TP13042E

Risk Assessment:
Navigation Aids for Shipping in Canso Strait

Prepared for

Transportation Development Centre
Safety and Security
Transport Canada

prepared by

GeoInfo Solutions Ltd.
10352 Arbay Close
Sidney, British Columbia
V8L 4S2

with

Institute for Risk Research
AXYS Environmental Consulting Ltd.
Enfotec Technical Services Inc.

June 1997

GeoInfo Solutions Ltd.

TP13042E

Risk Assessment:
Navigation Aids for Shipping in Canso Strait

by

Brad Judson
GeoInfo Solutions Ltd.

June 1997

This report reflects the views of the authors and not necessarily those of the Transportation Development Centre.

The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

Since the accepted measures in the marine navigation industry are imperial, nautical and metric, metric measures are shown alongside imperial measures.

Project Team

B. Judson, Project Manager
J. Shortreed, Risk Consultant
D. Del Bel Belluz, Risk Consultant
S. Aleksa, Programmer
A. Blyth, Geography Consultant
D. Cake, Programmer
L. Giles, Programmer
J. Wessels, Quality Control
Z. Eshete, Testing
R. Wood, User Guide

Un sommaire français se trouve avant la table des matières.

Transport Canada | Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 13042E	2. Project No. 9077	3. Recipient's Catalogue No.
4. Title and Subtitle Risk Assessment: Navigation Aids for Shipping in Canso Strait		5. Publication Date June 1997
		6. Performing Organization Document No.
7. Author(s) B. Judson		8. Transport Canada File No. ZCD1460-369
9. Performing Organization Name and Address GeoInfo Solutions Ltd. 10352 Arbay Close Sidney, British Columbia V8L 4S2		10. PWGSC File No. HAL-6-40581
		11. PWGSC or Transport Canada Contract No. T8200-6-6531
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West 6th Floor Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final
		14. Project Officer J. Reid

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract

The overall goal of the Marine Navigation Safety System (MNSS) project was to develop the Tanker Navigation Safety System (TNSS) into a more generalized marine casualty risk analysis application capable of measuring the effectiveness of different combinations of fixed and floating aids to navigation, Electronic Chart Display and Information System (ECDIS), and other shipboard navigation aids in improving the safety of transport of dangerous liquids in bulk. The development and analysis focussed on Canso Strait, Nova Scotia, where the combination of shipment of oil by tankers and the navigation environment provided a highly-marked waterway to consider in the development of the risk model and a test bed for the application of the MNSS.

The system includes 32-bit MapInfo application and system files, an Excel application to assist with a Level of Service analysis, the data base files from the TNSS prototype, Canada-wide traffic, casualty and low resolution map data, as well as detailed files specific to Canso Strait. All software and data were transferred to the Transportation Development Centre and the Canadian Coast Guard, Marine Navigation Services.

17. Key Words Risk analysis, aids to navigation, Electronic Chart Display and Information System (ECDIS), Differential Global Positioning System (DGPS), Marine Navigation Safety System (MNSS), Canso Strait	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) —	22. No. of Pages x, 20, apps	23. Price —

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 13042E	2. N° de l'étude 9077	3. N° de catalogue du destinataire
4. Titre et sous-titre Risk Assessment: Navigation Aids for Shipping in Canso Strait		5. Date de la publication Juin 1997
		6. N° de document de l'organisme exécutant
7. Auteur(s) B. Judson		8. N° de dossier - Transports Canada ZCD1460-369
9. Nom et adresse de l'organisme exécutant GeoInfo Solutions Ltd. 10352 Arbay Close Sidney, British Columbia V8L 4S2		10. N° de dossier - TPSGC HAL-6-40581
		11. N° de contrat - TPSGC ou Transports Canada T8200-6-6531
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest 6e étage Montréal (Québec) H3B 1X9		13. Genre de publication et période visée Final
		14. Agent de projet J. Reid

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

16. Résumé

Le projet de système d'aide à la navigation maritime (MNSS) avait pour objet de développer le logiciel d'aide à la navigation des pétroliers (TNSS) afin d'étendre son application à l'analyse des risques maritimes et de mesurer ainsi l'efficacité de différentes combinaisons d'aides fixes et flottantes, du système électronique de visualisation des cartes marines (SEVCM) et d'autres systèmes à bord pour réduire les risques du transport de liquides dangereux en vrac par navire citerne. Les travaux de développement et d'analyse étaient focalisés sur le détroit de Canso, en Nouvelle-Écosse, car le trafic maritime de pétroliers et les caractéristiques géographiques de la région en faisaient un cadre idéal pour le développement du modèle d'analyse de risques et pour servir de banc d'essai du MNSS.

Le système comprend une application MapInfo 32 bits avec fichiers système, une application Excel pour l'analyse de niveau de service, les fichiers de la base de données du prototype de TNSS, les données concernant les accidents, le trafic et les cartes marines pour le Canada ainsi que des fichiers détaillés particuliers au détroit de Canso. L'ensemble des données et des logiciels ont été transférés au Centre de développement des transports et aux Services à la navigation maritime de la Garde côtière canadienne.

17. Mots clés Analyse des risques, aides à la navigation, Système électronique de visualisation des cartes marines (SEVCM), Système de positionnement global différentiel (DGPS), Système d'aide à la navigation maritime (MNSS), détroit de Canso	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	x, 20, ann.	—

Executive Summary

This report summarizes the methodology and findings related to the development and testing of the prototype Marine Navigation Safety System (MNSS) through the modification of the Tanker Navigation Safety System (TNSS). A case risk analysis study of tanker transport in the Strait of Canso, Nova Scotia, was conducted by using the MNSS prototype and its companion navigation safety estimation tool, the 99.9% pre-processor. This risk analysis compared the status quo risk in Canso Strait to several other mitigation measure combinations including the use of Differential Global Positioning System (DGPS) and Electronic Chart Display and Information System (ECDIS) and the phasing out of redundant fixed and floating aids to navigation. The MNSS is a 32-bit PC-based software application that utilizes the Commercial-Off-the-Shelf (COTS), GIS-based Windows software development platforms, MapInfo and Excel. The risk model in TNSS was modified, improved, and ported to an Excel spreadsheet application which uses Crystal Ball for Monte Carlo simulation and sensitivity analysis. The project consisted of the redevelopment and delivery of a working prototype, including source code, the configuration of environmental and navigation chart data files for Canso, and the provision of traffic and accident data in MapInfo GIS format.

The development of MNSS into a tool that can be used to assess most marine risks in many Canadian waterways expands the functionality of TNSS in terms of its geographic extent, resolution and casualty types. The risk assessment of tanker traffic in Canso Strait demonstrated the ability of the navigation safety 99.9% pre-processor to estimate the manoeuvring room required by a vessel of a specific beam and length given various combinations of external aids to navigation, weather and topography, and on-board navigation aids. By applying the grounding and collision rates for the Quebec VTS zone to the traffic, navigation and environmental conditions characterizing Canso Strait, an estimate of these annual casualty rates as well as costs was provided.

One recommendation for its parent TNSS was to develop the application into a fully robust system that is generalized to work with any ship type along with a complete environmental data base. MNSS has been generalized to work with any ship type and has been redeveloped with an open architecture for the use of external models to analyse input parameters such as measures of safety, consequence magnitude, or cost. The MNSS prototype can now be calibrated with input from the Canadian Coast Guard and developed into robust problem-specific applications such as a tool to assist with Level of Service analysis of aids to navigation, and can also be maintained as a more generic open system which can be used to manage a greater diversity of marine risk analyses. MNSS use of the most detailed environmental, navigation chart, traffic and accident data available enhances risk communication by providing both decision makers and stakeholders with organized and relevant information. This risk information data base is designed to grow as other marine risk issues are examined.

Sommaire

Le présent rapport donne un aperçu de la méthodologie appliquée au développement et aux essais d'un système prototype d'aide à la navigation maritime (MNSS), version évoluée du système d'aide à la navigation des pétroliers (TNSS), ainsi que des résultats de ces travaux. Une analyse des risques inhérents à la circulation des pétroliers dans le détroit de Canso, en Nouvelle-Écosse, a été effectuée au moyen d'un prototype du MNSS et de son outil d'évaluation de la sécurité, le programme de prétraitement à 99,9 %. Pour cette analyse, on a comparé les risques associés à l'état actuel dans le détroit de Canso à ceux associés à la combinaison de plusieurs autres mesures de prévention dont l'utilisation du système de positionnement global différentiel (DGPS) et du système électronique de visualisation des cartes marines (SEVCM) et la mise hors service progressive des aides fixes et flottantes à la navigation, éventuellement redondantes. Le système MNSS est une application logicielle 32 bits tournant sur ordinateur personnel de type PC et qui fait appel à MapInfo et Excel, des systèmes du commerce voués au développement de logiciels à base d'information SIG et qui fonctionne en environnement Windows. Le modèle TNSS d'analyse des risques a été modifié, amélioré puis connecté à un tableur Excel utilisant le logiciel Crystal Ball pour la simulation et l'analyse de sensibilité selon la méthode de Monte-Carlo. Le projet visait la mise au point et la réalisation d'un prototype opérationnel et de son code source, la configuration de fichiers de données environnementales et de cartes de navigation concernant la détroit de Canso et la fourniture de données de trafic et d'accidents en format MapInfo SIG.

Le développement du MNSS en outil d'évaluation de la plupart des risques maritimes dans un bon nombre de voies navigables au Canada étend la fonctionnalité du TNSS pour ce qui est de la couverture géographique, de la résolution et des types d'accidents maritimes. L'évaluation des risques associés au trafic de navires citernes dans le détroit de Canso a démontré la capacité du prétraitement à 99,9 % de la sécurité maritime d'estimer l'espace de manoeuvre requis pour un navire affichant des caractéristiques données de largeur et de longueur, et pour des combinaisons diverses d'aides à la navigation, de conditions météorologiques, de topographie et d'aides à la navigation embarquées. En appliquant les taux d'échouement et d'accident enregistrés par le STM-Québec aux conditions environnementales et aux conditions de trafic et de navigation qui caractérisent le détroit de Canso, on a pu obtenir, pour cette zone, une estimation des taux annuels d'accidents et des coûts associés.

Une des conclusions de ces travaux consistait à recommander le développement, à partir du système principal TNSS, d'un système entièrement fonctionnel assorti d'une base complète de données environnementales et s'appliquant à tous les types de navires. L'application du MNSS a été étendue à tous les types de navires; sa mise au point lui a donné une architecture ouverte autorisant l'emploi de modèles externes pour analyser des paramètres d'entrée comme les indices de sécurité, la gravité des conséquences ou les coûts. Le prototype de MNSS est maintenant prêt à être adapté par la Garde côtière canadienne à une application spécifique fonctionnelle, soit un outil d'assistance à l'analyse du niveau de service des aides à la navigation; on peut également en faire un système général ouvert utile pour la gestion d'une plus grande diversité de risques maritimes. Enfin, grâce aux données les plus détaillées disponibles sur l'environnement, sur les cartes de navigation, sur le trafic et sur les accidents, le MNSS permet de mieux appréhender les risques, l'information fournie aux décideurs et aux acteurs du milieu étant à la fois pertinente et bien structurée. Cette base de données prendra de l'expansion avec l'élargissement de l'analyse à d'autres risques maritimes.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ATRA	Arctic Tanker Risk Analysis
CCG	Canadian Coast Guard
DGPS	Differential Global Positioning System
DWT	Deadweight Tonnage
ECDIS	Electronic Chart Display and Information System
IRR	Institute for Risk Research
LOS	Level of Service
MARSIS	Marine Casualty Information System
MNSS	Marine Navigation Safety System
NM	Nautical mile
TDC	Transportation Development Centre
TNSS	Tanker Navigation Safety System
TSB	Transportation Safety Board
USCG	United States Coast Guard
VTS	Vessel Traffic Services
WAMS	Waterways Analysis Management System

1. INTRODUCTION

1.1 Scope

1.1.1 Objective

The overall goal of the Marine Navigation Safety System (MNSS) project is to support the design of the aids system of tomorrow and help communicate that a mix of conventional aids to navigation with Electronic Chart Display and Information System (ECDIS) is as good as the present service by modifying the Tanker Navigation Safety System risk analysis software and conducting a risk analysis for Canso Strait.

The objective of the Marine Navigation Safety System will be to assist with a quantitative analysis of the effectiveness of a mix of conventional aids to navigation and ECDIS (or other electronic navigation aids as they are introduced in the future) and to output its measure of risk in various tabular, graphical and map formats. The analysis of risk scenarios will aid in the validation of the software tool by both the developers and users.

1.1.2 Scenario Analysis

This analysis was confined to the study of Canadian Coast Guard Marine Navigation Services Category I Level of Service: Commercial vessels—more specifically, tankers. Marine Casualty Information System (MARSIS) and Vessel Traffic Services (VTS) data supported the calculation of casualty frequency for tankers less than 50 000 DWT. The MNSS software will enable the calculation of common Transportation Safety Board of Canada (TSB) casualty types.

Table 1 outlines the various combinations where comparative estimates are required. In addition to casualty probability, oil spill probability and total costs will be provided. Total costs provide a comparative measure of risk between scenarios.

1.1.3 Software Flexibility

The MNSS software tool will enable users to apply unique pre- and post-processors as future requirements are conceived. One such post-processor might include a consequence analysis tool to measure the magnitude and affected area arising from an Liquid Natural Gas (LNG) explosion or chemical spill event. The delivered system includes a pre-processor designed to measure the change in safety afforded by differing waterways, aids to navigation, ship sizes and on-board navigation aids.

Table 1 Canso risk analysis scope

Casualty Type and Track Segment	Status Quo Conventional Aids	ECDIS and Reduced Buoyage	ECDIS and Reduced Range Lights/marks	Conventional Aids & ECDIS
p(Grounding) Tanker < 50,000 DWT in S Curve				
p(Collision) Tanker < 50,000 DWT in S Curve				
p(Grounding) Tanker < 50,000 DWT on course 320°				
p(Collision) Tanker < 50,000 DWT on course 320°				

1.2 Study Area

The study area includes the inner approaches (confined waters) to Canso Strait, Nova Scotia from the Pilot station in the northern approaches to the southern entrance, Figure 1. This includes the critical manoeuvring leg in the southern approaches described as an ‘s curve’ and several miles leading up to this turn.

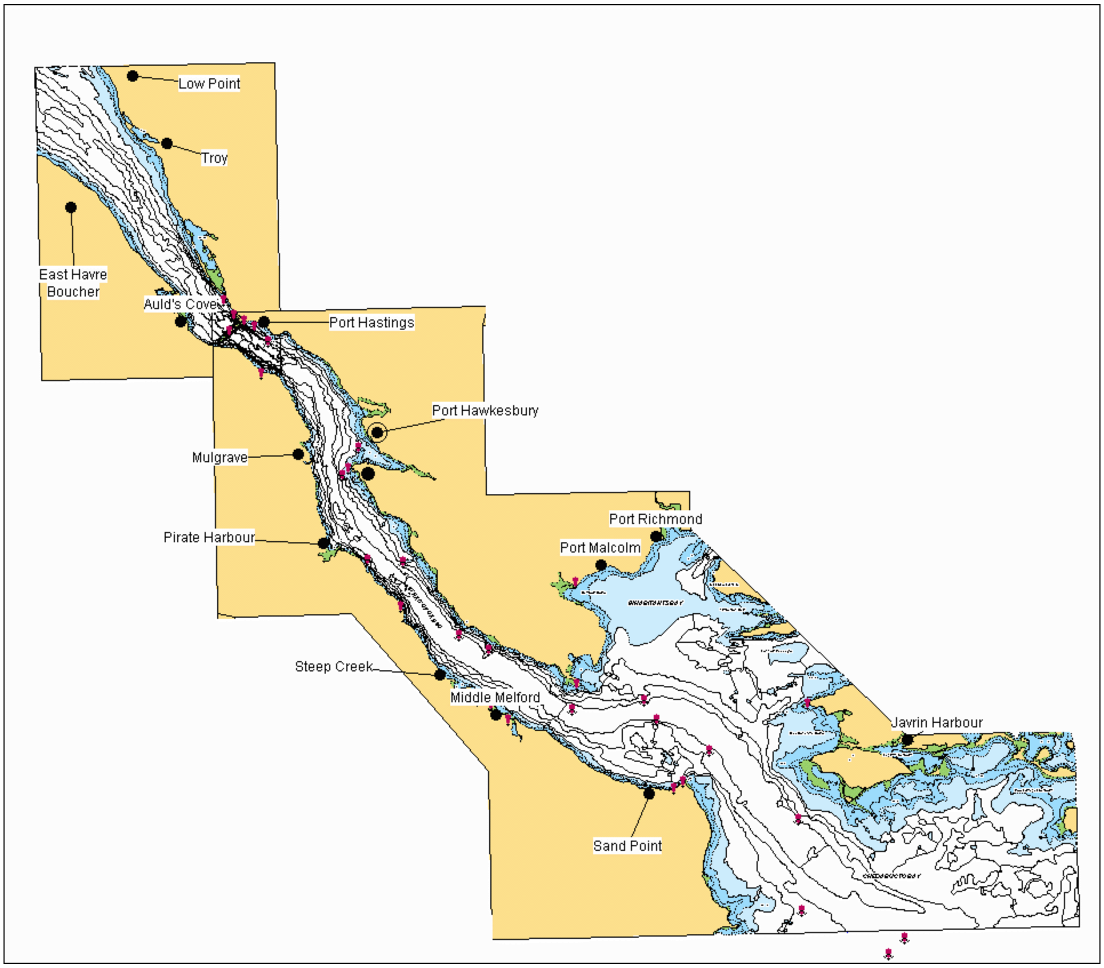


Figure 1 Strait of Canso Study Area

2. METHODOLOGY

2.1 Overview

Two tracks were identified within the Canso Strait study area as having a tight manoeuvring and fixing room for a 760-ft (232-m) tanker: The ‘s’ turn and its approach track at the southern entrance to the strait, are depicted in Figure 2. Shown are the entire ‘s’ turn and the northernmost section of course 320°. The light blue shaded water is water of less than 20 fathoms—a hazard to tankers. The white area is the water available for safe manoeuvres. Within the safe water area are the tracks, blue buffers and red buffers. These buffers represent the extremes of the required safe widths for the various options identified in the scope. These and other options and the risk analysis outputs are discussed below.

2.2 Risk analysis process

The process to estimate the change in risk (measured in dollars) between various options was as follows:

- The buffer widths were estimated using the 99.9% pre-processor, plotted in MNSS and examined to be within safe water.
- The ratio between water required and water available was used as a measure of Level of Service (LOS).
- It was assumed that a relationship exists between collision or grounding rates and the LOS or navigation safety within a waterway[1], therefore, a change in the accident rates can be estimated.
- The change in the accident rates was an input parameter into MNSS where accident rates were calculated for the status quo and various options.
- The result was tabular reports of grounding and collision rates and total costs.

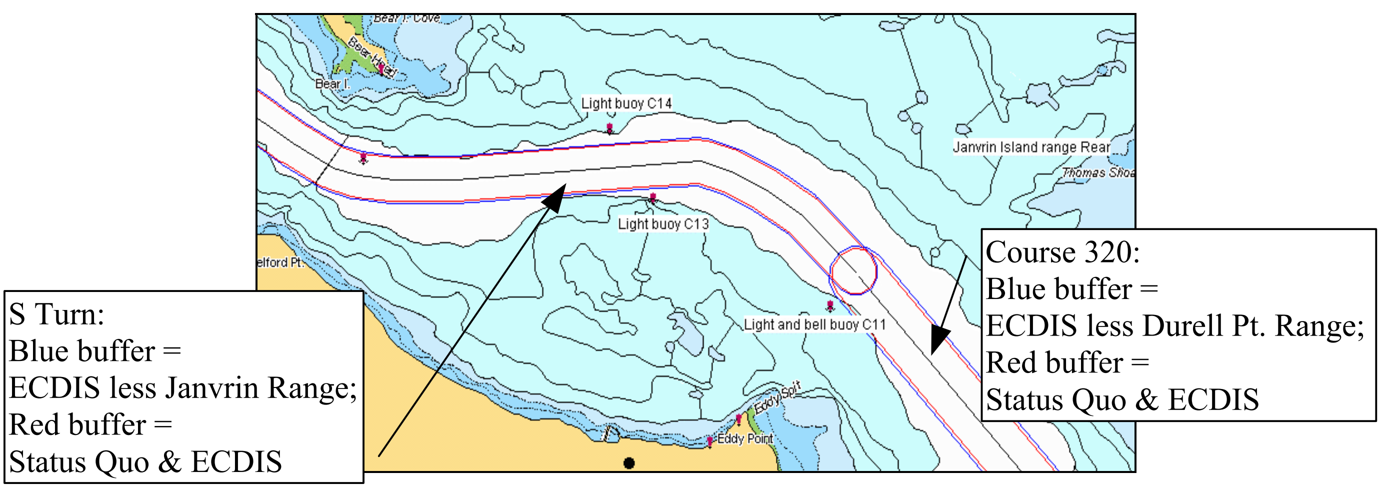


Figure 2 Canso Strait approaches 'S' turn and course 320°

[1] See Appendix E

2.3 99.9% LOS pre-processor

2.3.1 Overview

The 99.9% pre-processor replaces the configuration dialog of the Tanker Navigation Safety System (TNSS) where factors such as ship size and navigation aids were selected. It expands the positioning aspect of the input choices of TNSS, but removes some factors related to ice and escort. These could be considered with further development of the existing or other pre-processors.

The 99.9% pre-processor is a custom Excel spreadsheet model which uses a Crystal Ball Monte Carlo analysis simulator, waterway specific data and expert judgment to estimate the manoeuvring room or '99.9% track width' used by 99.9% of vessels for a given category, length and beam (see Figure 3). Working with the pre-processor spreadsheet is the best way to examine its functionality however, details of the workings of the 99.9% pre-processor are documented in Appendix A.

The model implemented in the spreadsheet recognizes that ECDIS, aids to navigation, radar, good landmarks, relief, and other factors all combine to improve the positioning capability of the bridge. As one's ability to position the ship improves, less margin of safety will be required. Similarly, other factors which affect manoeuvring room include beam, crab, shiphandling ability, turn path, weather and sea state, passing distance, tug escort, pilots, VTS, set or drift, etc. Not all these factors were implemented, but sufficient factors were considered to provide a working model and tool which can be tested and improved. These ideas are not new. With the exception of the impact of navigation aids on the bridge, and the ability to adjust the safe width by the frequency of low visibility or night, most of the functions are present in the current LOS analysis used by the CCG.

