lights had the same utility in each location?	
4	Do you feel that the lights had the same utility in good versus poor visibility?	
5	Did the lights help with identification of vessels alone? Intent of vessels alone? Or both?	
6	Any other Comments?	

9. Appendix 4C: Details of Simulation Runs

	Run 1					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	No	Vessel 1	0200	0300	P to S	20°
2	Yes	Vessel 2	0330	0430	S to P	30°
3	No	Vessel 3	0530	0630	S to P	25°
4	Yes	Vessel 4	0645	0745	S to P	35°
5	Yes	Vessel 5	0830	0930	P to S	15°
6	No	Vessel 6	0945	1045	S to P	20°
7	Yes	Vessel 7	1100	1200	S to P	40°
8	Yes	Vessel 8	1245	1345	P to S	15°
9	No	Vessel 9	1430	1530	P to S	20°
10	No	Vessel 10	1600	1700	P to S	80°
	End		2000			

	Run 2					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	Yes	Vessel 1	0200	0300	P to S	25°
2	No	Vessel 2	0330	0430	P to S	15°
3	Yes	Vessel 3	0515	0615	P to S	15°
4	No	Vessel 4	0630	0730	S to P	20°
5	Yes	Vessel 5	0800	0900	P to S	25°
6	No	Vessel 6	0920	1020	P to S	5°
7	Yes	Vessel 7	1100	1200	S to P	30°
8	No	Vessel 8	1240	1340	P to S	45°
9	No	Vessel 9	1430	1530	S to P	35°
10	Yes	Vessel 10	1730	1830	S to P	40°
	End		1930			

	Run 3					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	No	Vessel 1	0200	0500	P to S	20°
2	No	Vessel 2	0530	0815	P to S	40°
3	No	Vessel 3	0835	0935	S to P	5°
4	Yes	Vessel 4	0955	1055	P to S	35°
5	Yes	Vessel 5	1120	1220	P to S	45°
6	No	Vessel 6	1250	1350	S to P	25°
7	Yes	Vessel 7	1410	1510	P to S	15°
8	Yes	Vessel 8	1550	1650	P to S	70°
9	Yes	Vessel 9	1720	1820	S to P	40°
10	No	Vessel 10	1930	2030	S to P	40°
	End		2110			

	Run 4					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	Yes	Vessel 1	0200	0300	S to P	45°
2	Yes	Vessel 2	0335	0435	S to P	30°
3	No	Vessel 3	0500	0600	S to P	25°
4	Yes	Vessel 4	0650	0750	P to S	35°
5	No	Vessel 5	0900	1000	S to P	25°
6	No	Vessel 6	1020	1120	P to S	65°
7	No	Vessel 7	1200	1300	P to S	75°
8	No	Vessel 8	1400	1500	P to S	45°
9	Yes	Vessel 9	1700	1800	P to S	60°
10	Yes	Vessel 10	1840	1940	S to P	45°
	End		2030			

	Run 5					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0200	0300	S to P	0°
2	Yes	Vessel 2	0340	0440	S to P	20°
3	Yes	Vessel 3	0530	0630	P to S	20°
4	no	Vessel 4	0730	0830	S to P	20°
5	No	Vessel 5	0940	1040	S to P	45°
6	yes	Vessel 6	1140	1240	P to S	25°
7	No	Vessel 7	1420	1520	S to P	20°
8	yes	Vessel 8	1800	1900	P to S	15°
9	no	Vessel 9	1930	2030	P to S	10°
10	Yes	Vessel 10	2150	2250	P to S	15°
	End		2345			

	Run 6					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0200	0400	P to S	20°
2	no	Vessel 2	0500	0600	P to S	40°
3	no	Vessel 3	0630	0730	S to P	15°
4	yes	Vessel 4	0800	0945	P to S	45°
5	yes	Vessel 5	1030	1130	P to S	45°
6	yes	Vessel 6	1230	1330	S to P	15°
7	yes	Vessel 7	1400	1500	P to S	60°
8	no	Vessel 8	1600	1700	P to S	80°
9	no	Vessel 9	1720	1820	S to P	25°
10	no	Vessel 10	1900	2000	S to P	35°
	End		2030			