Masters/pilots/navigation officers acting as subject matter experts with local knowledge and ECDIS experience (Smith, Judson, Dubé, and Dory)[2] collaborated with Shortreed of IRR at the early stages of the pre-processor development to provide a structure to the model and estimates of input parameters including: position quality, crab, shiphandling, turn path, passing distance and the effect of weather and sea state.

[2] Val Smith, Navigation Specialist, Canadian Coast Guard; Brad Judson, MA,MM, President, GeoInfo Solutions Ltd., Jean Pierre Dubé, Commanding Officer, CCGS Mary Hitchens; Captain Elias Dory, Canso VLCC Pilot, Canso Pilots Association; John Shortreed, PhD, Director, Institute for Risk Research

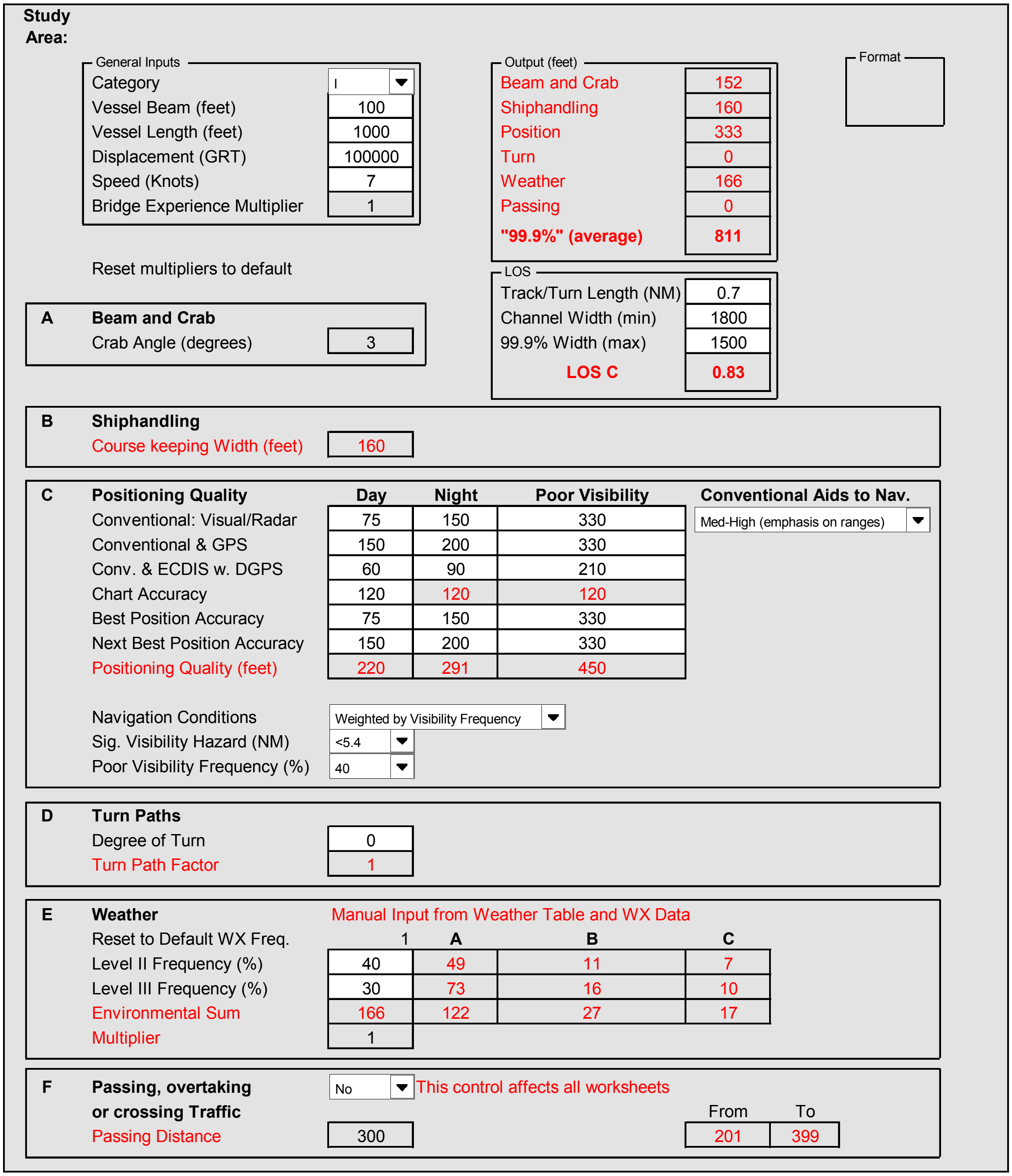


Figure 3 99.9% pre-processor

2.3.2 Use of the pre-processor in the analysis

The process to obtain an answer from the pre-processor was as follows:

1. Copy the workbook to an appropriate name.
2. Input the track name at the top of the spreadsheet, rename the spreadsheet and rename the 'Forecast' cell property of the Crystal Ball 'define forecast'.
3. Input the vessel beam and length. Input the available track width. Select conventional aids-to-navigation quality.
4. Examine and input the best and next best position quality for day, night and low visibility. Choose to have the output use the positioning quality for day, night, low visibility or weighted by the visibility frequency. Input the visibility frequency. Input the significant visibility hazard distance in nautical miles (NM).
5. Input the degree of turn, if any, for the track being examined.
6. Input the Level II and III weather frequency.
7. Input the passing distance for a significant hazard and choose passing or not.
8. Run the Monte Carlo simulation and choose the maximum width for the forecast.
9. Select the LOS spreadsheet and transfer the channel, track and 99.9% values.
10. Conduct the above steps for both the status quo and an aids-to-navigation option and the LOS spreadsheet will enable the calculation of a Muliplier representing the change in collision or grounding frequency.
11. Apply this multiplier to appropriate casualty cause factors in MNSS that would be affected by the change in the LOS using the Modify Rates option in the Scope Definition window of MNSS.

2.4 MNSS

MNSS was used to plot tracks within the study area, buffer these tracks with safe widths estimated from the 99.9% pre-processor, estimate historical casualty rates and calculate costs associated with a tanker grounding or collision. Data input tables are described below.

Although MNSS can be operated in a 'screening mode' (Figure 4) where the only modification to casualty rates and consequence magnitudes is via choices made on the scope definition dialog such as: Aids to navigation 'above average', MNSS was used in a detailed mode which enabled the input of multipliers which, in this case, were estimated as an output of the 99.9% pre-processor.

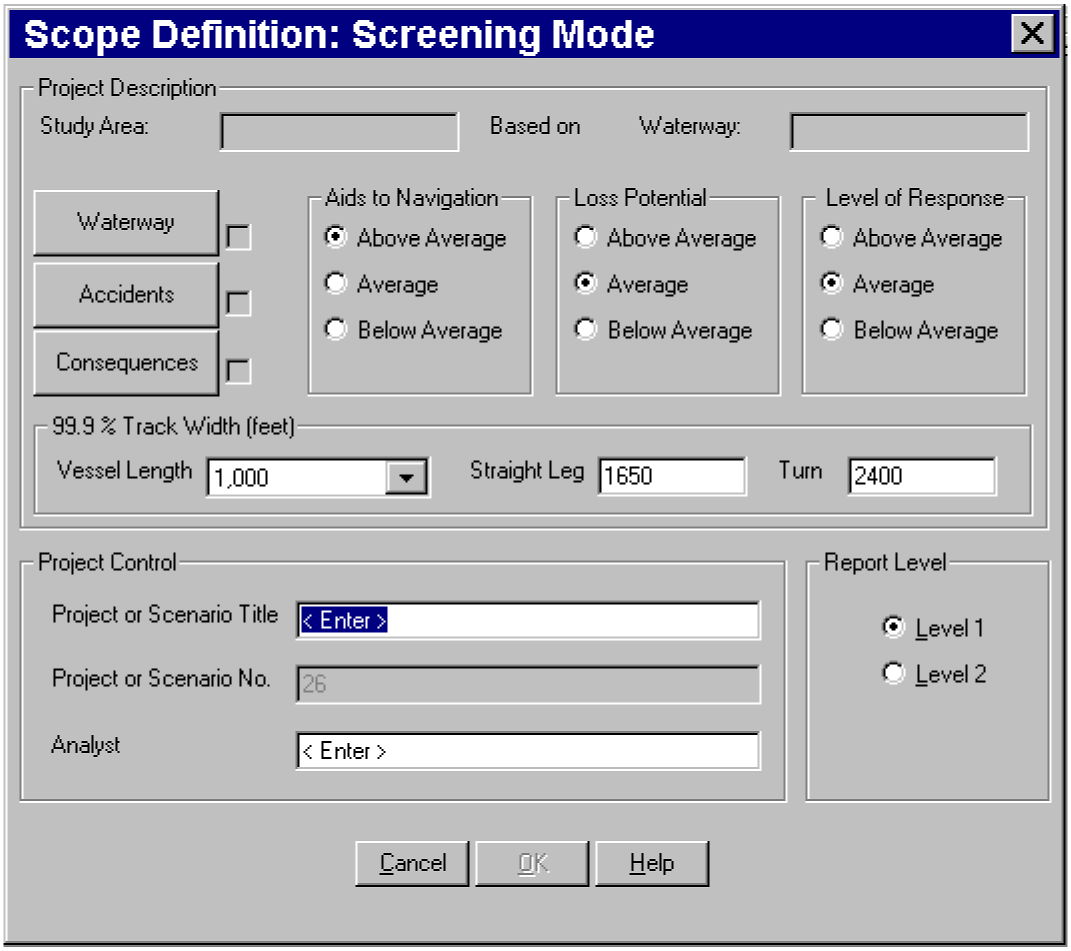


Figure 4 MNSS Risk analysis scope definition dialog

The process to obtain an answer from MNSS in detailed mode was as follows:

1. Run MapInfo and the MNSS.mbx MapBasic executable.
2. The waterway was defined by selecting the trackplot chart with the 's' turn, the traffic file for Canso VTS, and the Quebec VTS zone as the representative waterway because of the small historical tanker accident experience in the study area.
3. A level 2 report was required to get total accident costs, not just accident rates.
4. Accident types were tanker <50 000 DWT collisions and groundings. An optional port casualty cause table was selected.
5. All consequence types were selected.
6. For the status quo, no modifications to the accident rates were made; for the various changes involving ECDIS, the rates were modified by the multiplier from the pre-processor. Only those causes, such as position fixing and shiphandling were modified.

The output was a status report, a risk report and a map of the study area. The answer to the risk for the given scenario can be found in the 'Level 2' report where the column name is total cost and the row name is total (see Table 2). The other rows show the cause factors, the consequence frequencies and a breakdown of costs (not shown in Table 2). Analysis results can be found in Section 3, and details are provided in Appendix F.

Table 2 Level 2 tanker grounding report for the 's' turn status quo (exported to and modified in Excel)

Cause Factor	Statistic	Grounding Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency
Grounding	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Position Fixing	Min	0.0028	$1 735	0.0003	0.0000	0.0002
Position Fixing	Max	0.0084	$27 004	0.0008	0.0001	0.0005
Shiphandling	Min	0.0046	$2 863	0.0004	0.0000	0.0003
Shiphandling	Max	0.0139	$44 615	0.0013	0.0001	0.0008
Engine, power or prop failure	Min	0.0029	$1 808	0.0003	0.0000	0.0002
Engine, power or prop failure	Max	0.0088	$28 179	0.0008	0.0001	0.0005
Steering gear breakdown	Min	0.0017	$1 054	0.0002	0.0000	0.0001
Steering gear breakdown	Max	0.0051	$16 437	0.0005	0.0001	0.0003
Total	Min	0.0122	$7 536	0.0011	0.0001	0.0007
Total	Max	**0.0366**	**$117 409**	**0.0034**	**0.0004**	**0.0022**

Details of the workings of MNSS are documented in the MNSS Functional Specifications[3]; an overview can be examined in Appendix C.

2.5 Data input

Data tables in MNSS are from government sources and ATRA phase III (TP12814E). All tables can be viewed in MNSS. The casualty data base currently holds over 27 000 records. An example of the biological resources table shows the shoreline type and fishing areas in the vicinity of Port Hawkesbury (see Figure 5).

Casualty data from the Canadian Accident Investigation and Safety Board were converted into MapInfo format and categorized by GeoInfo Solutions into the VTS ship type and TSB casualty type groups. These classifications are listed in the report entitled: MNSS Functional Specifications Marine Risk Analysis Core Common Unit Process IT-6531.3.1 (see page A-4 to that document). The MNSS casualty table contains 20 year averages from 1975 to 1995. The classification of TSB casualty types into ten MNSS casualty types is presented in Appendix G.

Traffic data were converted from summary VTS Lotus tables into an Excel spreadsheet format. This involved the cleaning of data for the Laurentian VTS Region to avoid double-counting of traffic volumes compared to other VTS regions (see Appendix G). Both accident and traffic data were pre-processed into frequency counts by casualty type, VTS region,

[3] The functional specifications for MNSS is a separate background document titled: Marine Navigation Safety System Interactive Unit Process IT-6531.3 produced by GeoInfo Solutions Ltd. for Transportation Development Centre, March, 1997.

vessel type and month. The traffic table produced for MNSS contains 4 year averages from 1990 to 1993.

Cause, conditional probability and cost data provided in MNSS as default tables are primarily from the final reports of the Arctic Tanker Risk Analysis project (ATRA II - TP12325E, ATRA III - TP12814E). ATRA II details how these parameters were determined. A user may choose to temporarily replace these default tables from other studies.

Biophysical and social data were obtained from Statistics Canada and Environment Canada to help identify resources at risk and associated stakeholders.

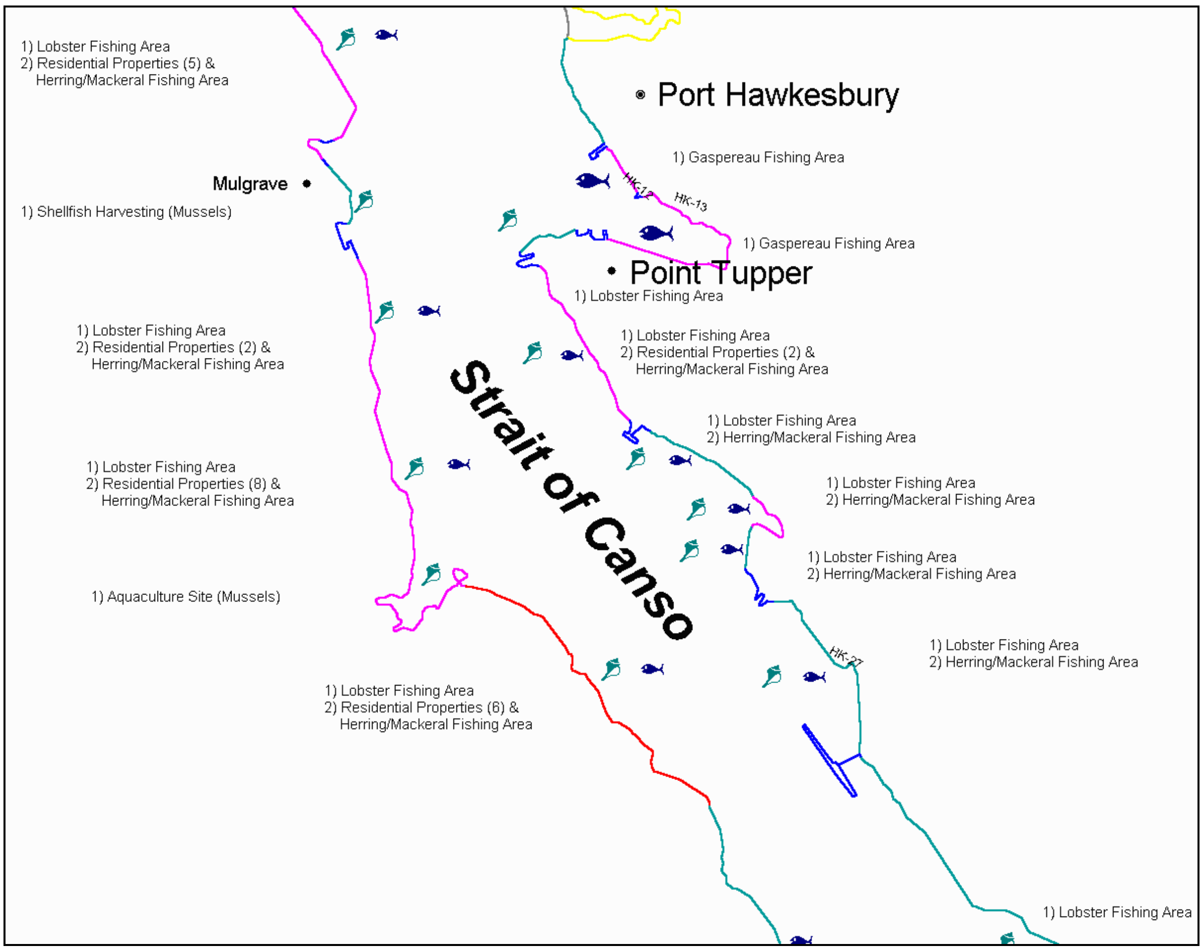


Figure 5 Biological resources data map (see key, Figure 6)

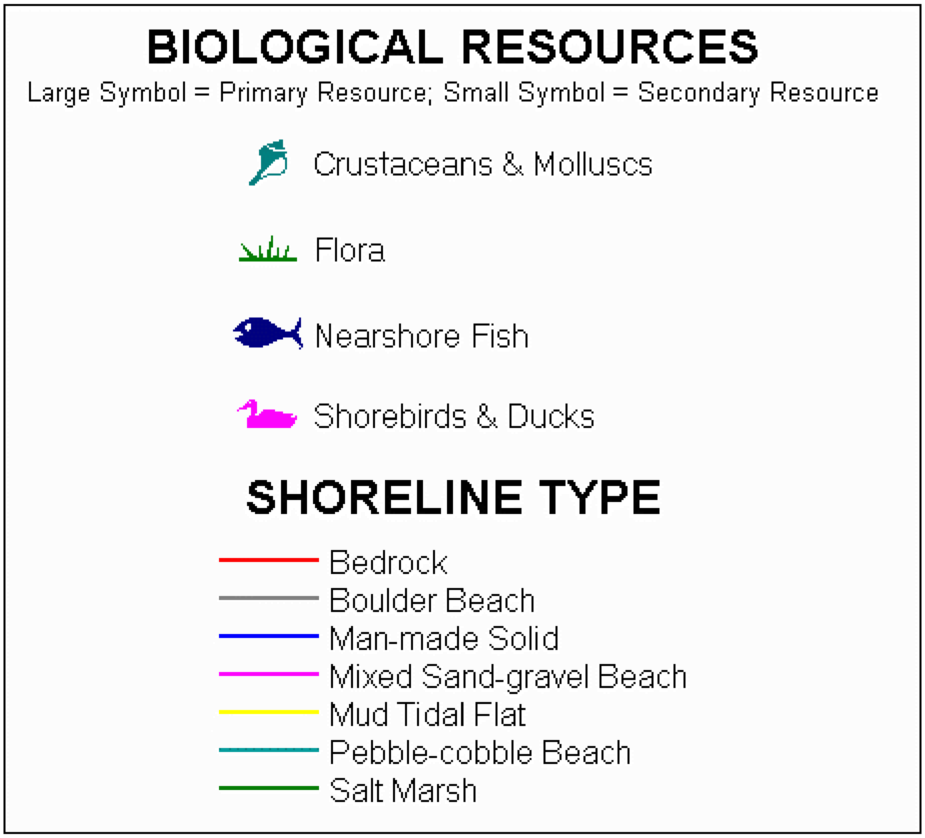


Figure 6 Key to biological resources

3. FINDINGS

3.1 LOS 99.9% pre-processor

Referring back to Figure 2, one can see that the pre-processor indicates a minimal change to the navigation safety or LOS with the introduction of ECDIS and the removal of some aids to navigation. This is because the status quo navigation situation is highly marked, and the improvement in positioning quality by the use of ECDIS will probably offset the removal of what would become redundant navigation aids such as Buoy C11, C10, Janvrin Island (Thomas Head) ranges, and Durell Point ranges. The effect of these changes on casualty risk in Canso Strait will be minimal if a transition occurs where ECDIS is fully used and understood before all changes to aids to navigation are finished. The percentage changes to grounding or collision rates are shown as 'total passage grounding or collision modify rates multipliers' in the LOS worksheet in Appendix E. Comparative accident rates and costs are shown below in Section 3.3, Table 4.

Figure 7 illustrates the pre-processor 99.9% width output for the 's' turn for a 760-ft (232-m) vessel with ECDIS and a no passing restriction. This is a reduction of 50 feet (15.2 metres) in manoeuvring room required compared to the status quo, and accordingly warrants a small reduction in the potential for grounding and collision. Each worksheet, the LOS worksheet and the Crystal Ball Monte Carlo simulation frequency charts created in the analysis are provided in Appendix E.

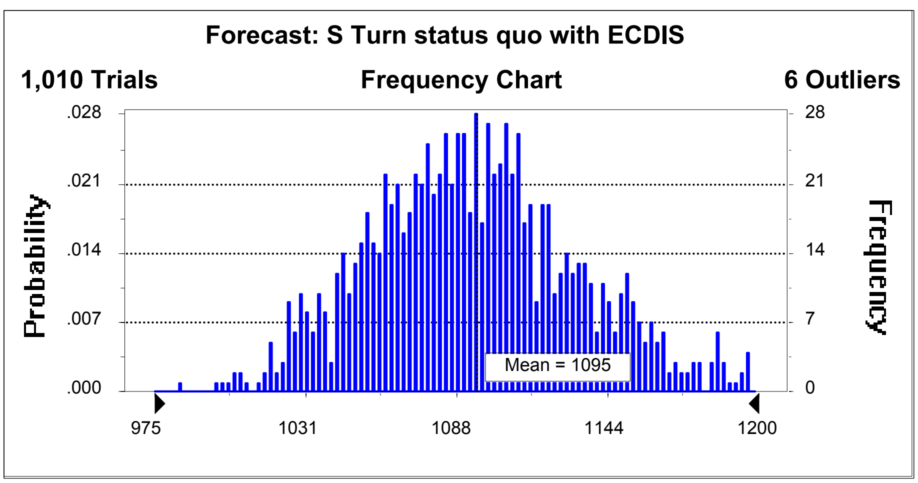


Figure 7 Crystal Ball Monte Carlo simulation output

Table 3 shows the sensitivity of the pre-processor to the six components which combine to result in the 99.9% track width. The parameters that have the greatest impact on the buffer zone width are 'Turn Path', 'Passing', and Shiphandling. In the example depicted in Table 3, a turn of 60° requires an additional 950 ft (290 m) of width compared to a turn of 0°. Passing by two 1 000-ft (305-m) tankers requires a channel width 750 ft (229 m) greater than if no passing were allowed. The pre-processor is also sensitive to the 'Shiphandling' setting which is sensitive to the category of vessel, vessel speed and weather. Since each analysis performed with the pre-processor is unique, the tool includes a built-in sensitivity analysis routine to help document those parameters which result in the greatest change in the estimated buffer width.

The prototype pre-processor might overestimate the safe width for very narrow channels such as the Traverse du Nord where 1 000-foot (305-m) tankers pass and share a 600-foot (183-m) channel. CCG LOS indicates that 200 feet (61 metres) between two such tankers passing is a highly significant hazard, as is navigating within 800 feet (244 metres) from a hazard. Boundary markers may greatly reduce the threat of grounding, but by how much? It is likely that some waterways are too narrow for a small percentage of vessels which means that the risk of grounding increases significantly. Many vessels will navigate safely without incident, but more than one in a thousand might ground, e.g., in the Quebec VTS zone, where one tanker goes aground or touches bottom on average every two years.

Table 3 Sensitivity of 99.9% pre-processor input parameters

Comparison of parameter changes on the 99.9% width in feet

99.9% Query Input Vessel Parameters: Beam 100 ft, Length 1 000 ft, GRT 100 000

(Beam 30.5 m, Length 305 m)

A: BEAM & CRAB

Primary Settings	Variable from 2.7 to 6 degrees of Crab
Changed Settings	Changed by weather and sea conditions. See parameter E: WEATHER

B: SHIPHANDLING

Primary Settings	Preset: Category I vessels:if speed >3 knots, 160 ft, otherwise, 600 ft
Changed Settings	Changed by weather and sea conditions. See parameter E: WEATHER

C: POSITIONING QUALITY

Primary Settings	High: Waterway completely marked with aids to navigation; No ECDIS				
Changed Settings	**High with ECDIS**	**High**	**Medium High:Ranges**	**Medium High: Buoys**	**Medium**
	1 600	**1 650**	1 750	1 800	1 850
	Also changed by weather and sea conditions. See parameter E: WEATHER				

D: TURN PATH

Primary Settings	Degree of turn: 0 "zero"				
Changed Settings	**0**	**15**	**30**	**45**	**60**
	1 650	1 850	2 150	2 450	2 700

E: WEATHER

Primary Settings	Level II weather frequency 40%, Level III weather frequency 30%, Weighted by visibility 40%				
Changed Settings	**10/10**	**20/10**	**30/20**	**40/20**	**40/30**
	1 450	1 500	1 550	1 600	**1 650**

F: PASSING, OVERTAKING, OR CROSSING

Primary Settings	Passing is enabled	
Changed Settings	**Passing is enabled**	**Passing is disabled**
	1 650	900

3.2 Comparison to CCG LOS and USCG WAMS

Although the 99.9% pre-processor takes a quantitative approach and measures safe widths like Waterways Analysis Management System (WAMS), it is based on the hazard identification and measurement methodology of CCG LOS. Unlike WAMS, the 99.9% pre-processor structure makes sense, is understandable by LOS officers and navigators, has input for expert judgment and can be developed and expanded in the future. Like the CCG LOS method, it uses existing LOS input parameters.

A comparison between WAMS and the 99.9% pre-processor output was conducted by IRR as part of this project. This report is included as Appendix D[4]. For 600 foot vessels, the pre-processor estimated track widths tend to be wider than WAMS and for 1000 foot vessels, the reverse was true. The comparison was difficult because of the different variables being measured. They found that the 99.9% pre-processor has more variables and a wider range of possible input values.

3.3 MNSS output

Since Canso Strait has too few casualties by tankers compared to other waterways in Canada, a collision and grounding rate for another waterway was needed to be applied to the Strait of Canso. A number of waterways could be used such as Halifax, Montreal or Quebec VTS or casualty rates for ports only in the St. Lawrence River. The manoeuvring in the ‘s’ turn and its approaches is river like, the deepsea traffic interaction is also more river like than a harbour, but the interaction with smaller Category II vessels is more harbour like. Therefore, a comparison of the port versus river channel collision and grounding rates was necessary to justify the selection of representative base casualty rates.

A comparison between the annual grounding rate in Canso Strait using the Quebec VTS tanker average grounding rate resulted in a Canso annual rate of 0.0244 or 41 years between an accident and using the St. Lawrence River ports average grounding rate results in a Canso annual rate of .0203 or 49 years. This showed that either grounding rates are equally applicable. However, using the St. Lawrence River ports collision rate would likely overestimate a collision rate for Canso because tankers do not pass in the ‘s’ turn and there is more interaction with other deepsea vessels in ports in the St. Lawrence River. Not surprisingly, the annual collision rate for Canso using the Quebec VTS rate was 0.0577 or 17 years between a collision; the annual collision rate for Canso using the the St. Lawrence River ports rate was 0.0840 or 12 years between a collision. Therefore, the rates for the Quebec VTS zone were used in the analysis of aids to navigation configurations with ECDIS.

---

[4]The reader is cautioned that the IRR report sometimes uses the terms MNSS and 99.9% interchangeably. MNSS should read 99.9% pre-processor because both software programs return separate, but dependent numeric data.

The detailed MNSS output tables from the analysis are provided Appendix F. Learning that the change in LOS was minimal for the 's' turn and the 320° approach course for the aids to navigation configurations being analyzed, no significant change was expected in the overall risk of a collision or grounding from the status quo to any of the options. However, in an area such as Montreal VTS which has 20 times the tanker traffic, a small change in the accident rate might have 20 times the impact on the overall risk and costs. Nevertheless, an incremental change in the estimated maximum annual grounding and collision frequency resulted in a small change in annual costs (see Table 4).

Table 4 Canso risk analysis annual casualty rates and costs (maximum or +50% of the average)

Casualty Type and Track Segment	Status Quo Conventional Aids	ECDIS and Reduced Buoyage	ECDIS and Reduced Range Lights/marks	Conventional Aids & ECDIS
			Min Safety	*Max Safety*
p(Grounding) Tanker < 50,000 DWT in S Curve	.0366 $117 409	.0366 $117 409	.0377 $120 989	.0354 $113 829
p(Collision) Tanker < 50,000 DWT in S Curve	.0865 $242 760	.0865 $242 760	.0897 $251 741	.0833 $233 776
p(Grounding) Tanker < 50,000 DWT on course 320°	.0366 $117 409	.0379 $121 707	.0393 $126 003	.0353 $113 110
p(Collision) Tanker < 50,000 DWT on course 320°	.0865 $242 760	.0904 $253 539	.0942 $264 317	.0827 $231 980

The collision and grounding rates can also be expressed using other units. For example, the annual maximum collision rate (average + 50%) of 0.0865 is also a return period of 12 years between collisions or a collision likelihood of 1.37 E-5 per ship per mile traveled. Similarly, the annual maximum grounding rate (average + 50%) of 0.0366 is also a return period of 27 years between groundings or a grounding likelihood of 5.8 E-6 per ship per mile traveled.

4. CONCLUSIONS & RECOMMENDATIONS

4.1 Conclusions

4.1.1 The MNSS application and the LOS 99.9% pre-processor

With further input from the CCG the LOS 99.9% pre-processor and MNSS could be developed into a tool which could help CCG personnel assess the safety and risk of Canadian waterways. As it exists, the 99.9% pre-processor probably provides a good measure of the safety for all but the narrowest waterways and the MNSS application can provide marine risk analysis answers for every waterway within Canada for which there is casualty data and applicable traffic data. With practice, the MNSS risk analysis tool provides results in seconds which would otherwise take days of working with multiple tables of casualty and traffic records, navigation charts and weather printouts.

4.1.2 Tanker grounding and collision risk in the Strait of Canso

Grounding and collision rates for the Strait of Canso were based upon the rates for the Quebec VTS zone because of the small tanker casualty frequency in the Canso waterway. Casualty rates were expressed as an annual rate, return period or rate per ship per mile traveled (shipmile). The tanker grounding rate has a return period between 27 and 82 years. The tanker collision rate has a return period between 12 and 35 years. The range spread is based upon the average rate ± 50%.

Because a high level of safety exists in the ‘s’ turn and the approaches to Canso Strait, a small change to the LOS in the waterway had a minimal effect on the risk of a casualty. The addition of the use of DGPS as an input to an ECDIS display could increase the status quo safety in the waterway by 6%. The effect of using ECDIS and eliminating redundant aids decreased safety by a range between zero and 12%.

4.2 Recommendations

4.2.1 99.9% Pre-processor

The modification of TNSS to enable the analysis of aids to navigation as an input parameter to a navigation risk analysis required a significant effort to shift some hard-coded routines to external processors. For MNSS this meant producing a pre-processor which intended to measure the impact on ship size, on-board navigation aids, weather and external aids to navigation. The quantification of these parameters was formerly accomplished to a more limited extent as part of a fault tree within TNSS.

The structure of the pre-processor was demonstrated to be based upon navigation practice and some of the current LOS methodology, but as a minimum, three steps are required to improve the processor so that it is valid and useful. First, CCG and other personnel need to understand and learn how the pre-processor works and what the results mean. This was not achieved in the delivery meeting, but was agreed to be a follow-on requirement. Second, CCG LOS personnel and the contractor can improve the structure or design and develop navigation quality lookup tables for Category II and III vessels. The pre-processor enables the input of expert judgment for most of the parameters, but this needs to be defined in greater detail once an enhanced structure is developed. Third, a comparison between the CCG design availability approach to LOS ranks, the 99.9% pre-processor output and historical casualty rates can be conducted to calibrate the model and evaluate its validity (see a similar comparison completed for the pre-processor and WAMS in Appendix D).

4.2.2 MNSS Core program

MNSS has improved flexibility to read risk analysis input parameters. Input tables for conditional probabilities, costs and cause factor frequency can be chosen as default or correctly formatted tables can be imported from Excel. Most dialogs in MNSS have hard-coded categories for selection, some display data on the fly, but they do not dynamically list available options based upon what the data can support. During the programming of MNSS it became apparent that the program could be enhanced by a significant effort to develop helpful dialogs on the fly based upon the input parameter tables chosen by a user. The effect of processing data and developing dynamic dialogs is that the user should not be presented 'sorry no data' at the end of an analysis, and MNSS will present selection options based upon the data. For example, if a chemical spill risk analysis was desired, conditional spill probabilities and costs in excel tables would be imported. The dialogs that include several 'oil spill' options would contain more 'chemical spill' options.

While this was beyond the scope of the present modification to TNSS, it is recommended that further work include an examination of the functionality of the MNSS prototype core model, and the design and documentation of both a dynamic, enhanced 'open' version with greater functionality and a 'closed' version which limits functionality to that which is absolutely necessary for a specific analysis, such as LOS, and has hard-coded processes rather than external processors. Before this can happen, CCG, IRR and other personnel need to understand and learn how MNSS works and what the results mean. Although the MNSS functional specification documentation was extensive and enabled the development of MNSS by a small team of programmers, the description of input output interaction should be further documented in an enhanced MNSS design task. IRR should acquire MapInfo 32bit in order to evaluate MNSS and more fully participate in its design and development. Because the MNSS core is largely a straightforward data query and risk calculator, IRR and GeoInfo Solutions focused 95 percent of the design efforts on the 99.9% pre-processor. This team needs further time to give the same level of effort to MNSS so that it can be explained easily and accommodate further expansion.

MNSS includes several measures to guide a user through an analysis: modal dialogs which do not let a user select options in an incomplete or out of order manner; a Windows help file which documents both MNSS and the 99.9% preprocessor; user guide and configuration documentation and detailed information in this report and its appendices. Further work to MNSS design should include working with the CCG and the Transportation Development Centre (TDC) to improve the functionality and understanding of the program.

4.2.3 Data collection and display

MNSS maintains the ability to display maps, tables and graphs, plot navigation passages, buffer route segments or other objects, create thematic maps and conduct detailed SQL queries. It demonstrates the ability to display navigation charts overlaid with accident and/or environmental data. Its data coverage includes low resolution TNSS data covering a very wide area from the St. Lawrence River to the high Arctic, and very high resolution data for the Strait of Canso. The format of the high resolution environmental sensitivity data is becoming a norm that is in development at Environment Canada. Navigation charts and climate data are translated into MapInfo format as required. Further work to collect data in another geographic area would require the collection of high resolution environmental data and the conversion of navigation charts.

4.2.4 Risk analysis

Cause factor input parameters in MNSS were developed in TNSS as the result of a cause analysis for several hundred casualty cases for the St. Lawrence River and the Arctic. To enhance MNSS to be applied in other areas, a marine casualty cause analysis would be required. For example, cause input tables could be developed for the Great Lakes, west coast ports, specific navigation waterways, specific vessels, etc. The effect of not doing this research is that the contribution of a specific cause factor such as position fixing for St. Lawrence River ports would be applied to the Strait of Canso on the assumption that the human error and its relative contribution to the probability of a casualty is equivalent.

During the design stage, the statistical output of MNSS was discussed with the scientific authority. The confidence limits of 'averages' were considered a problem if presented in a way which suggested a statistical measure of confidence where each input parameter had a separately calculated confidence measure when none were computed. Percentages of spill sizes, consequence costs, cause factors are examples of input parameters where some fitting of distributions has or could be applied. Similarly, various methods of providing confidence limits for average accident frequency were discussed including standard deviation, coefficient of variation, etc. It was decided that at this stage, it was best to provide a 'min max' range calculated by ± a percentage of the average (50 percent was applied). Further work would be required to provide statistical confidence bounds. This would impact on the

MNSS core in that each parameter input table of pre-processed frequencies, costs, etc. would have to provide confidence limits to MNSS.

4.2.5 Ownership

A week-long in-house training session with the 99.9% pre-processor and MNSS in each CCG region would contribute greatly to the development of MNSS and provide it with a stronger structural base. A further step is to facilitate an acceptance of the modernization of LOS analytical methods within CCG. A transition plan should be written which describes the process of introducing MNSS as a tool to assist the existing LOS method.

4.2.6 Communication

Tanker masters that use the waterway are considered primary stakeholders because they are directly affected by the benefits of ECDIS and costs of conventional aids reduction. Although local fisherman are Category I or II users of the waterway, they are only considered stakeholders in the scope of the present analysis because they may be adversely affected by oil spill damage to fishing gear and marine habitat.

The decision to present the results of the study to tanker masters concurrently with another stakeholder group should consider the various levels of experience of the stakeholders with ECDIS, the common familiarity of masters with decision making involving risk, and the possible unfamiliarity of masters with probabilistic mathematics and fault trees.

REFERENCES

Judson, B. (1996) ATRA III *Tanker Navigation Safety System*, TP12814E, Transportation Development Centre, Transport Canada.

Judson, B. (1997) *MNSS Functional Specifications. Marine Risk Analysis Core Common Unit Process. Interactive Unit Process IT-6531.3.1*, Transportation Development Centre, Transport Canada.

Judson, B. (1997) *MNSS Functional Specifications. Marine Risk Analysis Core Screening Mode. Interactive Unit Process IT-6531.3.2*, Transportation Development Centre, Transport Canada.

Judson, B. (1997) *MNSS Functional Specifications. Marine Risk Analysis Core Advanced Mode. Interactive Unit Process IT-6531.3.3*, Transportation Development Centre, Transport Canada.

Loughnane, D. and B. Judson. (1994) *Final Report: Arctic Tanker Risk Analysis, Phase II*, TP12325, Transportation Development Centre, Transport Canada.

APPENDIX A: 99.9% PRE-PROCESSOR DESIGN

CONTENTS

1.0 Introduction: Making Good Decisions to Reduce Risk and Increase Safety

Navigational aids in the Strait of Canso are risk management controls to provide safety for ships and the environment. Safety is measured by the level of risk in two ways:

1. The trends in ship casualties, groundings and strikings in particular since they are more likely to be prevented by navigational aids, and

2. The "risk analysis" estimates (e.g., accident probability by ship type, release of cargo and environmental damage, etc.) based on accident statistics and trends for a larger area than Canso Strait, since the local data is insufficient to estimate the probability of rare events.

With the introduction of DGPS it is possible to evaluate a policy of modification to existing navigational aids in terms of the overall goal of having the safest possible system given the existing risk management budget.

In the Canso Strait case, risk estimates are highly uncertain. This uncertainty arises for a variety of reasons including: there are only a few casualties on which to base the analysis; the mechanisms leading to casualties and the role of navigational aids in a cause and effect relationship is not easy to predict; given a casualty the laws of chance result in a wide range of possible outcomes in terms of impact on the environment, fishing, tourism, etc.

It is essential that decision makers are aware of all the uncertainties and understand the basis for the risk estimates of the policy alternatives so they can make as informed a decision as possible and be able to explain the rationale for their decisions.

2.0 Producing Safety: The CSA Process to Assist Decision Makers make "good" Decisions with Economy

Risk analysis and risk management have a proven track record for supporting and assisting decision makers facing difficult and uncertain choices. The CSA guideline for Risk Management (to be issued shortly but available in final draft form) is used to assist decision to make “defensible” decisions as well as providing a basis for communication of the risks and risk controls with stakeholders.

The CSA process involves:

1. using risk analysis to evaluate the change in risk due to any policy proposal,
2. evaluate the change in risk against other opportunities to reduce risks,
3. set priorities for changes in regulation, investments, etc. that is expected to reduce risk, and

4. monitor the selected controls to be sure they have the expected effect and also, if possible, to measure the reduction in risk.

2.1 Risk management issues

Every risk policy decision is unique and to reflect this uniqueness the risk management and risk analysis process must be designed and modified to reflect the most important aspects of the situation. Priorities for analysis must be set to ensure that the results are useful and practical—the role of the stakeholders is critical to establishing risk management priorities.

For example, in the analysis of navigational aids in Canso Strait the risk analysis must be looked at in a comprehensive manner but then the work must focus in on the details of the key elements of the risk analysis, stakeholder concerns and other requirements of the decision maker. The key risk management issues are:

1. The number of casualties that are effected by navigational aids and their expected consequences—this is the maximum risk that can be reduced. Care must be taken to avoid double counting of the impact of marine safety measures. 1996 VTS data indicate 27 transits of tankers < 50K DWT, 115 tankers > 50K, 7 chemical tankers and 0 LPG/LNG carriers. Casualty from 1975-1995, by TSB definition to include collision, grounding, striking, fire/explosion.

2. The role of navigational aids in Bridge Activities of navigation and ship handling. In particular the redundancy of the many available navigational aids must be taken into account as well as the redundancy of activities inherent in the Bridge with many eyes supporting the Officer of the Watch. It is not possible to predict with any accuracy the effect of a particular navigational aid, however, it may be possible to reach an informed decision on "good" policy decisions.

3. Given the uncertainty and lack of accuracy in the risk analysis it is critical to have a well structured dialogue with the stakeholders both to improve the risk analysis and to ensure that they are sufficiently informed in terms of their needs, issues and concerns.

4. The uncertainty in the risk analysis and evaluation must be clearly presented through tables, map displays, repeat of input assumptions, and other methods of communication. The decision maker must have a clear and concise picture of the risks and the effects of the navigational aids.

2.2 Stakeholders and their needs, issues and concerns

Stakeholders and their needs, issues and concerns are:

1. TDC with concerns that there is research, development and demonstration of tools for rule-making in marine safety including human factors investigations.

2. CCG with concerns for a useful tool for assisting them to do analysis and communicate results of policy analysis

2.3 Existing Risks

Existing Risks (Probability and Consequences) are:

1. strikings (probability per ship transit and range of consequences)
2. groundings (probability and range of consequences)

2.4 Impacts of risk control measures

Impacts of Risk Controls (Existing, DGPS and reduction in buoys, DGPS & reduction in range marks, DGPS and reduction in buoys and range marks) are:

1. change in casualties (range of values)
2. change in environmental damage (range of values or distribution)
3. others to be entered later

Figure 1 illustrates the use of the risk based approach to make decisions on Aids to Navigation (The Canso Strait will be a case study to illustrate the approach). In Figure 1, Policy Options such as the implementation of a regulation requiring ECDIS on vessels combined with a reduction in Aids to Navigation, is proposed. The proposal is analysed using the risk management process (i.e. following CSA Q850—Guideline for Risk Management and Q634—Guideline for Risk Analysis). The process is outlined in Figure 1 and results in analysis of the proposal in terms of:

1. Stakeholders's views of the proposal
2. Changes in risks (casualties and their consequences) due to the proposal., and
3. Changes in Costs due to the proposal

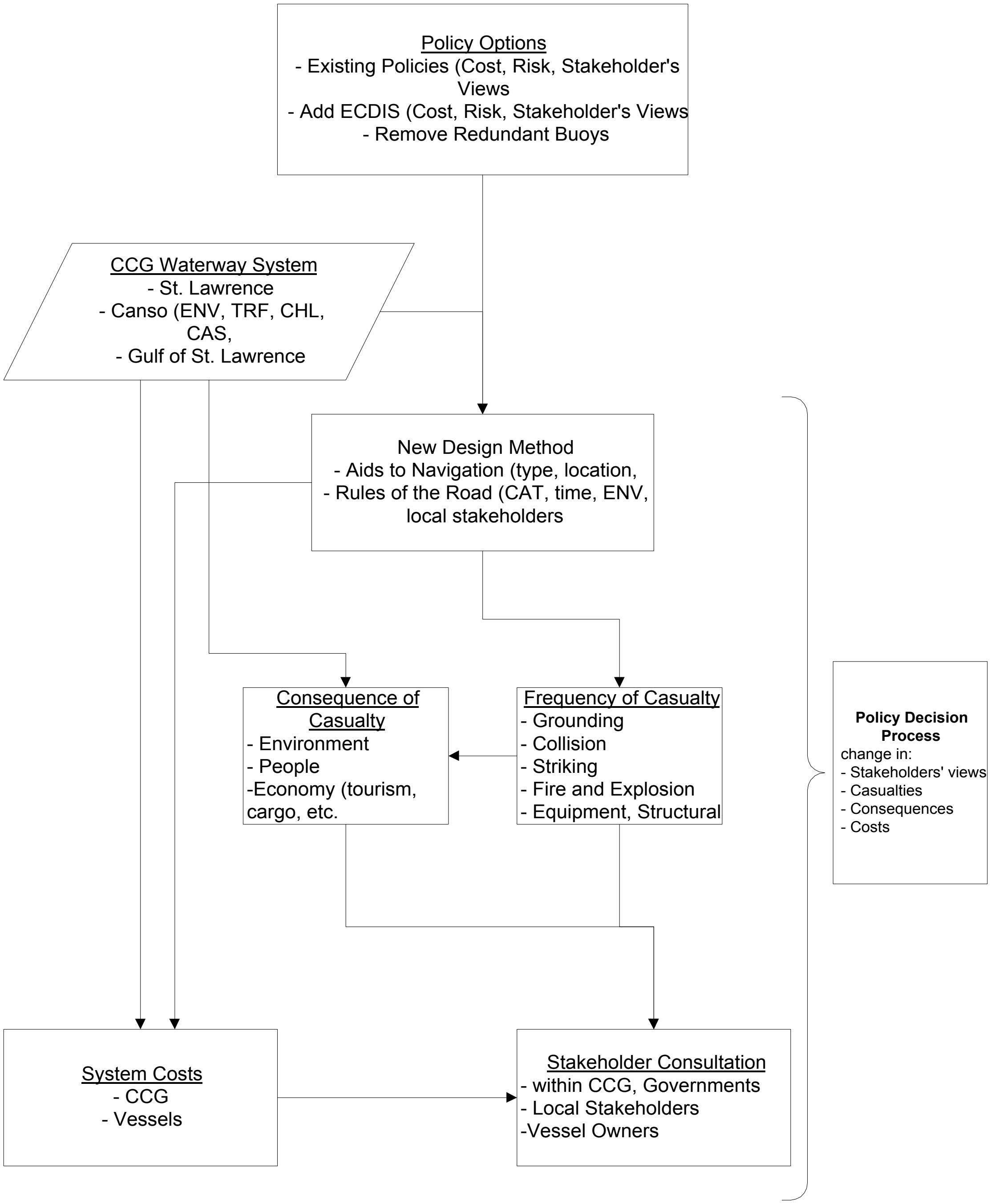


Figure 1 Risk based approach to decision-making on Aids to Navigation

At this point the policy decision may be taken if further analysis is not required.