	Run 7					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0200	0300	P to S	25°
2	yes	Vessel 2	0330	0430	P to S	15°
3	no	Vessel 3	0500	0600	P to S	30°
4	no	Vessel 4	0630	0730	S to P	30°
5	yes	Vessel 5	0830	0930	P to S	45°
6	no	Vessel 6	1030	1130	P to S	45°
7	yes	Vessel 7	1230	1330	S to P	35°
8	no	Vessel 8	1430	1530	P to S	40°
9	yes	Vessel 9	1600	1700	S to P	20°
10	yes	Vessel 10	1800	1900	S to P	25°
	End		1930			

	Run 8					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0200	0300	S to P	20°
2	yes	Vessel 2	0330	0430	S to P	25°
3	no	Vessel 3	0500	0600	P to S	45°
4	yes	Vessel 4	0630	0730	S to P	25°
5	no	Vessel 5	0815	0915	S to P	15°
6	no	Vessel 6	1000	1100	P to S	25°
7	yes	Vessel 7	1130	1230	S to P	15°
8	no	Vessel 8	1400	1500	P to S	15°
9	no	Vessel 9	1620	1720	P to S	10°
10	yes	Vessel 10	1800	1900	P to S	10°
	End		1945			

	Run 9					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0140	0240	S to P	30°
2	no	Vessel 2	0330	0430	S to P	30°
3	yes	Vessel 3	0500	0600	S to P	35°
4	no	Vessel 4	0630	0730	P to S	65°
5	no	Vessel 5	0850	0950	S to P	35°
6	yes	Vessel 6	1200	1300	P to S	80°
7	yes	Vessel 7	1330	1430	P to S	40°
8	yes	Vessel 8	1520	1620	P to S	35°
9	no	Vessel 9	1700	1800	P to S	40°
10	no	Vessel 10	1830	1930	S to P	30°
	End		2000			

	Run 10					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0130	0230	P to S	20°
2	yes	Vessel 2	0300	0430	S to P	20°
3	no	Vessel 3	0500	0600	S to P	5°
4	no	Vessel 4	0635	0735	S to P	35°
5	yes	Vessel 5	0800	0900	P to S	15°
6	no	Vessel 6	0930	1030	S to P	15°
7	yes	Vessel 7	1200	1300	S to P	20°
8	yes	Vessel 8	1400	1500	P to S	45°
9	no	Vessel 9	1600	1700	P to S	50°
10	no	Vessel 10	1730	2000	P to S	80°
	End		2025			

	Run 11					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0145	0245	S to P	30°
2	no	Vessel 2	0315	0415	P to S	65°
3	yes	Vessel 3	0445	0545	P to S	35°
4	no	Vessel 4	0615	0715	S to P	30°
5	yes	Vessel 5	0800	0900	S to P	30°
6	no	Vessel 6	0930	1030	P to S	65°
7	yes	Vessel 7	1150	1250	P to S	80°
8	no	Vessel 8	1400	1500	S to P	35°
9	yes	Vessel 9	1530	1630	P to S	55°
10	no	Vessel 10	1700	1800	S to P	35°
	End	1830				

	Run 12					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0200	0300	P to S	20°
2	yes	Vessel 2	0400	0500	P to S	20°
3	no	Vessel 3	0545	0645	S to P	10°
4	yes	Vessel 4	0730	0900	S to P	20°
5	no	Vessel 5	0930	1030	P to S	5°
6	yes	Vessel 6	1130	1230	S to P	15°
7	no	Vessel 7	1330	1430	S to P	25°
8	yes	Vessel 8	1520	1620	P to S	50°
9	no	Vessel 9	1700	1800	P to S	60°
10	yes	Vessel 10	1830	1930	P to S	50°
	End		2000			