The analysis of Aids to Navigation is based on a design methodology, which in Figure 1 is shown as "New Design Methodology". The methodology is an evolution of the existing methodology, with changes made to make the risk based approach more practical. The modifications do not change the basic ideas of maritime safety principles contained in the present methodology but only introduce a methodology that can be used for either analysis or design, and a methodology that can respond to new technology such as ECDIS or other yet unknown future NavAids or Aids to Navigation. The methodology can also be used to examine policy options involving regulations.

Figure 1 indicates that the CCG data on the Waterways, including Canso, provides the basic inputs on the Channel characteristics (e.g. data on Charts including Aids to Navigation), Environmental Conditions (wind, waves, visibility, cross currents, etc.), Traffic activity, Vessel Characteristics, and so forth. The results of the new design methodology, which is described below, then feed into analysis tasks to estimate the frequency of the risks, the consequences of the risks, and the costs implications of the proposed policy. Finally Figure 1 illustrates the important activity required by Q850—stakeholder consultation. In the Canso example, the stakeholders are mainly marine safety experts within the CCG and TDC.

3.0 Proposed Design Methodology

3.1 Overview of the design methodology

The proposed design methodology in Figure 1 is expanded in Figure 2 and Figure 3 to illustrate the details of the proposed methodology and the calibration of the methodology. The key risk analysis model is presented. It estimates the required Channel width and the Level of Service (LOS) for specific Channel and Traffic Conditions.

Figure 2 illustrates the LOS Design/Analysis Methodology. The objective of this methodology is to design Aids for Navigation for a Channel to meet a LOS criteria. The basic LOS criteria is “C” which is a level that will allow a transit of a waterway with only about 1 in 10 000 transits having a risk of casualty, due to the basic characteristics of the Channel, the Aids to Navigation, and the waterway Regulations. The design methodology estimates the 99.9% track width or the Channel width that is sufficient to allow 999 transits out of a 1 000 to pass through the Channel without risk of standing into danger. It is assumed that only 1 out of 10 vessels that stand into danger will result in a casualty, i.e. giving a combined risk frequency of a casualty of 1 in 10 000 or E10-4 (to be checked against data if possible).

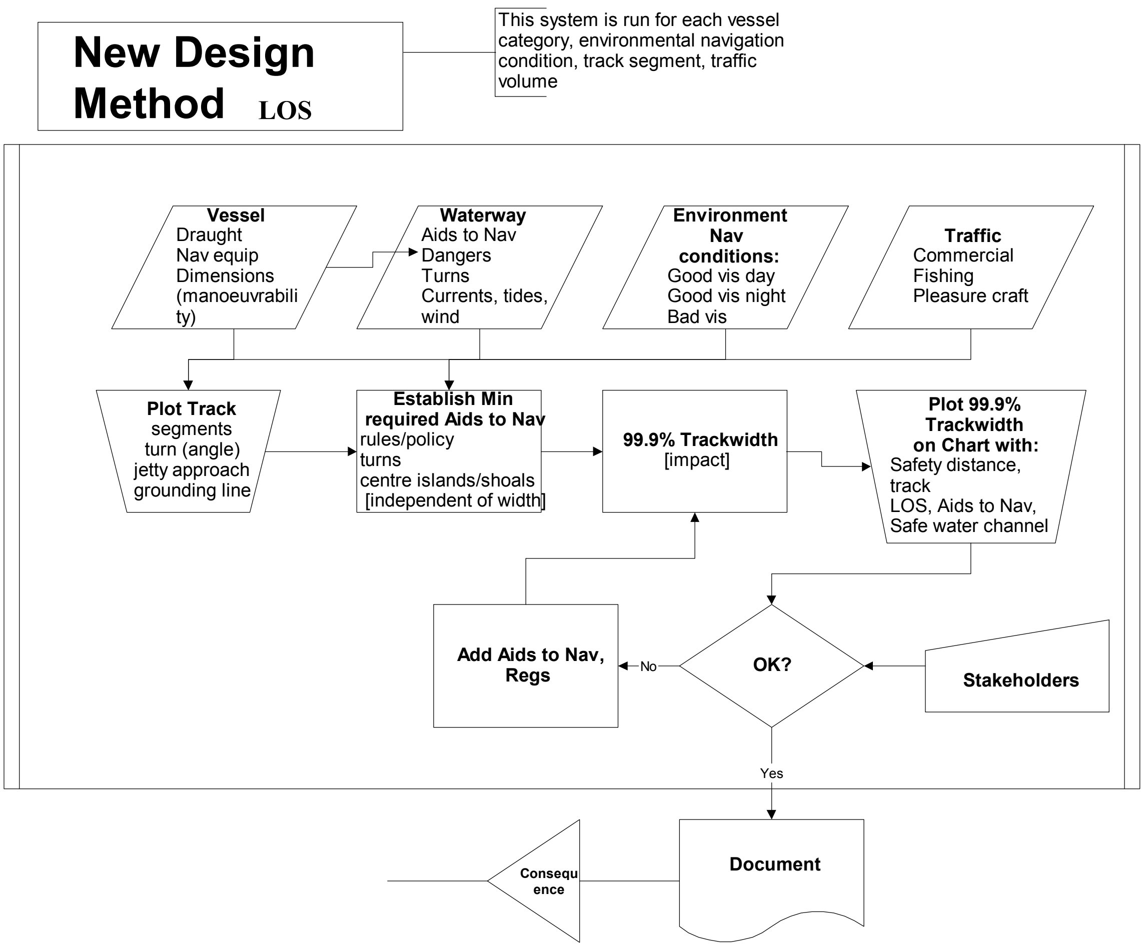


Figure 2 Details of LOS & 99.9% methodology

In most cases the Channel will be wider than the 99.9% width required for LOS "C" and this will result in higher LOS "B" or "A".

The method in Figure 2 also can be used along with the other analysis models in Figure 1 to evaluate the absolute change in risk due to a policy option.

In Figure 2 The data on Vessels, Waterways, Environmental conditions, and Traffic are used as input into the 99.9% determination as well as to plot the results of the LOS analysis on the Chart of the Waterway being examined. There are three basic analysis tasks in Figure 2 as shown by the rectangular boxes. These are the introduction of the minimum number of Aids to Navigation, the calculation of the 99.9% distance and the process to add Aids to the Channel to achieve a minimum LOS "C". In addition Figure 2 illustrates the decision process that evaluates the design for the waterway and adds Aids until the design both achieves a LOS "C" and also considers the results of the Stakeholder consultations and dialogue.

In Figure 2 the Minimum Required Aids to Navigation process applies the basic rules for marking Channels that are required by CCG policies no matter what the LOS is in the

Waterway. Examples of minimum provision of Aids might be; the marking of turns by two buoys on the inside edge of the approach (resulting in a minimum of 4 buoys per turn), the marking of dangers in the center of the Channel, and the marking with an Aid of the entrance to the Channel. The minimum Aids should represent a basic minimum number of Aids to Navigation.

Given the minimum required Aids the 99.9% analysis is carried out to determine for each Segment of the Channel the width required for LOS "C". This width is determined by an design method that considers the requirements for channel width to accommodate the basic elements of a safe Channel:

1. distance for the vessel beam and crab angle
2. distance for Shiphandling about the set course
3. distance for Positioning the vessel course in the channel
4. distance for variation in Turn Paths in turns
5. distance to allow for Environmental Conditions, e.g. bad weather
6. distance to allow for Passing another vessel

The next process in Figure 2 after the 99.9% LOS "C" is determined is to plot the required distance width on the chart of the Channel. This then allows for the estimation of the LOS for the Channel, since LOS "A" and "B" are multiples of the 99.9% distance which defines LOS "C".

The 99.9% LOS refers to the level of service for the actual channel width relative to the 99.9% distance. LOS are designated by A, B, and C. C is a minimum channel width and represents a condition in a Waterway Segment where the available Channel width is at least equal to the 99.9% distance. The division between LOS A and B, and between LOS b and C are ratios of the 99.9% distance. The division points are selected to correspond to the expected level of risk. The following suggestion indicates the basic structure of the approach (division points are illustrative only and will be revised as Waterway calibration data becomes available):

A - perhaps > two and one half (2.5) times the 99.9% distance (risk > 10E-6 per transit) [example for 99.9% distance = 800 feet: LOS A if channel width > 2 000 feet]

B - perhaps between 1.5 times and 2.5 times the 99.9% distance (risk < 10E-5 per transit) [example (cont.) if channel width is between 1 200 and 2 000 feet]

C - perhaps between 1.0 times and 1.5 times the 99.9% distance (risk < 10E-4 per transit) [example (cont.) if channel width is between 800 and 1 200 feet]

The LOS information for each Segment (e.g. entrance segments, straight track segments with similar widths, turn segments, etc.) is then examined and a decision made on the acceptability of the LOS for the Waterway. This would normally be based on policies about the amount of traffic, level of danger, Stakeholders's views, and Priorities established based on minimizing the risk in the total system, given the available resources.

Finally in Figure 2, if the LOS is not acceptable (or to evaluate the priority for risk reduction expenditures or reallocation of resources) the impact of adding Aids for Navigation to the Channel are analysed. The key step is to identify, analyze and evaluate Aids to Navigation. This can be done easily since the design methodology software is easy to use and understand in terms of traditional marine safety concepts.

The 99.9% Channel width is the distance required for a segment of a waterway for the minimum safe operation of a vessel. Safe is defined as the distance that 999 out of 1 000 transits, operating with normal care and attention, would not go aground, or that only.1% of transits would experience any difficult. It is expected that even the 1 out of 1 000 would usually have luck and would not result in a casualty. In risk terms the 99.9% distance will likely result in a risk of 10E-4 to 10E-6 per NM.

The 99.9% distance is measured perpendicular to the Channel Track and has up to 6 independent components, each of which contributes to the safe distance in a separable way. These components are defined as follows:

A. Beam and Crab - the physical distance across the channel of the vessel at a nominal 3 degrees to the Track. The is the overall lateral distance covered by the vessel as it proceeds down the channel at an angle to the track (part width, part length). The Environmental factor includes a factor to increase the crab angle in response to environmental conditions.

B. Shiphandling - The maximum range of distance of the center-line of the vessel about the intended track of the vessel in calm conditions, on a straight segment of the waterway, with a given level of Visibility. This distance depends on the physical characteristics of the vessel (e.g. inertia, rudder response time) and the course keeping skill of the bridge team (e.g. ability to detect deviations from course). The Shiphandling distance varies with the skill of the bridge team.

C. Position in Channel - the maximum range of the center-line of the vessel about the intended track of the vessel due to the estimation of the location or position of the vessel in the Channel or relative to the Track on the Chart. This distance varies with the Aids to Navigation of the Waterway, the Navigational Aids on the Vessel, the Visibility, the definition of the Channel shore, landmarks, and the variation of the clearing contour line (defined by limit of safe water) with the shore. This distance is estimated as the "maximum probable error" in the determination of the position of the vessel in the Channel Segment. The position distance varies with the skill of the bridge team.

D. Turn Paths - the maximum range of the center-line of the vessel about the Chart Track in a turn. Each vessel will chose a different start location, turn radius, and end location for a turn. This will trace out a defined path for vessels making the turn. The cross track width of the locus of all paths defines the turn path distance. Increase in the 99.9% distance due to the radius of the curve and the length of the vessel are accounted for in factor A. (Beam and Crab). Environmental Conditions are accounted for in the Environmental factor E.

E. Environmental Distance - the increase in the 99.9% distance due to the effects of wind, waves, visibility, tides, and cross currents in the Waterway Segment. The distance is estimated based on experience with the impact of these factors as defined by the current CCG design method. The Environmental factor includes distance components for the ship crab angle, for Shiphandling and for positioning. The environmental distance varies with the skill of the bridge team. For extreme conditions such as hurricanes it is assumed that vessels will not travel.

F. Passing Distance - If passing is not permitted then the 99.9% distance is found from the sum of A+B+C+D+E, allowing for variation in the determination of the component distances (see below). If passing is permitted then the 99.9% distance is found from the combination of two specified vessel passing (1 and 2) as the sum A1+A2+B1+B2+((C1+C2)/2)+((D1+D2)/2)+ ((E1+E2)/2)+F1-2. Where F1-2 is the maximum probable (i.e. the 99.9% extreme) least clearance distance between Vessel 1 and Vessel 2.

The 99.9% distance is found for a given level of Visibility (which impacts mainly C. the error in position in the Channel), for a given type of Vessel (i.e. representative vessels for each of Categories I, II, and III), for the specific characteristics of a Segment of a Waterway (e.g. traffic, NavAids visible, landmarks including shore line on radar, ranges, visibility,…). The 99.9% distance is found by simulating 1 000s of transits of the waterway segment, each time varying the input parameters for the individual components as indicated in Table 1. Recognizing the relative accuracy of the method the 99.9% distance is rounded up to the nearest 50 feet for design purposes. For analysis purposes (for example the analysis of the effect of a new Navigation Aid) the 99.9 % distances are taken as the mean plus 3 standard deviations from the simulation results.

The design method considers the impacts of navigational aids in terms of their effect for a hypothetical Channel width that is just equal to the 99.9% distance, even though the actual channel width is wider. This is because the design method only considers intervention in the Navigational Aids and Aids to navigation when the actual channel width is less than the 99.9% distance.

The design method must combine the 99.9% distances for all Categories of Vessels, all Visibility Conditions, and all Segments of the Waterway. This usually is done by selecting the largest distance unless it can be argued that that Category, Visibility, or Segment represents only a negligible situations with respect to the overall safety of the Channel.

Table 1 Variables that are varied in the Simulation to determine the 99.9% distance

99.9% Distance Component

	A. Beam & Crab	B. Ship handling	C. Position in Channel	D. Turn Paths	E. Environmental Conditions	F. Passing
Vessel length and beam	Yes	Yes		Yes	Yes	Yes (length)
Crab Angle	Yes					
Aids to Navigation			Yes			
Navigation Aids			Yes			
Degree of Turn				Yes		
Visibility,			Yes		Yes	
Wind, waves, currents					Yes	
Bridge Team Performance		Yes	Yes	Yes	Yes (indirect)	
Speed		Yes				
other?						

Note 1 - this table is constantly revised as the individual components are estimated, calibrated and then simplified according to the relative sensitivity, ease of understanding, etc.
Note 2 - there are variables used for a component but not varied in the simulation these are not yet completely indicated in the table.

3.2 Calibration of the 99.9% methodology

Figure 3 illustrates the approach to the calibration of the design methodology, and in particular the 99.9% methodology. The calibration is limited by the extent of the Canso example and the available resources. After the Canso application and evaluation of the methodology it will be clear as to the priorities for further model development and calibration.

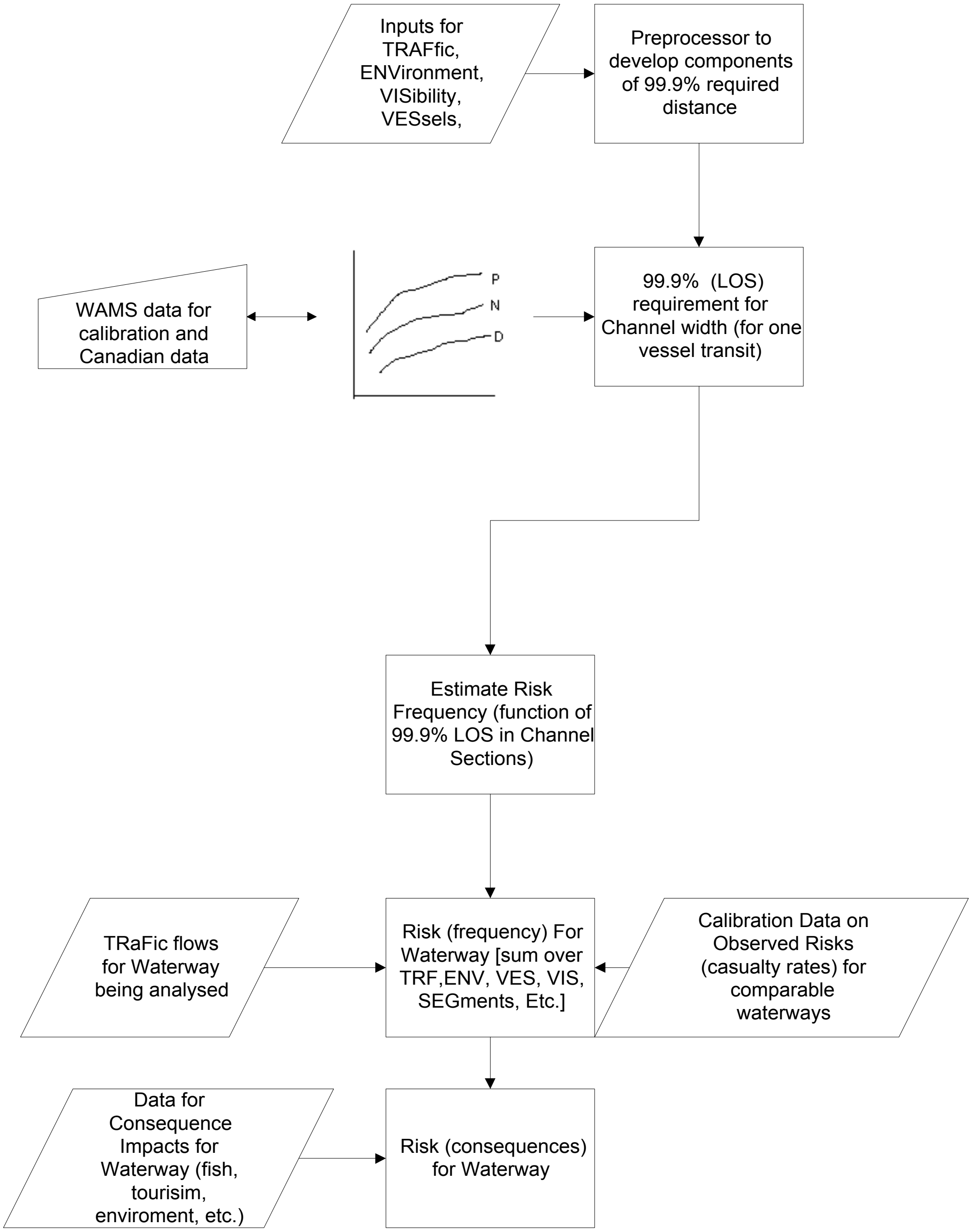


Figure 3 Calibration of the 99.9% methodology

As indicated in Figure 3 there are a number of sources of simulation data and sea trials that are available to compare against the 6 component distances, as well as the 99.9% distance estimated by the methodology. These sources are:

WAMS data from the US which is a key source since the US approach which as been developed and used in practice for over 10 years has a similar theoretical basis, but it should be noted that the proposed approach is recast into a more practical approach that can be understood in terms of traditional Navigational practice and skills. Canadian simulation data from the Centre for Marine Simulation suggested cross track variation for ECDIS in the order of 15% of the average track width of 2.2 cables (or 1 320 feet) used in visual pilotage. Additionally, the standard deviation for visual pilotage was 6.5 cables or 2.8 times that of ECDIS. This variation was due to the way mariners used the ECDIS information in both collision avoidance and track keeping. Canadian Coast Guard channel design criteria suggest a minimum of 2.8 to 4.2 times the vessels beam for a one lane channel and 5.6 to 7.8 times the beam for a two lane channel (about 780 feet for a VLCC).

Once the 99.9% LOS “C” design method is calibrated to the extent possible in this study the method can be applied to the Canso Strait and the resulting LOS found. As indicated in Figure 3 the estimated LOS values for the Channel Segments can then be compared to the available accident data for CANSO and other similar Canadian waterways. This comparison will allow for the calibration of the LOS “A”, “B”, and “C” in terms of risk frequencies. In a similar way the other components of the policy option evaluation method outlines in Figure 1 can also be evaluated and to a modest extent “calibrated” at least to the level required to provide for an evaluation of the policy options for the Canso Strait case study.

4.0 Software tools for marine risk analysis

4.1 Software objectives and requirements

The study will produce a software tool for use by CCG and potentially others to assess risks for specific locations and tracks. The software will use Canso Strait as an example of a typical policy analysis. The software has a number of objectives and requirements to meet:

1. The assumptions and limitations of the "model" must be clearly understood by every user.
2. The key characteristics of the policy issue must be represented in the model.
3. The software must be easy to use and be perceived as useful.
4. The model must accurately reflect the current state of knowledge about the cause and effect of marine casualties. It must be capable of validation against existing data.
5. The software must be maintainable both in terms of modifications in the risk analysis and in terms of incorporating new data.
6. The software must be flexible and be able to address new policy issues with limited modifications.
7. The software must be as simple as possible given that it meets other requirements.
8. The model must accurately reflect uncertainty in the risk.
9. The model, software and general policy analysis approach should meet the CSA guidelines for Risk Management (Q850, 1997) and Risk Analysis (Q634, 1991). Compatibility should also be achieved with any emerging international marine risk analysis procedures.

In the next section there are a number of options and choices presented that will use these objectives and requirements for selection of the basic model structure. There must be a "buy in" by stakeholders for the basic structure of the model and the data to be used for the calibration of the model and for policy analysis. During discussions with the stakeholders it may be necessary to revise these objectives and requirements.

Each potential user of the software will have a set of typical issues and demands, these must be considered in the selection of the basic structure and capabilities of the model and software:

1. CCG - policy analysis for navigational aids, changes in regulations, response to accidents/incidents, etc.

2. Ships - navigation safety via buoys and DGPS, etc.

5.0 A new design methodology and software component structure

The proposal and model approach contain an initial structure for the model and the software with the following implicit choices:

A. A simple core analysis model which determines casualty rates for the chosen study area or another area used to represent the casualty rates and provides a consistent user interface to plot tracks and input the results of a Monte Carlo analysis. The core provides the link to the geographic data used by the 99.9% preprocessor. This was chosen rather than the prototype version of TNSS which was a more complex integrated model to estimate marine risk. The reasons for the choice included; explicit treatment of uncertainty, ability to validate against existing data, improved understanding of the model cause and effect structure, etc. The suggested model structure is in the proposal at pages 5 and 6, (will be incorporated in this section if general agreement by stakeholders and after a more detailed development and specification phase).

B. Use of pre-processors incorporating simplified fault trees and Monte Carlo analysis using Crystal Ball®)to determine the 99.9% safe channel width and the relative risk. The prototype was a fully integrated model. This choice allows the model to be developed application by application, to be validated in a comprehensive overall way against the existing casualty data, to allow for special cost benefit analysis and other output reports using standard spread sheet analysis, to incorporate a sophisticated human factor pre-processor for specific policy issues such as Canso Strait NavAids, and so forth. A post-processor would be used to determine the probability of spill events, the magnitude of impacts and various measures of risk.

C. Separation of Inputs into two groups: standard inputs that would be developed from standard statistics (e.g., probability of release of cargo given a grounding or collision in the St. Lawrence), and inputs specific to the policy issue or analysis (e.g., ship type, crew training, local environmental vulnerability, etc.). In TNSS, there was no differentiation between the general risk analysis inputs and the problem specific inputs. The advantage of separating out the standard inputs is that they can be validated against historical data and through stakeholder review.

There are a number of other model structure issues that should be resolved before the software is developed, these include:

E. Flexibility of the software for the user. The software can be very flexible, with all possibilities included as separate input variables. This can result in a very complex software that is easy to use but hard to develop and maintain. It may also give the decision maker a false sense of accuracy. Alternatively the software can be very inflexible as it will use a small core risk analysis with standard inputs, and flexibility will have to be introduced by the expertise of the user in specifying modifications to inputs to reflect the special characteristics of the problem at hand. This will simplify the software, data requirements and understandability of the model. To some extent the choice depends on the degree of uniqueness of the problems that will be used with the model. If each problem is unique and requires model modification, then clearly the simpler, less flexible software is better.

The software tool will enable users to apply unique pre and post processors and future requirements are conceived. One such post processor might include a consequence processor to measure the impact of an LNG explosion based upon external analyses of event trees and conditional probabilities. Another might apply a conditional probability for a chemical release and its impact. If such data parameters are readily available, it will be worth including simple processors for these events.

F. Integration of the route sections. A typical vessel voyage can be divided into sections, such as the St. Lawrence from Quebec City to Montreal, which have special and consistent risk characteristics. The simplest approach is to make the model applicable to each section independently. The alternative is to integrate the sections on the route to reflect the level of fatigue of the crew and how this might impact the crew performance in an individual section, rather than assuming average crew condition. For Canso Strait an integrated approach is not required but for route planning it might be considered. While this issue would not be coded in this project the issue needs to be addressed so that the structure of the software can incorporate in the future.

G. Consideration of only direct "marginal" effects of variable or include interaction effects (e.g., the cause and effect relationship between visibility and accident risk is impacted by the language/comprehension of the crew, over and above the direct impact of the crew capability on accident risk). Given the current accuracy and availability of validated relationships, it may be best to use only direct effects analysis in the initial model structure.

H. Use of the concept that:

Casualty rates are proportional to the waterway risk where waterway risk is a function of the characteristics of the channel, the wind/sea state, type of vessel [stopping and maneuverability], experience and training of the crew, bridge complement and fatigue status, available NavAids and their capability [including the effects of redundancy], etc. The concept is incorporated into the new design method in the pre-processor.

I. The organization of key software components:

MapInfo® will provide the functionality for storage of geographic information (such as environmental data, casualties, charts and aids to navigation), user input of tracks and 99.9% distances and possible the core shell functionality of calculating overall risk.

"Modifiable" spreadsheets will be used for pre and post processing.

The extent of GIS visualization by the user such as designing with electronic vs. paper charts and the illustration of risk areas should be addressed.

The development of standard "cost-benefit" analysis might best be left to a post-processor.

APPENDIX B: MNSS TEST REPORT

CONTENTS

1.0 Report on test results of MNSS Software

Comments noted in BOLD SMALL CAPS by GeoInfo Solutions Ltd.

The contents, functionality of test results of the two sub-modules, MNSS1 and MNSS2 are as follows:

1.1 MNSS1

This module shows the following menu-items after loaded in MapInfo as map basic application. The menu-items in ***Bold-italic*** are items which are not implemented in MNSS1 sub-module.

Screen mode…
Detailed Mode
- ***Scope definition..***
- ***LOS Pre-processor***

Track plotting
- New Track
- Process Track

99.9% Plotting
- Open Chart and Track
- Buffer Track

Casualty maps
Loss potential map
Project Tables
Consequence Dialogs
Costs Dialog
Accident Dialog
Cause Dialog
Modify Rates
Exit MNSS

THE TEST RESULTS

Menu Item 1: Track Plotting

Sub-Menu Item: New Track

This function seems to be properly implemented. It enables the user to open workspace where the user could draw a track as polyline. The user can also terminate the drawing of polyline by Esc key or by double clicking the left mouse button.

Select a Navigation Chart Workspace Dialog

- used to displays workspace files,
- has proper file filter (*.wor),
- displays all files with .wor extension in a drop down list box.
- OK and CANCEL buttons are working.

MenuItem 1: Track Plotting

Sub-MenuItem: Process Track

This function allows the user to process the new track drawn as polyline using new track function as above. After selecting process track menu item, a dialog box, Enter track name, appears for the user to input the name of the workspace.

Enter track name Dialog

- This dialog box has edit box for user created workspace name input.
- protected against invalid input by the user,
- both the dialog box and the workspace disappears upon clicking OK button.

Remark: I could not understand why the window with new track information should be closed before a user finished his analysis of 99.9% plotting.

[MAY 7: THE FILE COULD REMAIN OPEN. 99.9% BUFFER FUNCTION REQUIRES A WORKSPACE AND WILL CLOSE ALL OPEN FILES. CLOSING THE FILES AFTER PROCESSING A TRACK PLOT SESSION PREVENTS A USER FROM INADVERTENTLY CHANGING THE WORKSPACE FILE DURING THE SESSION, BJ]

MenuItem 2.1: 99.9% Plotting

Sub-MenuItem: Open Chart and Track

This function enables the user to open workspace together with new track drawn under the track plotting menu.

Select a Track plot Workspace Dialog

- used to displays workspace files,
- has proper file filter (*.wor),

- displays all files with .wor extension in a drop down list box.
- OK and CANCEL buttons are working

<u>MenuItem 2.2</u>: 99.9% Plotting

<u>Sub-MenuItem</u>: Buffer Track…

Buffer track menu item can be used to generate 99.9% track width as a buffer zone of safe water around the track or turn. After the user selecting a segment of a polyline the MNSS display a dialog box, Buffer Track with 99% displays to accept a buffer track width.

<u>Buffer Track with 99% dialog box</u>

This dialog box enables the user to input width parameters in feet, meter, … The dialog box checks for the validity of the user inputs.

The buffer track with 99% dialog box does not respond to six digit width values. For input, for example 123456, the buffer track function neither process the input nor return an error message.

[MAY 7: ACTUALLY, NO ERROR OCCURS AS THE BUFFER FUNCTION DOES CREATE A BUFFER WHICH IS SO LARGE IT IS OFF THE SCREEN. 123456 FEET IS OVER 20 NM IN WIDTH, BJ]

No help file can be opened after clicking the HELP button on the Buffer Track width 99.9% dialog box.

[MAY 7: HELP TOPIC TO BE CREATED, BJ]
[MAY 23: HELP FILE COMPLETED, BJ]

<u>MenuItem 3</u>: Casualty map…

Not implemented.

<u>MenuItem 4</u>: LOS potential maps…

Displays open LOSS potential maps dialog box.

<u>Open LOSS potential map Dialog</u>

- used to displays workspace files,
- has proper file filter (*.wor),
- displays all files with .wor extension in a drop down list box.
- OK and CANCEL buttons are working.

<u>MenuItem 5</u>: Project table…

Not implemented.

[MAY 7: FUNCTION TO BE CREATED, BJ]
[MAY 23: COMPLETED, BJ]

<u>MenuItem 6</u>: Consequence Dialogs

Displaying the **Consequence dialog** box is possible after opening the test "Gummy" browser as MapInfo table. If the Test "Gummy" browser is not opened as MapInfo table the selection of Consequence dialog from the menu item terminates the MNSS application.

[MAY 7: SYMPTOMATIC OF THE APPLICATION NOT BEING INTEGRATED, BJ]
[MAY 23: APPLICATION INTEGRATION NO LONGER REQUIRES THE TEMPORARY FILE "GUMBY.TAB", BJ]

When the Test "Gummy" browser is loaded clicking the Consequence dialog menu item displays **Please locate default file CONSCOST dialog box.**

[MAY 7: PROGRAM WILL BE CORRECTED TO POINT TO THE \MNSS DIRECTORY WHERE SYSTEM FILES CAN BE FOUND, BJ]
[MAY 23: PROGRAM NOW POINTS TO THE CORRECT FOLDER AND A USER WILL ONLY BE PROMPTED IF THE FILE IS MISSING, RENAMED BY ACCIDENT OR CORRUPT, BJ]

<u>Please locate default file CONSCOST dialog box</u>

- used to displays workspace files,
- has proper file filter (*.xls),
- displays all files with . xls extension in a drop down list box.
- OK and CANCEL buttons are working.

After selecting conscost.xls files in the Please locate default file CONSCOST dialog leads the display of Consequence Type dialog.

<u>Consequence Type dialog box</u>

- Displays a dialog box with 10 consequence type check boxes.
- Select All button,
- Select None button,
- Costs button,
- OK, CANCEL, and HELP buttons.

When no Consequence type is checked Select None and OK buttons are disabled.
When all Consequence types are selected Select All button is disabled, OK and Select None buttons are enabled
OK, CANCEL and HELP buttons are functioning properly
Cost button leads to the display of Costs table dialog, which is also accessible through menu-item 7.

<u>MenuItem 7</u>: Costs Dialog

This menu-item enables the display of Costs table dialog. The cost table dialog is contained with one 8 columns by 11 and one 3 columns by 9 rows consequence costs(CAN$1000) read-only tables. It also has:

- Other Costs button,
- Other Mags button,
- OK, CANCEL and HELP buttons.

Other Costs and Other Mags. Buttons allows the user to select and display other cost files with file extension .xls from a dialog called open.

[MAY 7: THE OTHER COSTS AND OTHER MAGS BUTTONS ENABLE A USER TO OPEN A USER-DEFINED SET OF COST AND MAGNITUDE PARAMETERS, BJ]

<u>MenuItem 8</u>: Accident Dialog

Accident type dialog box is contained with 13 radio buttons for selection of a ship type, 9 check boxes for casualty types and 3 radio buttons for unit of measure.
A user can choose only one ship type, maximum of 3 casualty types and one unit of measure. This dialog box also has a button for display of Cause dialog, which is also accessible through menu-item 9.

The help file attached to this dialog is very misleading. 9 check boxes for casualty types are replaced by radio buttons. This needs to be fixed.

[MAY 7: THE HELP FILE WILL BE UPDATED, BJ]
[MAY 23: HELP FILE COMPLETED, BJ]

<u>MenuItem 9</u>: Cause Dialog

This menu-item enables the display of Casualty cause table dialog. The dialog box is contained with a read-only table of size 9 rows by 10 columns, and 4 buttons:

- Other Source,
- OK, CANCEL and HELP buttons.

<u>MenuItem 10</u>: Modify Rates

A user can modify accident rates of the 3 selected accident type in the accident dialog box. The user inputs values between 0.1 and 10 is acceptable.
The modify rate dialog box a consequence multiplier group box which contain two group boxes with 4 radio button in each of them.

Loss Potential Group box has 4 radio buttons:

- Higher (x 1.5)
- average (no change)
- Lower (x 0.5)
- User defined

Spill probability Group box has 4 radio buttons:

- Higher (x 1.5)
- average (no change)
- Lower (x 0.5)
- User defined

Higher (x1.5) is selected as default setting.
When User defined radio button is selected an edit box becomes enabled to accept user input.

[MAY 7: AVERAGE (NO CHANGE), WHICH HAS A MULTIPLIER OF 1 IS NOW THE DEFAULT SETTING, BJ]

<u>MenuItem 11</u>: Exit MNSS

This command removes the MNSS from the menu-item before closing opened workspaces.

In general, these functional module seems designed in accordance with the specification. One of the major problems seen in this application is that whenever a letter in a menu-item is underlined, implies the function can be invoked not only by mouse click but also by a key strokes from the key board. None of the menu items are mapped to key board strokes.

[MAY 7: I DON'T KNOW WHY THIS DID NOT FUNCTION PROPERLY. IT DOES FUNCTION CORRECTLY ON THE PROGRAMMERS COMPUTERS. ALT + S CALLS THE MAIN MENU MNSS, AND JUST THE LETTER CALLS ALL SUBORDINATE MENUITEMS CORRECTLY. PLEASE CHECK, BJ]

MNSS1 terminates without notifying the user whenever Consequence Dialog, Accident Dialog and Loss potential maps menu-items are selected before loading the Test "Gummy" browser. No application should terminate by menu-items other than Exit command.

[MAY 7: THE PROJECT DEFINITION FILES HAVE BEEN INTEGRATED AS PROJ_DEF.TAB. INTEGRATION OF THE MNSS APPLICATION RESOLVES THE INTER-DEPENDENCY ISSUE NOTED ABOVE, BJ]

3D effect on display of elements of the Casualty Cause and Costs tables are not designed as shown in the design document.

[MAY 7: THE INTENT OF THESE DIALOGS WAS TO DISPLAY PARAMETER INFORMATION. IF A USER WISHED TO USE OTHER PARAMETERS, THESE XLS FILES CAN BE SELECTED IN THE DIALOG. A GREYED TEXTBOX CONTROL IS NOT AS VISIBLE AS A NORMAL LABEL CONTROL WHICH IS NOW USED, BJ]

1.2 MNSS2

This module shows the following menu items after loaded in MapInfo

Screen mode…
Detailed Mode
  Scope definition..
  LOS Pre-processor
Track plotting
  New Track
  Process Track
99.9% Plotting
  Open Chart and Track
  Buffer Track

Casualty maps
Loss potential map
Project Tables

The menu items in ***Bold-italic*** are not implemented in MNSS2 sub-module.

In MNSS2 module only the Scope definition menu-item is implemented.

When this menu-item is selected, a dialog box appears to enable the user to input or select a waterway, accident frequency and consequences analysis. In the current version, only waterway selection button is working.

> **[MAY 7: SCOPE DEFINITION WINDOWS FOR BOTH SCREENING AND DETAILED MODES AND THE WATERWAY WINDOW WERE IMPLEMENTED. THE CURRENT VERSION OF INTEGRATION WILL BE EASIER TO TEST FOR THE FUNCTIONALITY OF THE SCOPE DEFINITION CALLS TO ALL THE SUBORDINATE WINDOWS, BJ]**

May 8, 1997

From: Zebene
Enfotec Tech. Services. Inc.

<u>TEST RESULT on May 7 Version</u>

Although this version is well integrated, there are some problems related to unexpected termination of the MNSS from MapInfo program.

Here are some of the examples of operations where MNSS terminated unexpectedly:

1. Clicking on temp Consequence Dialog before doing any analysis using other menu-items.
2. Clicking on temp Cost Dialog before doing any analysis using other menu-items.
3. Clicking on temp Cause Dialog before doing any analysis using other menu-items.

'TEMP' MENUITEMS ARE REMOVED. THEY WERE TEMPORARILY IN PLACE FOR USE BY AXYS ONLY.

1. After getting check marks on the three main menu-items on Screen Mode dialog, Project definition browser table displays.

   - If consequence menu-item is selected MNSS again disappears from the MapInfo menu-item (terminates unexpectedly).
   - If we click screen mode again a dialog box with DISCARD and CANCEL displays, If we select CANCEL , "MNSS Analysis Aborted" message box disappears. It seems to me that CANCEL should return to analysis state prior to clicking the Screen mode menu-item.

RESOLVED BY SEQUENCING THE SELECTION OF FUNCTIONS BY A USER SUCH THAT PREREQUISITE SELECTIONS AND FILES ARE COMPLETE.

Noamrpoa.Tab file can not be found in casualty directory.

My suggestion to solve problems 1-4 is to disable menu-items which are not applicable at each stage of analysis and enable whenever the input data is available for execution.

SEE ABOVE COMMENTS. RESOLVED BY REMOVING THE TEMPORARY MENUITEMS AND SEQUENCING THE SELECTION OF FUNCTIONS BY A USER SUCH THAT PREREQUISITE SELECTIONS AND FILES ARE COMPLETE.

2.0 Test result on version of May 16, 1997

The following sub-menu-items are available after MNSS is run as MapBasic program in MapInfo.

Screen Mode….	
Detailed Mode	> Scope definition
	> LOS Pre-processor
Track Plotting	> New Track
	> Process Track
99% Plotting	> Open chart and Track…
	> Buffer Track…
Casualty Maps…	
Loss potential Maps	
Project tables…	
Exit MNSS	

Functionality test

Screen Mode :

Full functionality of this menu item can not be tested because Canso_proj_Level1CasualtyRate.Dat file could not be found. MNSS terminated abnormally. However, the main dialog, Scope Definition : Screen Mode, is designed in accordance with the specification.

ERRORHANDLER IMPLEMENTED TO WARN USER IF FILE IS MISSING, RENAMED OR CORRUPTED.

The waterway button enables to display waterway dialog where the user selects

- study area waterway,
- Time period and
- representative waterway.

Accident button enables to display accident and vessel types dialog where the user selects

- one ship type by clicking a radio button,
- up to three casualty types and,
- a unit of measure.

Consequences button enables to display Consequences type dialog. The user can select none, up to 10 or all the 10 consequence types listed in the dialog box.

Remark: conscost.xls file is not placed in the right subdirectory. It is difficult to locate this file easily**.**

RESOLVED BY CORRECTING PATH TO THE CONSCOST.XLS FILE.

Detailed Mode > Scope definition:

Full functionality of this sub-menu-item also can not be tested because Canso_proj_Level1CasualtyRate.Dat file could not be found. MNSS terminated abnormally attempting to run in the absence of Canso_proj_Level1CasualtyRate.Dat file. However, the main dialog, Detailed Mode :Scope definition, is designed in accordance with the specification.

ERRORHANDLER IMPLEMENTED TO WARN USER IF FILE IS MISSING, RENAMED OR CORRUPTED.

Detailed Mode > LOS pre-processor:

Functionality of this sub-menu-item can not be tested since no macro, RunXla, is available in the MNSS package.

MNSS terminated abnormally attempting to run in the absence of RunXla macro.

CRYSTAL BALL MUST BE INSTALLED IN ORDER TO USE THIS FUNCTION IN MNSS.

Track Plotting > New Track

This sub-menu-item works properly.

Track Plotting > Process Track

This sub-menu-item works properly.

99% Plotting > Open chart & Track…

This sub-menu-item works properly.

99% Plotting > Buffer Track

This sub-menu-item works properly.

Casualty Maps

Can not be fully tested because of absence of field ETYPE of table Noamrpoa.

PROBLEM IS THAT THE DIGITAL CHART OF THE WORLD FILE FOR NORTH AMERICA WAS NOT TRANSFERRED TO ENFOTEC.

Loss potential maps

Bio_reso.wor and Hum_reso.wor files could be displayed. Ns_bio,wor, Ns_canso.wor and Ns_geo.wor files could not be displayed because of absence of S_canso.TAB file.

PROBLEM IS THAT THESE FILES WERE NOT TRANSFERRED TO ENFOTEC.

Project Tables

This sub-menu-item works properly.

Exit MNSS

MNSS does not exit properly with this sub-menu-item. Exiting an application implies closing all files associated to it and terminate the process of execution. Clicking Exit MNSS sub-menu-item stops MNSS from running in MapInfo, but all files associated to it remain opened in MapInfo.

FIXED SO THAT ALL TABLES ARE CLOSED AND A USER IS PROMPTED TO CLOSE ANY TABLES THAT HAVE UNSAVED EDITS.

APPENDIX C: MNSS REQUIREMENTS SPECIFICATIONS

CONTENTS

1.0 Understanding the Possibilities

The first tasks of the project focused on understanding the current approaches to analyzing the level of risk or service in a waterway. This led to the development and testing of a key component of an improved TNSS which should now be called a Marine Navigation Safety System or MNSS as it applies to all vessels. This component was developed to a working stage in Task 2 as a pre-processor. The next step is to design the MNSS software CORE RISK ANALYSIS functionality.

2.0 Requirements Definition

The software requirements definition is produced in the form of a Requirements Specification Document. This document will be combined with preliminary and detailed design documents as these documents are developed to form the Software Development Plan. This document outlines a clear definition of the intended software product for which a preliminary software design document can be produced. It covers requirements such as: user, functional, ergonomic, operating system, memory, speed, storage capacity, off the shelf software etc. This document is produced for TDC input and approval and will guide the project team through the next design stages.