	Run 13					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0100	0200	P to S	30°
2	no	Vessel 2	0315	0415	S to P	20°
3	yes	Vessel 3	0445	0545	P to S	15°
4	no	Vessel 4	0615	0715	S to P	10°
5	no	Vessel 5	0800	0900	S to P	10°
6	yes	Vessel 6	1000	1100	P to S	10°
7	yes	Vessel 7	1130	1230	S to P	15°
8	no	Vessel 8	1400	1500	P to S	10°
9	yes	Vessel 9	1600	1700	S to P	10°
10	yes	Vessel 10	1730	1830	S to P	15°
	End		1900			

	Run 14					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0100	0200	P to S	30°
2	no	Vessel 2	0240	0340	S to P	20°
3	no	Vessel 3	0420	0605	P to S	15°
4	yes	Vessel 4	0700	0800	S to P	10°
5	yes	Vessel 5	0840	0940	S to P	15°
6	yes	Vessel 6	1030	1130	P to S	15°
7	yes	Vessel 7	1230	1330	S to P	20°
8	no	Vessel 8	1440	1540	P to S	10°
9	no	Vessel 9	1630	1730	S to P	20°
10	yes	Vessel 10	1810	1910	S to P	15°
	End		1930			

	Run 15					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0115	0215	S to P	30°
2	yes	Vessel 2	0300	0400	S to P	25°
3	no	Vessel 3	0430	0530	P to S	35°
4	yes	Vessel 4	0610	0710	S to P	30°
5	yes	Vessel 5	0800	0900	S to P	35°
6	no	Vessel 6	1000	1100	P to S	35°
7	yes	Vessel 7	1200	1300	S to P	30°
8	no	Vessel 8	1445	1545	P to S	35°
9	yes	Vessel 9	1700	1800	S to P	25°
10	no	Vessel 10	1830	1930	P to S	40°
	End		1945			

	Run 16					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0050	0150	S to P	5°
2	no	Vessel 2	0230	0330	S to P	0°
3	no	Vessel 3	0420	0520	S to P	15°
4	yes	Vessel 4	0600	0700	P to S	45°
5	no	Vessel 5	0750	0850	P to S	50°
6	yes	Vessel 6	0930	1030	P to S	25°
7	no	Vessel 7	1130	1230	P to S	40°
8	yes	Vessel 8	1345	1445	P to S	45°
9	yes	Vessel 9	1530	1630	S to P	10°
10	yes	Vessel 10	1715	1815	S to P	20°
	End		1845			

	Run 17					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0115	0215	P to S	20°
2	yes	Vessel 2	0315	0415	P to S	25°
3	yes	Vessel 3	0500	0600	S to P	15°
4	no	Vessel 4	0700	0900	S to P	20°
5	no	Vessel 5	0920	1020	P to S	5°
6	yes	Vessel 6	1100	1200	S to P	5°
7	no	Vessel 7	1240	1340	S to P	30°
8	yes	Vessel 8	1430	1530	P to S	25°
9	yes	Vessel 9	1610	1710	P to S	20°
10	yes	Vessel 10	1750	1850	P to S	30°
	End		1910			

	Run 18					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0145	0245	S to P	30°
2	no	Vessel 2	0320	0420	P to S	65°
3	no	Vessel 3	0500	0600	P to S	35°
4	yes	Vessel 4	0700	0800	S to P	35°
5	yes	Vessel 5	0830	0930	S to P	30°
6	no	Vessel 6	1030	1130	P to S	40°
7	yes	Vessel 7	1200	1300	P to S	35°
8	no	Vessel 8	1345	1445	S to P	25°
9	yes	Vessel 9	1600	1700	P to S	35°
10	no	Vessel 10	1730	1830	S to P	25°
	End		1900			