2.1 User Profiles

Various potential user profiles are described below in alphabetical order. Also included are profiles of Marine Navigation Services and the Transportation Development Centre who guide the current development and will be users upon completion of the MNSS tool. These profiles show how the MNSS could be applied in various government departments, private organizations and users.

2.11 Marine Communications & Traffic Services

On-going developments of an information system called INNAV (Information System on Marine Navigation could benefit by the development of a front-end desktop system such as MNSS for risk analysis.

2.12 Marine Navigation Services

Their functions involve establishing guidelines for aids to navigation for vessels. They are involved in defining the Level of Service for waterways which involves the analysis of weather, operations, user needs, threat rating, design, and risk analysis The present development of a LOS pre-processor will help with the measurement of risk in a waterway under various options for risk reduction.

2.13 National Search & Rescue Secretariat

This potential user of MNSS actively uses MapInfo to analyze trends in rescue operations on land, sea and air, however, much of their activity involves the analysis of marine search and rescue incidents. MNSS could help with the quantification of response times and the spatial comparative analysis of demand for services.

2.14 Rescue & Environmental Response

Rescue and environmental response resources must be sufficient to respond to marine emergencies in Canada. These potential users must establishment of guidelines for emergency response schedules, allocate resources and define response capabilities. They use MapInfo and Access to maintain oil spill information, however, these and other risk management functions could be augmented by the use of a MNSS tool for risk analysis.

2.15 Ship Operators, Pilots, Port Corporations, Spill Response Facilities

Ship operators, pilots and other risk managers are tasked with the test-bedding of new marine technology whenever decisions are made to purchase new equipment. Route planning and scheduling and ship management involves choices of efficiency and risk minimization. The balance of these choices contribute to decisions to use modern double-hull ships or perhaps aging single-hulled tankers; tight schedules in uncertain weather conditions, etc. The use of MNSS would help quantify the uncertainty in affects of ship type, equipment fit, weather, training on overall risk.

2.16 Transportation Development Centre

TDC has a key role in the development of innovative technology to the benefit of Canadian transportation systems, their competitiveness and safety. As TDC is involved in a wide range of Canadian and international projects, they are strategically networked to have each initiative learn from others. This broad experience can provide confidence to stakeholders who might be impacted by policy change. The TNSS and now MNSS development can assist with policy analysis and risk communication.

2.17 Transportation Safety Board

The role of TSB is to advance safety in the marine, commodity pipelines, rail and air modes of transport. They investigate individual marine accident cases and provide summary statistics of marine occurrences. These annual summary reports would greatly be enhanced by the use of thematic maps, pie charts, and accident locations overlaid on nautical charts. This functionality is a key aspect of MNSS and TSB has no Geographic Information System capability.

2.18 Transport Canada Economic Analysis Directorate

They are responsible for monitoring and analyzing trends in historical traffic and commodity flow data across different types of marine and surface modes. Their work involves uncertainty and has a major geographic component. Geographic display of traffic and commodities and the use of Monte Carlo simulations to quantify uncertainty would aid in their modeling and analysis tasks.

2.2 User Requirements

2.2.1 MNSS Overview

This section provides an overview of how a Marine Navigation Services might use MNSS to help resolve a policy question (refer to Figure 1).

The User will have a Question with respect to a Waterway(s) [i.e. data base might be organized by waterway and user could pick specific waterway, several waterways or all waterways]. For this project, the question is defined as several scenarios designed to compare the effects of the introduction of ECDIS and the removal of some redundant aids to navigation in the Strait of Canso.

The User will proceed by making choices or selections in a MNSS “dialog” (by selecting the Waterway and data available in the Core or alternatively by inputting the information). These choices will provide input on:

- Waterway Characteristics - turns, length, port berths, weather, name etc.
- Traffic by Category (number per year)
- LOS for Waterway (includes visibility, conventional NavAids by Category, channel width, etc.)
- Loss Potential; People, Special Dangerous Goods, Environmental, Fishing, Economics [all in terms of very general scale of: Average, Above Average, or Below Average]
- Level of Response; oil clean up, rescue vessels, ice breakers, etc.

These inputs will allow the Core program to estimate the Risk Frequency and the Risk Consequences in a "Screening" mode using "conservative" assumptions about the vessel characteristics, distribution of vessels in a Category, etc. The Core program will report the risks as follows:

Accident Frequency

- Level 1 reporting by Casualty data base (e.g. Grounding, Striking, etc).
- Level 2 reporting by Casualty type a list of "reported causes" e.g., Position fixing error, collision rules violation, failure to observe vessel in close quarters, failure to observe or determine ice type, shiphandling error, engine or screw failure, steering failure, total power failure etc.

Risk Consequences

- Level 1 reporting by number of People injured, number of People dead, Environmental damage, ship losses, cargo released, etc. by casualty type.

- Level 2 reporting giving the proportion of the Total loss by requested Accident Frequency such as by casualty type, cause group and accident costs.

It is noted that the risk consequences are not linked in a one to one way with Accident Frequency since release of cargo causing environmental damage may be due to multiple casualty types. Therefore, consequence types will be reported by casualty type. There are also available from the core program the probability of a release, and other intermediate results that may or may not be required

At this point the User has a "screening" risk estimate and the User may also have a comparison between the standard Core output (for the given Inputs for the Waterway) and the Casualty record for the Waterway [the Core may also extract this from the data] the User can then compare these and decide:

1. no problem or question answered and write report,
2. more analysis is needed and return to a preprocessor or estimate otherwise the impact of the proposed policy, or
3. go forward to a Stakeholder Dialogue if this is required. If the Stakeholder Dialogue is required it may result in
    - more analysis being needed, or
    - acceptable answer— proceed to a report/implementation/etc.

In all cases the Core accident frequency results are given as a range which is ± __%[1]. For example, a grounding rate of 1.0 x 10-4 ± 50% provides a measure of the range in the estimated risk which is chosen by the user as an output requirement. In addition the results will normally be given both as the annual risk, the return period, per ship per mile or per movement, e.g., 1.0 x 10-4 ± 50% per year, or, every 10,000 years.

In the Advance Mode, the user continues to repeat the basic cycle of:

1. Core analysis
2. Assessment of question and Core results (in terms of impact, sensitivity, or importance) to see if more information needed on either;
    - risks, or
    - stakeholders' views

Additional analysis or dialogue as required until satisfied with answer.

[1] The min and max range is taken as plus or minus 50% of the average casualty rate for the sample.

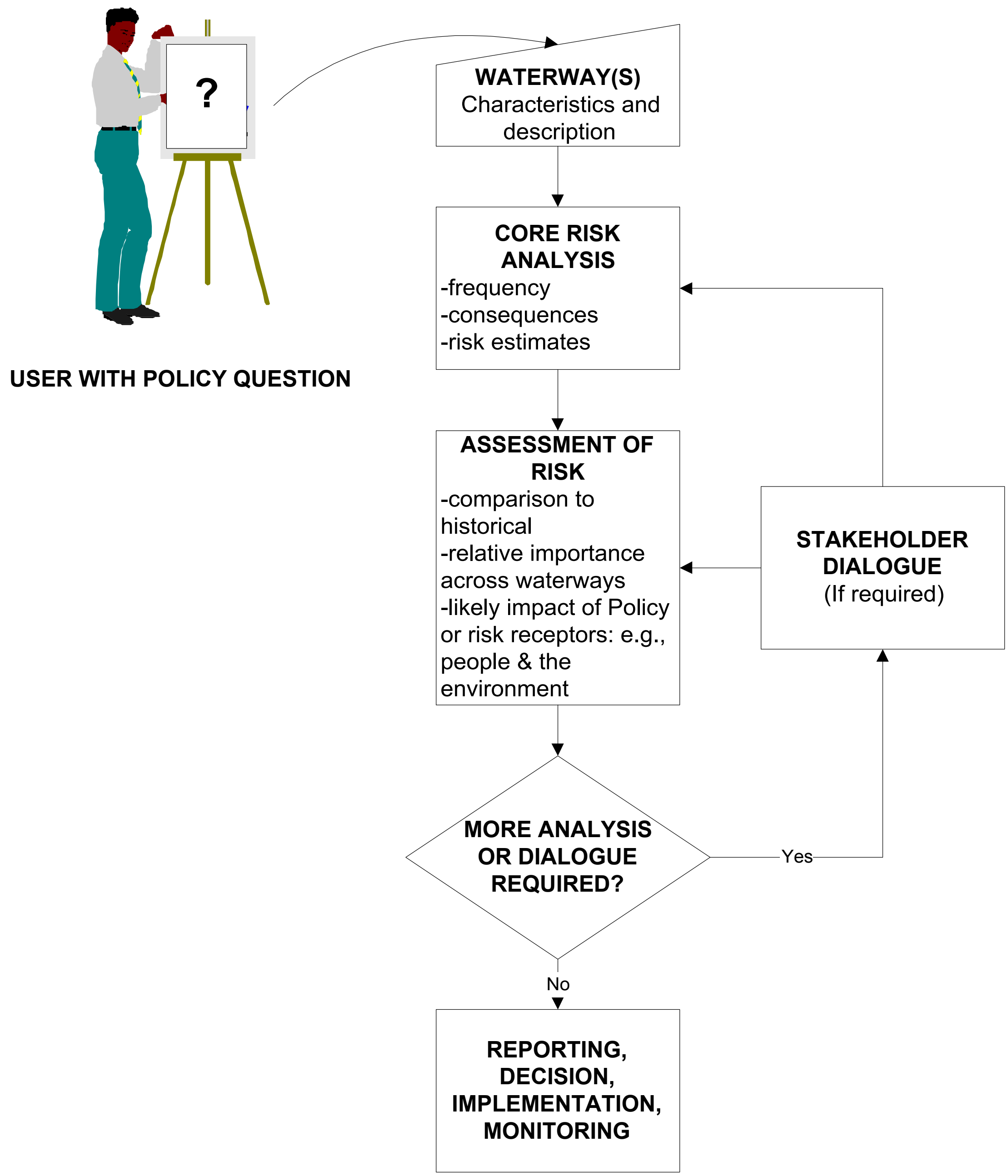


Figure 1 Typical analysis of a policy question

2.2.2 MNSS major modules

MNSS should operate in two modes: Screening and Advanced (see Figure 2). A screening mode is used to conduct a quick conservative risk analysis which can help identify where further in-depth analysis or stakeholder dialog is required. The screening mode uses historical accident frequency data, consequence estimates and a users understanding of the waterway system to prepare a screening risk analysis. The user is guided through the process with dialogs. The advanced mode is applied where further analysis is warranted. In this mode, accident rates can be modified through the use of a pre-processor which analyses "what-if" scenarios designed to increase safety. In the "99.9% LOS pre-processor, a measure of safety is an output which can be used to modify target accident rates (e.g., groundings, collisions and strikings caused by position determination or watchkeeping errors). As in the TNSS program, loss potential is measured and linked to specific casualty types. In MNSS, it is also linked to casualty cause because increased safety due to aids to navigation or ECDIS does not reduce all accident risk (e.g., groundings due to steering or engine failure). Requirements specifications are summarized in Table 1.

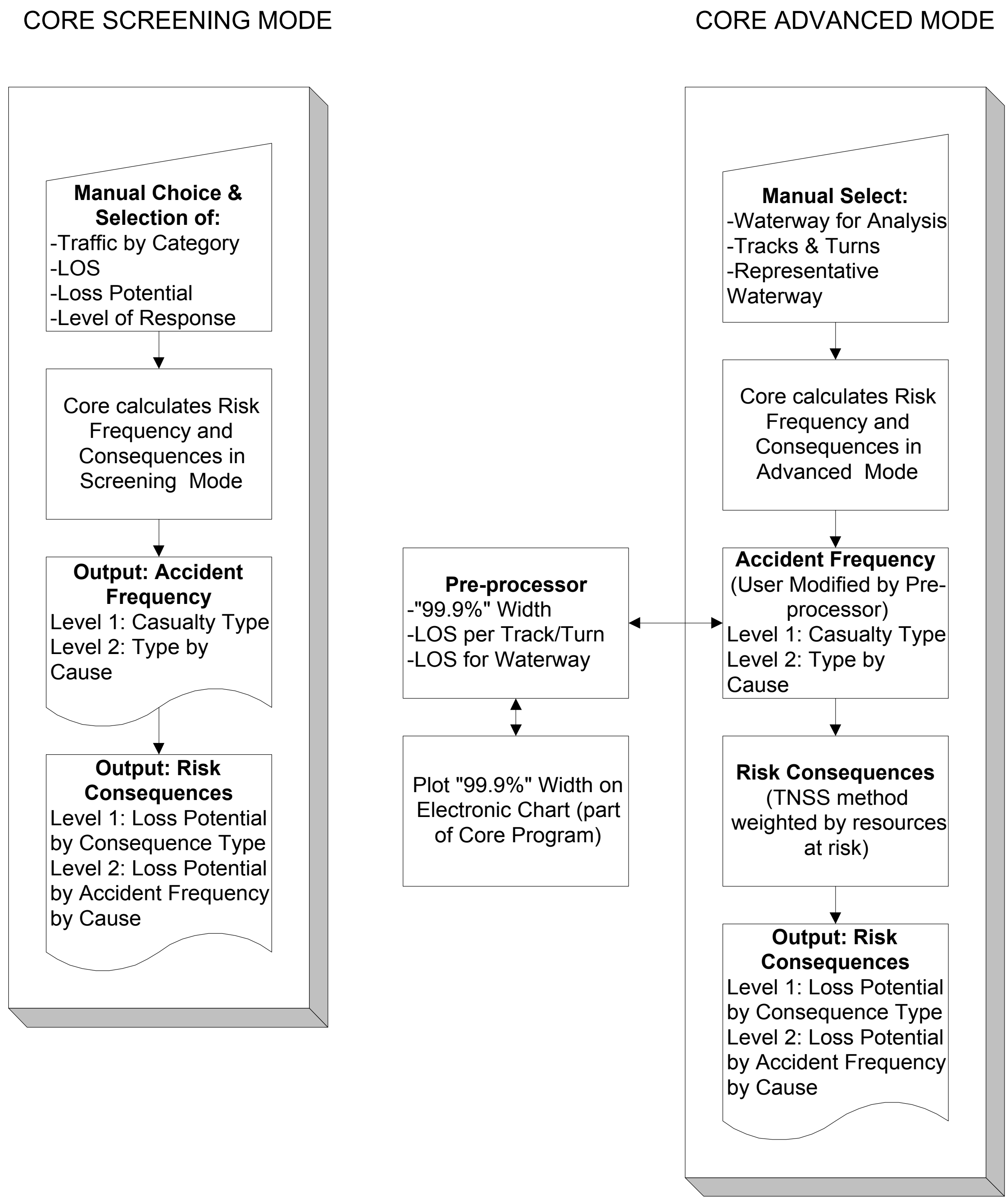


Figure 2 MNSS Core and preprocessor

Table 1 Requirements specification

Requirements and Functional Specifications Cross-reference

Requirement Number	Requirement Type	Description	Functional Specification Reference
1.1	OS	Windows NT 3.51+ or Windows 95+ (32bit)	Proposal
1.2	MEMORY	16mb OS RAM	
1.3	SPEED	100mhz Pentium CPU	
1.4.1	STORAGE	24 mb for MapInfo	
1.4.2	STORAGE	13 mb for Excel	
1.4.3	STORAGE	3 mb for Crystal Ball	Proposal
1.4.4	STORAGE	3 mb for TNSS 2.0	
1.4.5	STORAGE	50 mb for data (rough estimate based on TNSS)	
1.5.1	SOFTWARE	MapInfo 4.1 32 bit (One user licence and one upgrade supplied)	Proposal
1.5.2	SOFTWARE	Crystal Ball 4.0A 32 bit (One licence supplied)	Proposal
1.5.3	SOFTWARE	Excel 5 or 7 (Excel 7 for 32bit) (Required, but not provided)	Proposal
1.6.1	ERGONOMIC	Mouse	
1.6.2	ERGONOMIC	16+ bit video colour for optimum colour depth of electronic charts	
2.1	USER	Assist with a quantitative analysis of the effectiveness of a mix of conventional aids to navigation and ECDIS	Jan 31st LOS Design Doc., LOS Preprocessor
2.2	USER	Assist with the communication of the results of policy analysis	Common 2.1
2.3	USER	Enable assessment of acceptable risk by providing $value risk estimates, annual frequency, comparisons, simple language, and user input	Common 2.1, 3.4.1, 3.6.1 & Annex A
2.4	USER	Level of risk in a channel be related to LOS A, B, C	Jan 31st LOS Design Doc., LOS Preprocessor provides risk multiplier where C = 1
2.5	USER	Output in various tabular, graphical and map formats	Common 3.1
2.6	USER	Positioning accuracy values assumed to be practical without requiring further assessment for the project	Jan 31st LOS Design Doc., LOS Preprocessor
2.7	USER	Risk analysis should consider the marginal effects of buoys, ranges and their interaction	Jan 31st LOS Design Doc., LOS Preprocessor
2.8	USER	Uncertainty must be clearly presented	Common 2.1, 2.3.1
2.9	USER	Use threat rating guide values for navigation weather risk thresholds	Jan 31st LOS Design Doc., LOS Preprocessor
2.10	USER	Use threat rating guide values for passing clearance	Jan 31st LOS Design Doc., LOS Preprocessor

Requirement Number	Requirement Type	Description	Functional Specification Reference
3.1	FUNCTIONAL	Core risk analysis estimates accident frequency and consequences	Common 5.0
3.1.1	FUNCTIONAL	Core enables user selection of waterways in advanced mode	Common 3.3
3.1.2	FUNCTIONAL	Core enables user plotting of tracks and turns in advanced mode	Common 3.1
3.1.3	FUNCTIONAL	Core calculates accident rates: per year, per vessel, per mile and years between	Common 3.4.2
3.1.4	FUNCTIONAL	Core calculates risk consequences (loss potential) weighted by resources at risk in advanced mode	Advanced 3.8
3.1.5	FUNCTIONAL	Core illustrates accident types	Common 3.1, 3.8
3.1.6	FUNCTIONAL	Core illustrates environment and resources at risk	Common 3.1
3.1.7	FUNCTIONAL	Core provides thematic map of accident types for each VTS zone for comparison (pie charts)	Common 3.1, 3.8
3.1.8	FUNCTIONAL	Core provides trend charts of accidents and traffic	Common 3.1, 3.8
3.1.9	FUNCTIONAL	Core provides tables of accident rates	Common 3.1, 3.8
3.1.10	FUNCTIONAL	Core provides maps of risk receptors or resources at risk (see RS 3.1.6)	Common 3.1
3.2.1	FUNCTIONAL	Core accident rates and loss potential adjusted by user input ranks (above average, avg. below avg. in screening mode dialog	Screening 3.2.2
3.2.2	FUNCTIONAL	Core accident rates adjusted by user input from change in LOS, other pre-processors, expert judgement etc in advanced mode	Advanced 3.8
3.2.3	FUNCTIONAL	Core enables plotting of 99.9% width on electronic chart in advanced mode	Common 3.9
3.3	FUNCTIONAL	Core outputs accident frequency and consequences loss potential by accident cause group (risk summary)	Common 3.4 to 3.7, Annex A
4.1	FUNCTIONAL	Pre-processor to calculate safe water requirement 99.9% for each track/turn	Jan 31st LOS Design Doc., LOS Preprocessor
4.2	FUNCTIONAL	Pre-processor to calculate LOS for each track/turn and aggregate (weight by length) as a risk multiplier	Jan 31st LOS Design Doc.

APPENDIX D: A COMPARISON OF WAMS AND MNSS PRE-PROCESSOR RESULTS

RISK ANALYSIS OF MARINE NAVIGATION AIDS

Comparison of WAMS and MNSS Results

IRR Report 33

May 27, 1997

Prepared for:
GeoInfo Solutions Ltd.

Prepared by:
John Shortreed and Diana Del Bel Belluz
Institute for Risk Research
University of Waterloo
Waterloo, Ontario
N2L 3G1

Project Administered by:
Barry Scott
Waterloo Research Institute
University of Waterloo
(WRI Award # 2618401)

Comments on this report can be directed to Diana Del Belluz at the following address:

Diana Del Belluz, M.A.Sc., P.Eng.
Executive Director
Institute for Risk Research
University of Waterloo
Waterloo, ON N2L 3G1
Tel. (519) 888-4567, ext. 5136
Fax. (519) 725-4834

Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

In December 1996, GeoInfo Solutions Ltd. was awarded a contract to develop a Risk Assessment software tool for the Transportation Development Centre and the Marine Navigation Services branch of the Canadian Coast Guard (CCG). The contract also required a case study application to Navigation Aids for Shipping in Canso Strait. GeoInfo Solutions Ltd. sub-contracted the Institute for Risk Research (IRR) to assist in developing the structure of the marine risk analysis model, to validate the model results and to test the software in terms of its risk analysis features.

This report "Comparison Of WAMS And MNSS Results", presents a comparison of the estimated minimum channel width required to provide safe navigation, under given conditions from the WAMS and MNSS Systems. The 99.9% Pre-processor of the Marine Navigation Safety System (MNSS) Model was used to calculated the MNSS results. The WAMS results were calculated from the data in Waterways Analysis Management System (WAMS) as published in the U.S. Coast Guard document "Short Range Aids to Navigation Systems Design Manual for Restricted Waterways" (Smith et al., 1985). A general description of the approach used to compare the two systems is provided in Section 2 with details of the calculation method in Annex B. Annex A contains a summary of the data and input values used to calculate the WAMS and MNSS results.

2.0 THE MNSS AND WAMS APPROACHES

2.1 The MNSS System

The 99.9% Pre-processor of the MNSS system calculates the channel width required to avoid incidents for 99.9% of all transits for a ship of a given category and size under specified conditions. The results of the MNSS pre-processor are expressed in terms of the channel width required to allow only about 1 in 10 000 transits having a risk of casualty due to the basic characteristics of the Channel, the Aids to Navigation and the waterway Regulations. The MNSS methodology estimates the 99.9% track width that is sufficient to allow 999 transits out of 1 000 to pass through the Channel without risk of standing into danger. It is assumed that only 1 out of 10 vessels that stand into danger will result in a casualty, i.e., giving a combined risk frequency
of a casualty of 1 in 10 000.

The 99.9% Pre-processor estimates the channel width by calculating and summing the width required for the following six independent factors:

A) Beam and Crab
B) Shiphandling
C) Position
D) Turn
E) Weather
F) Passing.

An example of the data entry screen for the 99.9% Pre-Processor's six independent factors is shown in Figure 1. This information is fed into a monte carlo simulation which produces a forecast range for the 99.9% track width as illustrated in Figure 2. The upper bound on the estimate is the value used as the MNSS result.

General Inputs	
Category	I
Vessel Beam (feet)	150
Vessel Length (feet)	1000
Displacement (GRT)	30000
Speed (Knots)	7
Bridge Experience Multiplier	1

Reset multipliers to default

Output (feet)	
Beam and Crab	474
Shiphandling	320
Position	420
Turn	0
Weather	238
Passing	300
"99.9%" (average)	**1752**

LOS	
Track/Turn Length (NM)	0.7
Channel Width (min)	1800
Input max 99.9 width	1500
LOS C	**0.83**

A	**Beam and Crab**	
	Crab Angle (degrees)	5
B	**Shiphandling**	
	Course keeping Width (feet)	160

		Day	Night	Poor Visibility	Conventional Ai
C	**Positioning Quality**				
	Conventional: Visual/Radar	300	300	330	Medium (danger buo
	Conventional & GPS	300	300	330	
	Conv. & ECDIS w. DGPS	180	180	210	
	Chart Accuracy	120	120	120	
	Best Position Accuracy	300	300	330	
	Next Best Position Accuracy	300	300	330	
	Positioning Quality (feet)	420	420	450	
	Navigation Conditions	Day			
	Sig. Visibility Hazard (NM)	<5.4			
	Poor Visibility Frequency (%)	30			

D	**Turn Paths**	
	Degree of Turn	0
	Turn Path Factor	1

E	**Weather**	(Manual Input from Weather Table and WX Data)			
	Reset to Default WX Freq.	1	A	B	C
	Level II Frequency (%)	100	190	27	21
	Level III Frequency (%)	0	0	0	0
	Environmental Sum	238	190	27	21
	Multiplier	1			

F	**Passing, overtaking**	Yes
	or crossing Traffic	300
	Passing Distance	300

Figure 1: Data Entry Screen of the 99.9% Pre-Processor

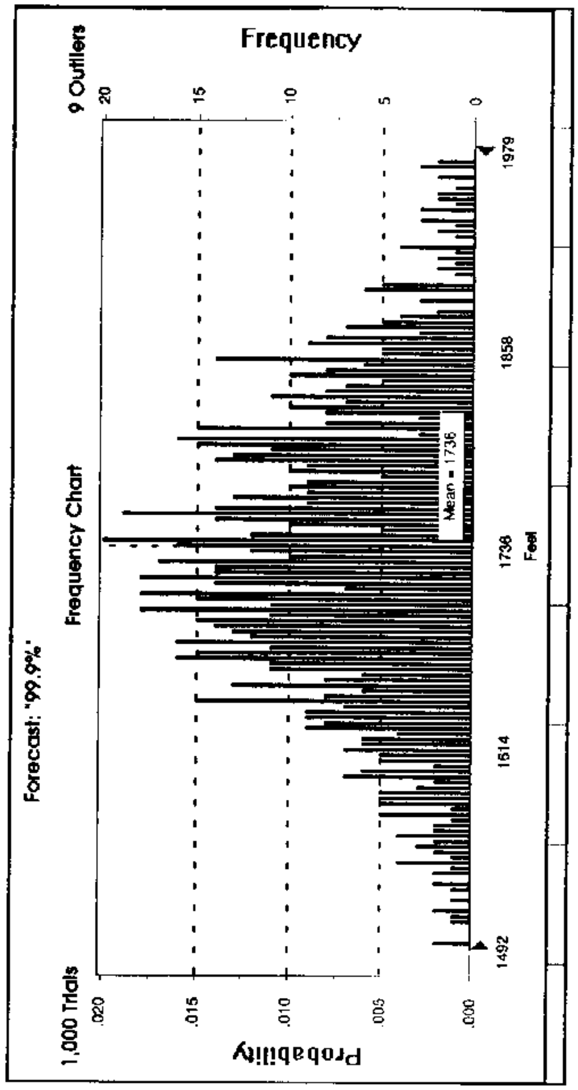


Figure 2: Forecast of the Required Track Width produced by the 99.9% Pre-Processor

2.2 The WAMS System

The following description of the Waterways Analysis Management System (WAMS) is paraphrased from the description in the U.S. Coast Guard document "Short Range Aids to Navigation Systems Design Manual for Restricted Waterways" (Smith et al., 1985).

‘The WAMS system provides a structured approach to system design and evaluation. It provides a measure of quality for candidate aid configurations, i.e., an assessment of relative risk.

> The WAMS system is the result of a project to examine and measure the relationships between aids to navigation and navigation performance. A series of controlled experiments was conducted to investigate vessel performance in response to varying levels of several environmental and aids to navigation variables. Most of the experiments were done using marine simulators, although significant at-sea data were obtained to help validate the findings. Specific variables studied included: aid number; configuration; spacing; type; characteristic; and radar presentation. External variable included: ship size; channel width; turn angle; wind and current; visibility; and meeting traffic.
>
> The methodology used in the WAMS study was to station experienced pilots in a life-size bridge mockup which displayed, in a conning officer’s perspective over a wide angle screen, various scenarios, representing different levels of the specific and external variables. The pilots were tasked with navigating vessels through these simulated waterways, while a computer recorded their performance. The primary performance measure was the cross track position of the ship’s centre of gravity with respect to the channel centreline. To verify the simulator’s ability to adequately represent real-life performance, at-sea data were collected from merchant vessels. Subsequent data analysis supported the simulator’s validity, lending credibility to the vast pool of experimental data.’

The results of the WAMS study provide an excellent source of data to assist in validating the 99.9% Pre-processor. Unfortunately, the comparison is subject to certain limitations of the WAMS data. For example, the sea trials were done with a group of ships of less than 45 000 dwt, and estimates for larger ships were obtained by using a scaling factor.

Annex B contains a description of how the "WAMS Results" (i.e., in terms of track width) were calculated in order to compare the WAMS data with the MNSS results.

2.3 Mapping the Parameters

Many of the six independent factors in the 99.9% Pre-processor are represented in the WAMS system, however, not always to the same level of detail. Also, some of the level of detail contained in the WAMS system (e.g., number and configuration of conventional aids) is not available in the MNSS system's 99.9% Pre-processor. Table 1 provides a descriptive comparison of the input parameters used to compare the results of the two systems.

Table 1: MNSS and WAMS Parameters

Parameter	MNSS (99.9% pre-processor)		WAMS	
	Present	input range	Present	input range
Beam (feet)	Yes		Yes	
Length (feet)	Yes		Yes	
Displacement (GRT)	Yes	not used	Yes	used to scale-up from standard ship size
Speed (Knots)	Yes	used in calculation of "Shiphandling" Component	No	
Bridge Experience Multiplier	Yes	used in calculation of "Position" Component	No	
Crab Angle (degrees)	Yes	continuous, range is 2.7° to 6°	Yes	2 categories: I = 0-2 degrees II = 2-5 degrees
Navigation Conditions	Yes	values include: day; night; poor visibility	Yes	values include: day; night; day or night; poor visibility
Sig. Visibility Hazard (NM)	Yes	Four choices: <0.5; <1.1; <2.2; <5.4.	No	
Poor Visibility Frequency	Yes	User can choose from 10-90% in increments of 10%.	No	
Conventional Aids	Yes	6 broad categories.	Yes	Preset configurations
Degree of Turn	Yes	continuous, range is 0° to 180°	Yes	values include: 0-20° degree <20°
Turn Type	No	used to calculate the turn path cross track distance	Yes	values include: cutoff; noncutoff
Weather	Yes	• Used as input to: "Beam and Crab", "Position", "Shiphandling" • Combination of: Wind Speed; Wave Height; Current Speed. Can specify percentage of each of 3 categories: I = light winds, etc. II = moderate winds, etc. III = strong winds, etc.	Yes	called "Environment", 2 categories: I = 0-2 degrees of crab II = 2-5 degrees of crab
F) Passing	Yes	If yes, user can specify number of feet to be added.	Yes	

3.0 RESULTS

3.1 Introduction

Key input parameters and the output (required track width for 600’ and 1 000’ ships) of MNSS and WAMS approaches are shown in tabular form in Annex A. Each row in the table in Annex A represents a unique case in terms of ship parameters, channel configuration, and environmental conditions in the WAMS study. The sample of cases was chosen to validate as many as possible of the MNSS parameters.

The results of the study are shown in graphical form in this section in Figures 3 through 8. Table 2 provides a description of the labels used in the figures in this section. The results (required track width in feet) are plotted with the WAMS results on the y-axis and the MNSS results on the x-axis. The same scale is used for each plot to assist in comparison of the various cases, e.g., passing, turn, straight/track, ECDIS. Each graph shows a "line of equality". Data points above this line are cases where the WAMS result is higher than the MNSS result. Data points below the line-of-equality are cases where the WAMS result is lower than the MNSS result.

Table 2: Legend for Chart Labels

Label	Case and/or Segment Type	Ship Size
ES-600	ECDIS - Straight (i.e., Track)	600’
ES-1 000	ECDIS - Straight	1000’
ET-600	ECDIS - Turn	600’
ET-1 000	ECDIS - Turn	1 000’
PS-600	Passing - Straight	600’
PS-1 000	Passing - Straight	1 000’
PT-600	Passing - Turn	600’
PT-1 000	Passing - Turn	1 000’
S-600	Straight	600’
S-1 000	Straight	1 000’
T15-600	Turn (15°)	600’
T15-1 000	Turn (15°)	1 000’
T35-600	Turn (35°)	600’
T35-1 000	Turn (35°)	1 000’

3.2 The Straight (Track) Case

Figure 3 shows the Straight (Track) results for 600’ and 1 000’ vessels.

For the 1 000’ vessel, there is good agreement between the WAMS and MNSS estimates, with most of the data points falling close to the line-of-equality. For the 600’ vessel, the WAMS results are lower than the MNSS results.