	Run 19					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0115	0215	S to P	5°
2	no	Vessel 2	0300	0400	S to P	0°
3	yes	Vessel 3	0440	0615	S to P	15°
4	no	Vessel 4	0700	0800	P to S	45°
5	yes	Vessel 5	0840	0940	P to S	45°
6	yes	Vessel 6	1020	1120	P to S	30°
7	no	Vessel 7	1220	1320	P to S	40°
8	yes	Vessel 8	1410	1510	P to S	40°
9	yes	Vessel 9	1600	1700	S to P	20°
10	no	Vessel 10	1730	1830	S to P	25°
	End		1900			

	Run 20					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0110	0210	S to P	30°
2	yes	Vessel 2	0300	0400	S to P	35°
3	no	Vessel 3	0430	0530	P to S	40°
4	yes	Vessel 4	0615	0715	S to P	25°
5	yes	Vessel 5	0820	0920	S to P	25°
6	no	Vessel 6	1000	1100	P to S	35°
7	no	Vessel 7	1130	1230	S to P	30°
8	no	Vessel 8	1315	1415	P to S	30°
9	yes	Vessel 9	1520	1620	S to P	35°
10	no	Vessel 10	1700	1800	P to S	35°
	End			1830		

	Run 21					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0100	0200	S to P	25°
2	yes	Vessel 2	0300	0400	S to P	35°
3	yes	Vessel 3	0430	0530	P to S	45°
4	no	Vessel 4	0625	0725	S to P	20°
5	no	Vessel 5	0800	0900	S to P	25°
6	yes	Vessel 6	0930	1030	P to S	35°
7	no	Vessel 7	1130	1230	S to P	25°
8	no	Vessel 8	1330	1430	P to S	30°
9	yes	Vessel 9	1545	1645	S to P	15°
10	yes	Vessel 10	1710	1810	P to S	30°
	End		1840			

	Run 22					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0100	0200	S to P	25°
2	no	Vessel 2	0230	0330	P to S	35°
3	yes	Vessel 3	0420	0520	P to S	35°
4	no	Vessel 4	0600	0700	S to P	25°
5	no	Vessel 5	0750	0850	S to P	30°
6	yes	Vessel 6	0930	1030	P to S	45°
7	no	Vessel 7	1110	1210	P to S	35°
8	yes	Vessel 8	1300	1400	S to P	20°
9	yes	Vessel 9	1500	1600	S to P	20°
10	no	Vessel 10	1640	1740	S to P	45°
	End		1800			

	Run 23					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0110	0210	P to S	75°
2	no	Vessel 2	0250	0350	P to S	60°
3	yes	Vessel 3	0440	0540	S to P	25°
4	no	Vessel 4	0620	0720	P to S	35°
5	no	Vessel 5	0810	0910	P to S	40°
6	yes	Vessel 6	0950	1050	P to S	40°
7	yes	Vessel 7	1130	1230	S to P	25°
8	no	Vessel 8	1330	1430	S to P	25°
9	yes	Vessel 9	1500	1600	P to S	45°
10	yes	Vessel 10	1640	1740	S to P	20°
	End		1810			

	Run 24					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0140	0240	P to S	30°
2	no	Vessel 2	0320	0420	S to P	15°
3	no	Vessel 3	0510	0610	S to P	25°
4	yes	Vessel 4	0650	0750	S to P	35°
5	yes	Vessel 5	0850	0950	P to S	35°
6	no	Vessel 6	1030	1130	P to S	30°
7	yes	Vessel 7	1250	1350	S to P	30°
8	no	Vessel 8	1430	1530	S to P	25°
9	yes	Vessel 9	1610	1710	S to P	35°
10	no	Vessel 10	1750	1850	P to S	35°
	End		1915			

	Run 25					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0115	0215	P to S	35°
2	yes	Vessel 2	0300	0400	S to P	0°
3	yes	Vessel 3	0420	0520	P to S	35°
4	no	Vessel 4	0530	0630	P to S	5°
5	no	Vessel 5	0710	0810	S to P	10°
6	yes	Vessel 6	0830	0930	P to S	35°
7	no	Vessel 7	1100	1200	P to S	55°
8	yes	Vessel 8	1230	1330	P to S	55°
9	yes	Vessel 9	1430	1530	S to P	30°
10	no	Vessel 10	1620	1720	S to P	40°
	End		1830			

	Run 26					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0130	0230	S to P	15°
2	yes	Vessel 2	0310	0410	S to P	10°
3	yes	Vessel 3	0440	0540	S to P	10°
4	yes	Vessel 4	0620	0720	P to S	10°
5	no	Vessel 5	0800	0900	S to P	10°
6	no	Vessel 6	1000	1100	P to S	20°
7	yes	Vessel 7	1140	1240	S to P	10°
8	no	Vessel 8	1400	1500	S to P	10°
9	yes	Vessel 9	1530	1630	P to S	20°
10	no	Vessel 10	1710	1810	P to S	15°
	End		1845			

	Run 27					
	Green Light Visible (Yes/No)	Action	Start	End	Direction (Starboard/Port)	Angle
	Start		0000			
1	yes	Vessel 1	0110	0210	S to P	15°
2	no	Vessel 2	0250	0350	S to P	10°
3	yes	Vessel 3	0500	0600	S to P	15°
4	no	Vessel 4	0630	0730	P to S	10°
5	no	Vessel 5	0830	0930	S to P	10°
6	yes	Vessel 6	1050	1150	P to S	10°
7	no	Vessel 7	1240	1340	S to P	15°
8	yes	Vessel 8	1500	1600	S to P	20°
9	yes	Vessel 9	1640	1740	P to S	10°
10	no	Vessel 10	1800	1900	P to S	15°
	End		1930			

	Run 28					
	Green Light Visible (Yes/No)	Action	Start	End	Direction (Starboard/Port)	Angle
	Start		0000			
1	no	Vessel 1	0045	0145	P to S	40°
2	yes	Vessel 2	0230	0330	S to P	10°
3	yes	Vessel 3	0420	0520	S to P	15°
4	no	Vessel 4	0600	0700	P to S	45°
5	no	Vessel 5	0800	0900	P to S	20°
6	yes	Vessel 6	1000	1100	S to P	10°
7	no	Vessel 7	1210	1310	S to P	20°
8	yes	Vessel 8	1410	1510	P to S	65°
9	no	Vessel 9	1600	1700	P to S	60°
10	yes	Vessel 10	1730	1830	P to S	70°
	End		1900			

	Run 29					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	no	Vessel 1	0115	0215	P to S	30°
2	no	Vessel 2	0300	0400	S to P	10°
3	yes	Vessel 3	0500	0600	S to P	15°
4	yes	Vessel 4	0630	0730	P to S	45°
5	no	Vessel 5	0830	0930	P to S	20°
6	no	Vessel 6	1010	1110	S to P	15°
7	yes	Vessel 7	1200	1300	S to P	25°
8	yes	Vessel 8	1430	1530	P to S	60°
9	no	Vessel 9	1620	1720	P to S	60°
10	yes	Vessel 10	1750	1850	P to S	70°
	End		1910			

	Run 30					
	Green Light Visible (Yes/No)	**Action**	**Start**	**End**	**Direction (Starboard/Port)**	**Angle**
	Start		0000			
1	yes	Vessel 1	0130	0230	S to P	10°
2	yes	Vessel 2	0310	0410	S to P	5°
3	no	Vessel 3	0500	0700	S to P	15°
4	yes	Vessel 4	0720	0820	P to S	50°
5	no	Vessel 5	0900	1000	P to S	30°
6	yes	Vessel 6	1050	1150	P to S	30°
7	no	Vessel 7	1300	1400	P to S	55°
8	no	Vessel 8	1430	1530	P to S	70°
9	yes	Vessel 9	1610	1710	S to P	30°
10	no	Vessel 10	1730	1830	S to P	30°
	End		1850			

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