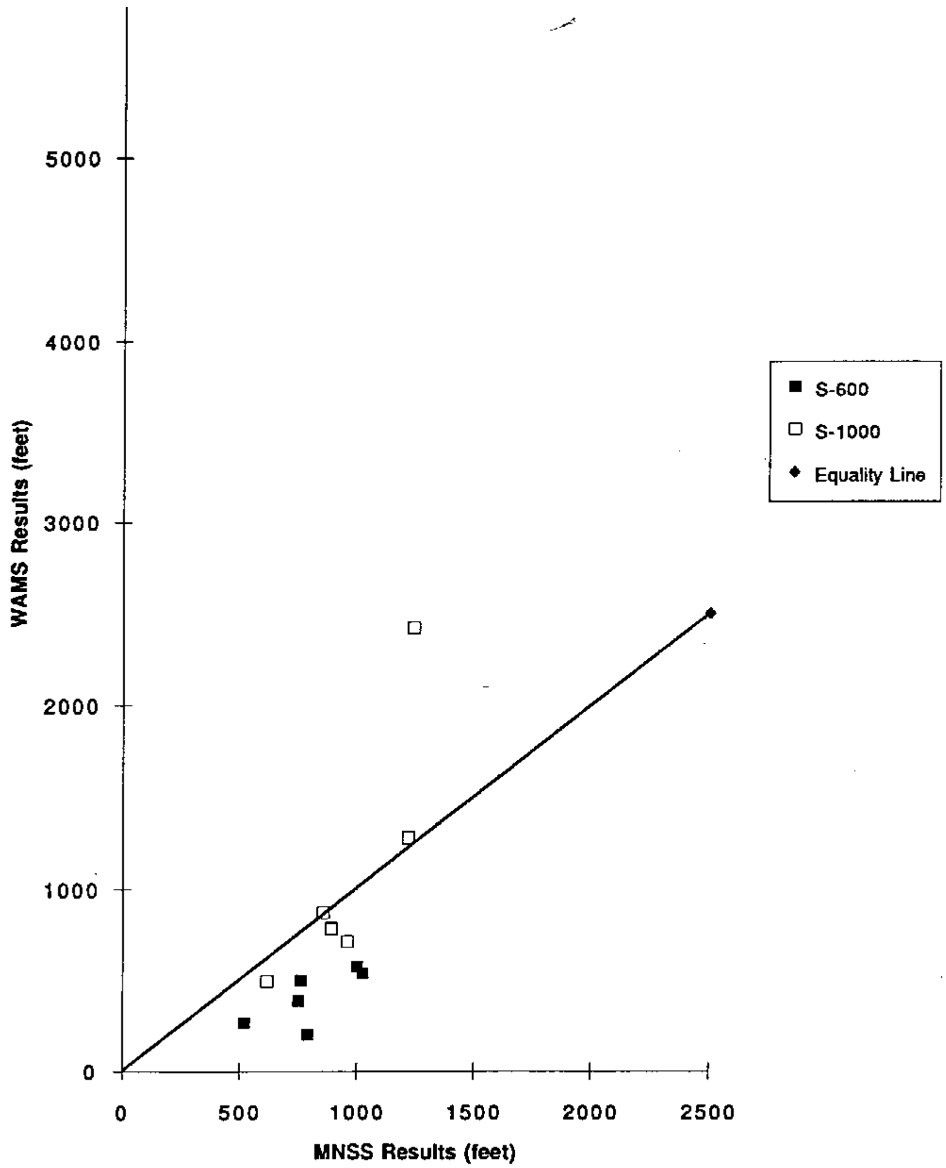


Figure 3: Straight (Track) results for 600' and 1 000' vessels

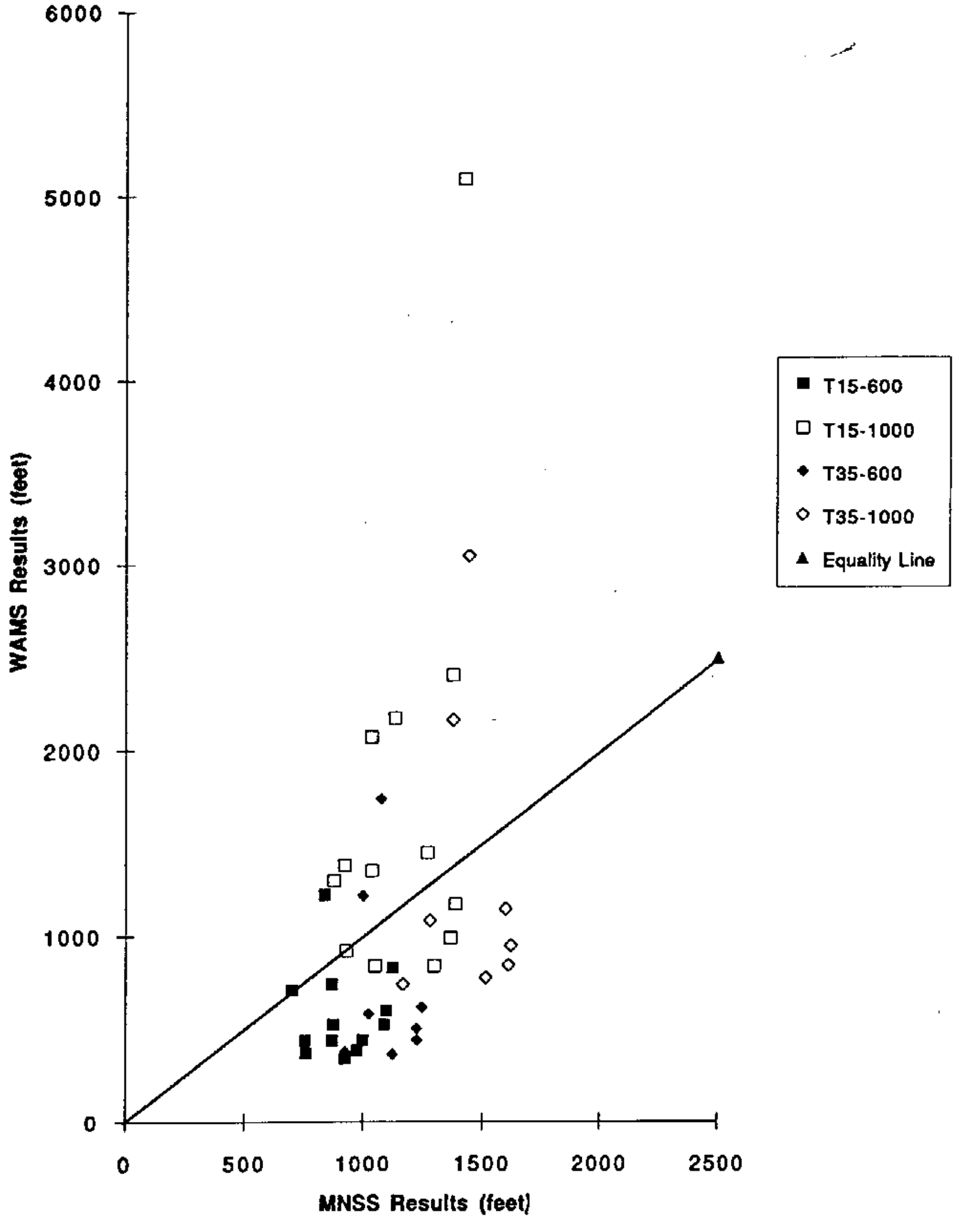


Figure 4: Turn results for 600' and 1 000' vessels

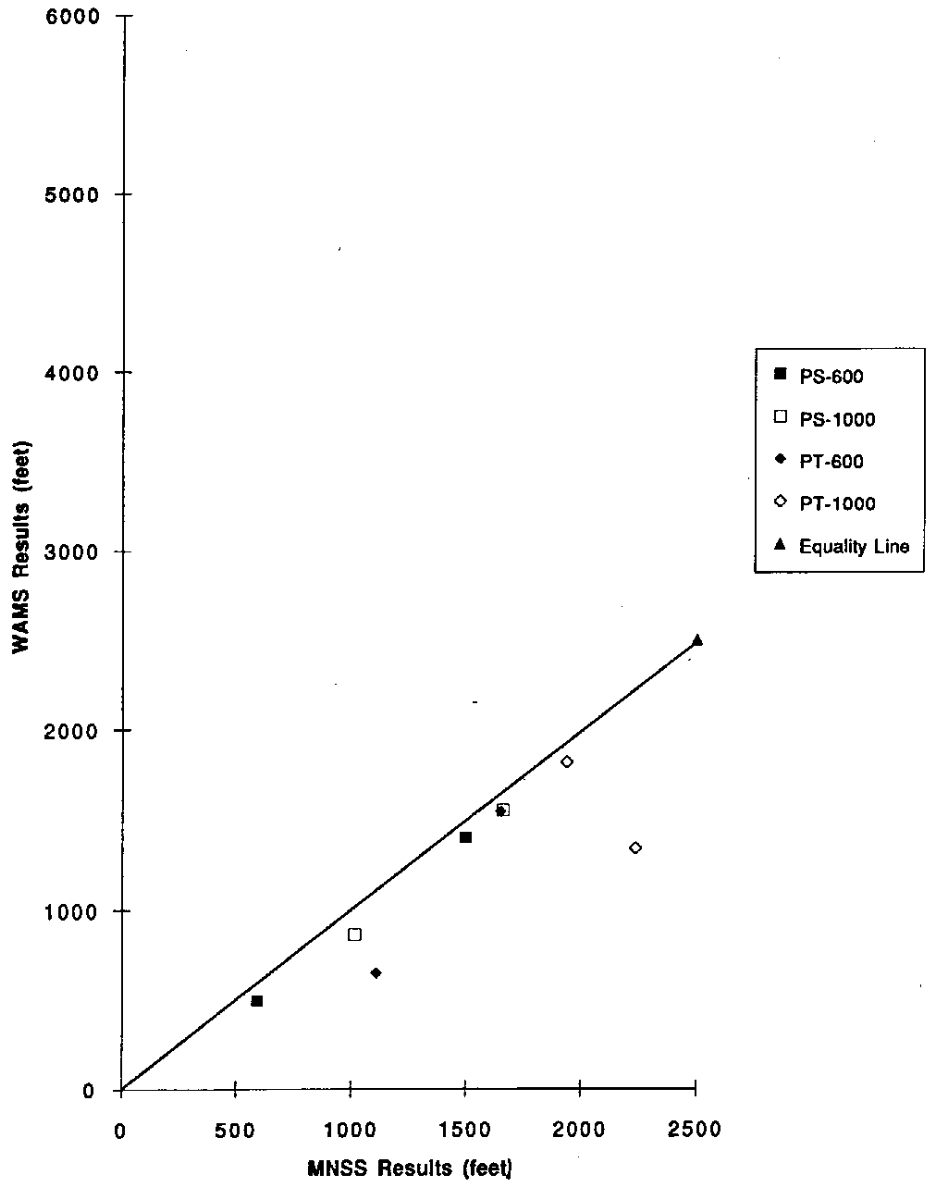


Figure 5: Passing results for 600' and 1 000' vessels

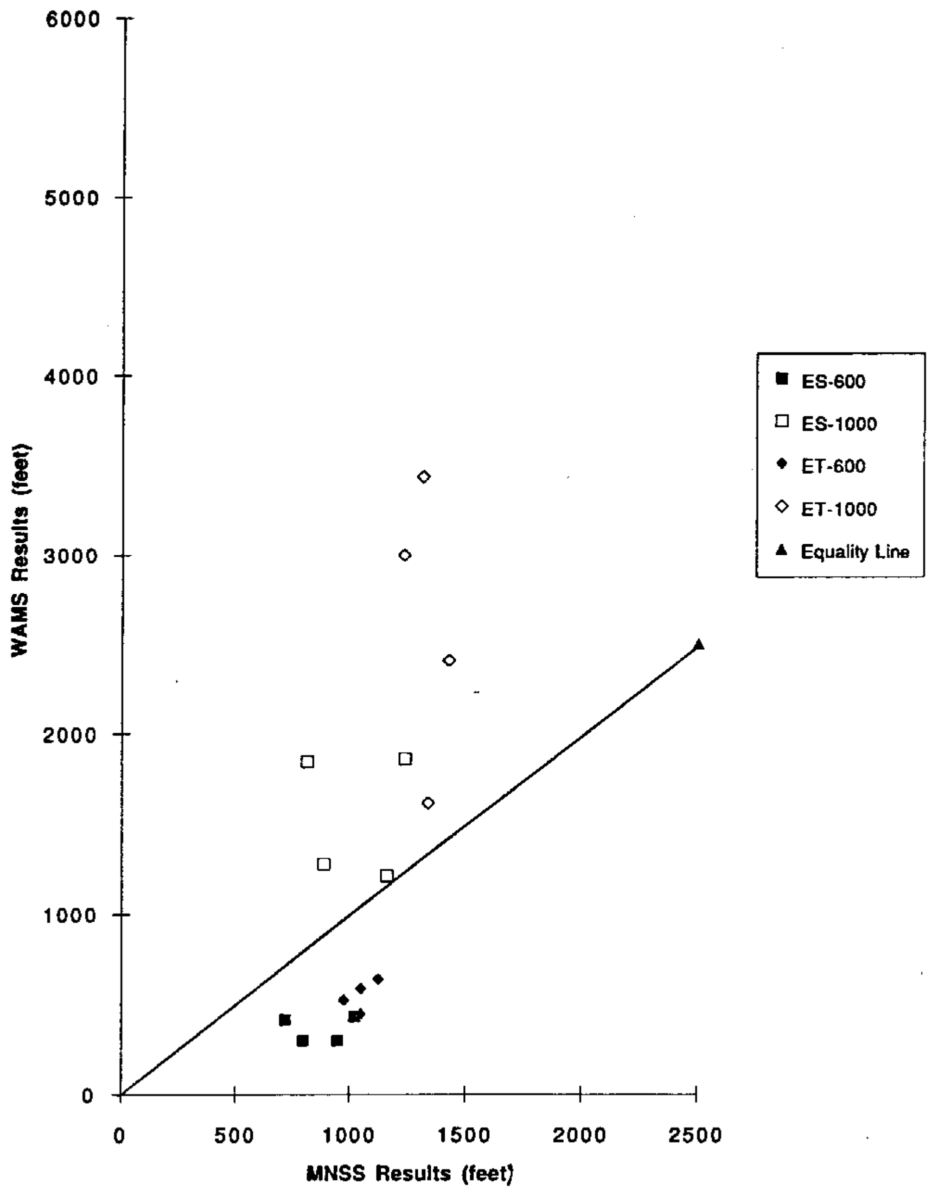


Figure 6: ECDIS results for 600' and 1 000' vessels

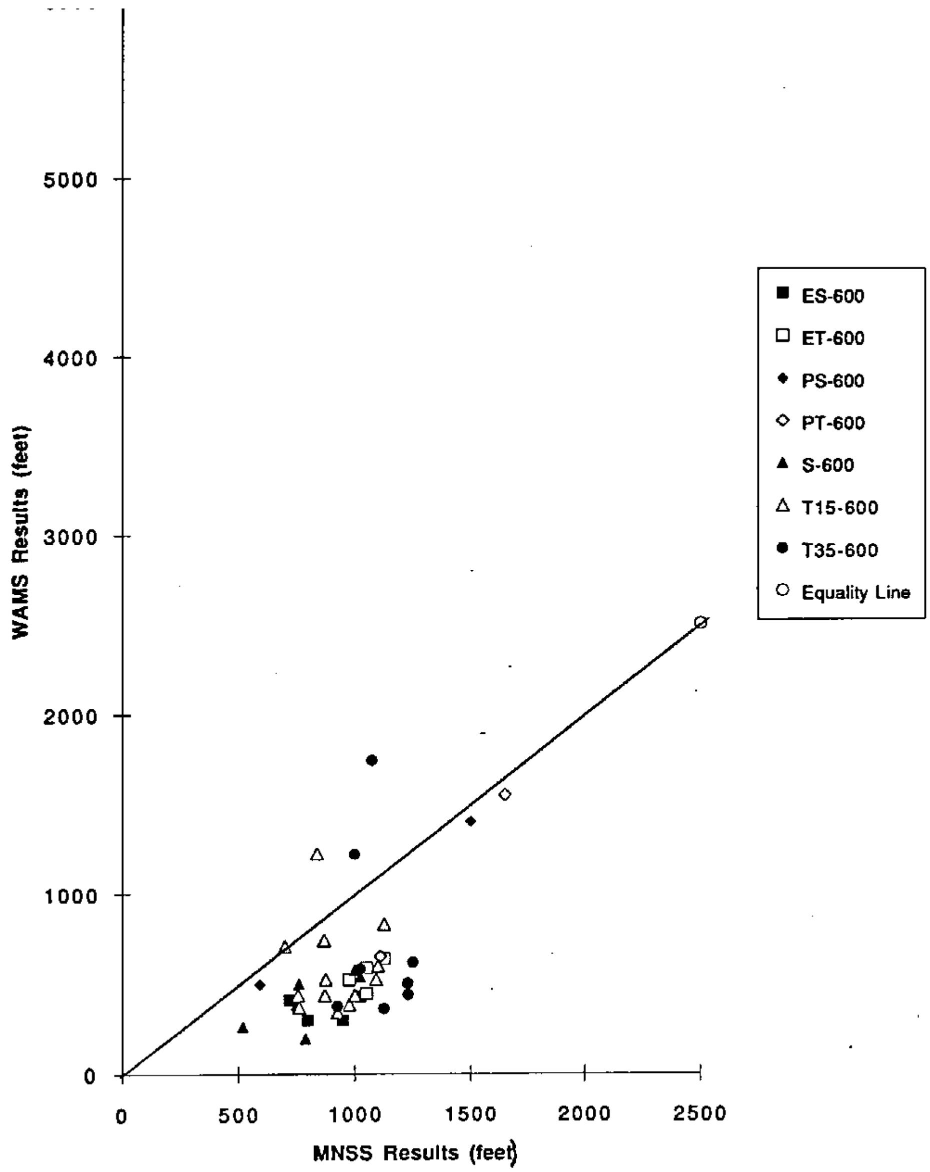


Figure 7: Results for all cases for the 600' vessel

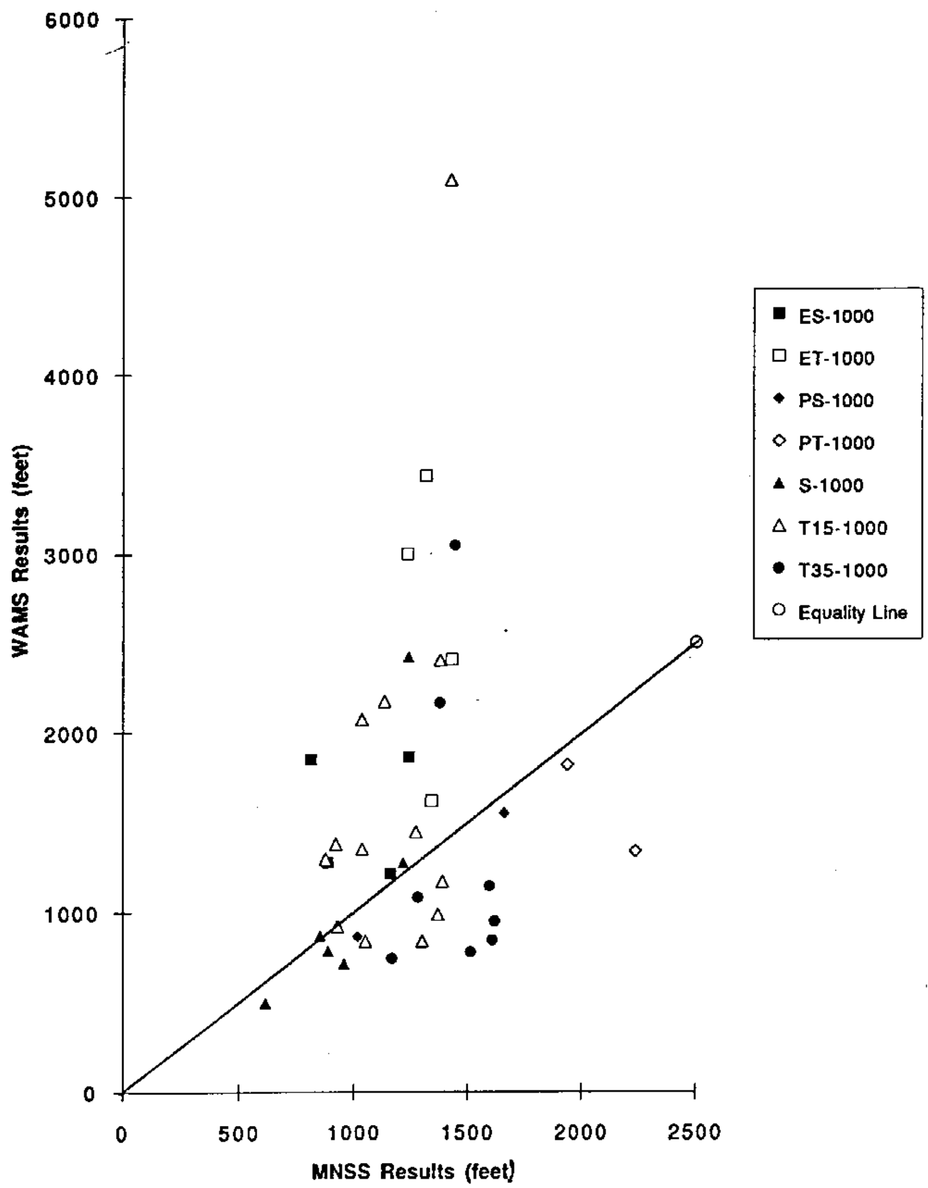


Figure 8: Results for all cases for the 1 000' vessel

3.3 The Turn Case

Figure 4 shows the Turn results for 600’ and 1 000’ vessels. The range of deviation from the line of-equality is very large, i.e., +100% to -50%.

For the 1 000’ vessel on the 35° turn, the MNSS results tend to be lower than the WAMS results. Whereas, the reverse is true for 1 000’ vessel on the 15° turn, i.e., the MNSS results tend to be higher than the WAMS results.

For the 600’ vessel, on both 35° and 15° turns, the MNSS results tend to be higher than the WAMS results.

3.4 The Passing Case

Figure 5 shows the Passing results for 600’ and 1 000’ vessels.

For both the 600’ and the 1 000’ vessel, there is good agreement between the WAMS and MNSS estimates, with most of the data points falling just below the line-of-equality.

3.5 The ECDIS Case

Figure 6 shows the ECDIS results for 600’ and 1 000’ vessels. It is noted that the WAMS data is for the best performance of "ECDIS-like" simulations. These ECDIS-like simulations were called "graphic display" (which showed the location of the vessel on a chart of the channel) and "predictor steering" which forecast the path of the vessel in the channel. Both are shown to reflect the variability in results, due perhaps to the inherent error in simulating reality.

For the 600’ vessel, the WAMS results are lower than the MNSS results.

For the 1 000’ vessel, the WAMS results are higher than the MNSS results.

3.6 600’ Vessel Results vs. 1 000’ Vessel Results

Figure 7 shows the results for all cases for the 600’ vessel. Figure 8 shows the results for all cases for the 1000’ vessel.

For the 600’ vessel, most of the MNSS results are higher than the WAMS results. Figure 7 shows that the majority of the 600’ vessel results from both the MNSS and WAMS systems are clustered together, with the range of estimates between 500’ and 1 300’.

For the 1 000’ vessel, the data points are more evenly divided between those that fall above the line of equality (i.e., MNSS results are lower than the WAMS results) and those that fall below the line-of-equality (i.e., MNSS results are higher than the WAMS results). Figure 8 shows that for the 1 000' vessel there is much more variation, especially for the WAMS results. The wide range of 'variation' in WAMS results for the 1 000' vessel may indicate that the WAMS expression used for scaling up from the 600' vessel to the 1000' vessel is suspect.

It is worth noting that for the 1 000' vessel, all the ECDIS results are higher for the WAMS system than those for the MNSS system, whereas for the non-ECDIS cases (i.e., conventional aids to navigation), the WAMS results tend to be lower than the MNSS results. This is curious, since one would expect better results (i.e., more narrow track widths) with a more accurate navigational aid such as ECDIS. This may be due to simulator error.

4.0 CONCLUSIONS & RECOMMENDATIONS

MNSS has more variables and a wider range of possible input values for many of the variables. The structure of the 99.9% Pre-Processor (i.e., 6 independent factors) provides a good basis for explaining the results.

For 600' vessels, MNSS results tend to be higher (i.e., more cautious) than the WAMS results.

WAMS results (especially for the Turn and ECDIS cases) change dramatically when scaling up from the 600' vessel to the 1 000' vessel.

The results of the MNSS and WAMS approaches have many points of difference which should be examined more closely to determine the reasons. This might be done by research on the observed variation in position of vessels in the channel or by expert judgement.

REFERENCES

SMITH, M.W., K.L. MARINO, J. MULTER (1985). "Short Range Aids to Navigation Systems Design Manual for Restricted Waterways", U.S. Coast Guard, Washington, D.C.

Annex A: Key Input Parameter Values and Output

MNSS-WAMS Comparison
DRAFT (Do not cite or quote)

	1 (WAMS)	2	3	4	5	6	7	8 (MNSS)	9	10	11	12	13	14	15
	Segment Type • Turn • Track	Turn (Type, Angle) • cutoff, noncutoff • 15 or 35 degree	Visibility • Day • Night • Poor	Passing • Yes • No	Environ. Level Crab Angle: I= 0-2 deg. II= 2-5 deg.	NavAids • conventional • conv. + GPS • conv. + ECDIS	Aid to Navigation	Crab Angle & Weather [% level 2, % level 3]	Conv. Aid Category	Pos'n Qual. Type Best, Next best	Chart Label	vessel length = 600' B=85' M600	W600	vessel length = 1000' B=150' M1000	w1000
1	Turn	Seatrial Recov., 15	Day	No	I	conventional	gated aids	2.7[0,0]	m-h(buoys)	200	T15	760	372	921	1384
2	Turn	Seatrial Recov., 15	Day	No	I	conventional	long-spaced, staggered aids	2.7[0,0]	m	200	T15	875	527	1034	2073
3	Turn	Seatrial Recov., 15	Day	No	II	conventional	gated aids	5[100,0]	m-h(buoys)	200	T15	975	387	1272	1451
4	Turn	Seatrial Recov., 15	Day	No	II	conventional	long-spaced, staggered aids	5[100,0]	m	300	T15	1100	601	1376	2404
5	Turn	15	Poor	No	II	conventional	2 buoys/gates	5[100,0]	m-h(buoys)	330	T15	1125	831	1422	5095
6	Turn		Poor	No	II	conventional	3 buoys/gates				T		603		2217
7	Turn	15	Poor	No	I	conventional	2 buoys/gates	2.7[0,0]	m-h(buoys)	330	T15	925	344	1389	1174
8	Turn		Poor	No	I	conventional	3 buoys/gates				T		296		980
9	Track	0	Poor	No	I	conventional	2 buoys/gates	2.7[0,0]	m-h(buoys)	330	S	790	201	888	788
10	Track		Poor	No	I	conventional	3 buoys/gates				S		207		818
11	Track	0	Poor	No	II	conventional	2 buoys/gates	5[100,0]	m-h(buoys)	330	S	1025	543	1240	2425
12	Track		Poor	No	II	conventional	3 buoys/gates				S		356		1494
13	Turn		Poor	No	II	conventional	1 buoy/long-spaced, staggered				T		551.5		3184
14	Turn		Poor	No	II	conventional	3 buoys/long-spaced gates				T		471		2633
15	Turn		Poor	No	I	conventional	1 buoy/long-spaced, staggered				T		302		1005
16	Turn		Poor	No	I	conventional	3 buoys/long-spaced gates				T		278.5		910
17	Track		Poor	No	I	conventional	1 buoy/long-spaced, staggered				S		168.5		626
18	Track		Poor	No	I	conventional	3 buoys/long-spaced gates				S		229.5		930
19	Track		Poor	No	II	conventional	1 buoy/long-spaced, staggered				S		539		2405
20	Track		Poor	No	II	conventional	3 buoys/long-spaced gates				S		336		1394

MNSS-WAMS Comparison
DRAFT (Do not cite or quote)

	1 (WAMS)	2	3	4	5	6	7	8 (MNSS)	9	10	11	12	13	14	15
	Segment Type • Turn • Track	Turn (Type, Angle) • cutoff, noncutoff • 15 or 35 degree	Visibility • Day • Night • Poor	Passing • Yes • No	Environ. Level Crab Angle: I= 0-2 deg. II= 2-5 deg.	NavAids • conventional • conv. + GPS • conv. + ECDIS	Aid to Navigation	Crab Angle & Weather [% level 2, % level 3]	Conv. Aid Category	Pos'n Qual. Type Best, Next best	Chart Label	vessel length = 600' B=85' M600	W600	vessel length = 1000' B=150' M1000	w1000
21	Track		Day	No	I	conventional	gated aids				Track		271		611
22	Track		Day or Night	No	I	conventional	gated aids				Track		348		626
23	Track		Day	No	I	conventional	short-spaced, staggered aids				Track		292		538
24	Track	0	Day	No	I	conventional	long-spaced, staggered aids	2.7[0,0]	m	300	S	760	503	855	873
25	Track		Day	No	I	conventional	one-side channel marking				Track		382		680
26	Track	0	Day	No	I	conventional	high-sensitivity range	2.7[0,0]	m-h(ranges)	75	S	520	268	614	498
27	Track		Day	No	I	conventional	low-sensitivity range				Track		430		955
28	Track		Day	No	II	conventional	short-spaced, gated aids				Track		359		809
29	Track		Day	No	II	conventional	gated aids, day				Track		363		816
30	Track		Day	No	II	conventional	long-spaced, gated aids				Track		448		1001
31	Track		Night	No	II	conventional	gated aids, night/dusk/dawn				Track		447		806
32	Track		Day	No	II	conventional	short-spaced, staggered aids				Track		484		1078
33	Track	0	Day	No	II	conventional	long-spaced, staggered aids	5[100,0]	m	300	S	1000	577	1217	1281
34	Track		Day	No	II	conventional	one-side channel marking				Track		684		1185
35	Track	0	Day	No	II	conventional	high-sensitivity range	5[100,0]	m-h(ranges)	75	S	750	390	958	716
36	Track		Day	No	II	conventional	low-sensitivity range				Track		833		1422

MNSS-WAMS Comparison
DRAFT (Do not cite or quote)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	WAMS							MNSS							
	Segment Type • Turn • Track	Turn (Type, Angle) • cutoff, noncutoff • 15 or 35 degree	Visibility • Day • Night • Poor	Passing • Yes • No	Environ. Level Crab Angle: I= 0-2 deg. II= 2-5 deg.	NavAids • conventional • conv. + GPS • conv. + ECDIS	Aid to Navigation	Crab Angle & Weather [% level 2, % level 3]	Conv. Aid Category	Pos'n Qual. Type Best, Next best	Chart Label	vessel length = 600' B=85' M600	W600	vessel length = 1000' B=150' M1000	w1000
37	Turn	Noncut, 15 degree	Day	No		conventional	1 buoy	2.7[0,0]	m	300	T15	870	438	1050	842
38	Turn	Noncut, 15 degree	Day	No		conventional	2 buoys	5[100,0]	m-h(buoys)	200	T15	1000	438	1300	842
39	Turn	Noncut, 15 degree	Day	No		conventional	3 buoys	2.7[0,0]	m-h(buoys)	200	T15	756	438	928	923
40	Turn	Noncut, 15 degree	Night	No		conventional	high-sensitivity range	2.7[0,0]	m-h(ranges)	75	T15	700	709	877	1300
41	Turn	Noncut, 15 degree	Day	No		conventional	low-sensitivity range	5[100,0]	m-h(ranges)	75	T15	837	1225	1133	2173
42	Turn	Noncut, 15 degree	Night	No		conventional	1 buoy	2.7[0,0]	m	300	T15	866	742	1037	1356
43	Turn	Noncut, 15 degree	Night	No		conventional	2 buoys	2.7[0,0]	m-h(buoys)	300	T15	868	742	1036	1356
44	Turn	Noncut, 15 degree	Night	No		conventional	3 buoys	5[100,0]	m-h(buoys)	300	T15	1091	526	1368	990
45	Turn	Noncut, 35 degree	Day	No		conventional	1 buoy	5[100,0]	m	300	T35	1229	440	1610	845
46	Turn	Noncut, 35 degree	Day	No		conventional	2 buoys	2.7[0,0]	m-h(buoys)	200	T35	925	379	1169	742
47	Turn	Noncut, 35 degree	Day	No		conventional	3 buoys	5[100,0]	m-h(buoys)	200	T35	1125	365	1515	779
48	Turn	Noncut, 35 degree	Day	No		conventional	high-sensitivity range	5[100,0]	m-h(ranges)	75	T35	1000	1220	1377	2164
49	Turn	Noncut, 35 degree	Night	No		conventional	low-sensitivity range	5[100,0]	m-h(ranges)	150	T35	1075	1744	1441	3050
50	Turn	Noncut, 35 degree	Night	No		conventional	1 buoy	5[100,0]	m	300	T35	1250	619	1597	1148
51	Turn	Noncut, 35 degree	Night	No		conventional	2 buoys	2.7[0,0]	m-h(buoys)	300	T35	1025	583	1282	1087
52	Turn	Noncut, 35 degree	Night	No		conventional	3 buoys	5[100,0]	m-h(buoys)	300	T35	1226	503	1620	951

MNSS-WAMS Comparison
DRAFT (Do not cite or quote)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	WAMS							MNSS							
	Segment Type • Turn • Track	Turn (Type, Angle) • cutoff, noncutoff • 15 or 35 degree	Visibility • Day • Night • Poor	Passing • Yes • No	Environ. Level Crab Angle: I= 0-2 deg. II= 2-5 deg.	NavAids • conventional • conv. + GPS • conv. + ECDIS	Aid to Navigation	Crab Angle & Weather [% level 2, % level 3]	Conv. Aid Category	Pos'n Qual. Type Best, Next best	Chart Label	vessel length = 600' B=85' M600	W600	vessel length = 1000' B=150' M1000	w1000
53	Turn	Cutoff, 15 degree	Day	No		conventional	1 buoy				Turn		679		1250
54	Turn	Cutoff, 15 degree	Day	No		conventional	2 buoys				Turn		353		697
55	Turn	Cutoff, 15 degree	Day	No		conventional	3 buoys				Turn		353		756
56	Turn	Cutoff, 15 degree	Day or Night	No		conventional	high-sensitivity range				Turn		709		1300
57	Turn	Cutoff, 15 degree	Day or Night	No		conventional	low-sensitivity range				Turn		985		1767
58	Turn	Cutoff, 15 degree	Night	No		conventional	1 buoy				Turn		680		1250
59	Turn	Cutoff, 15 degree	Night	No		conventional	2 buoys				Turn		591		1101
60	Turn	Cutoff, 15 degree	Night	No		conventional	3 buoys				Turn		591		1101
61	Turn	Cutoff, 35 degree	Day	No		conventional	1 buoy				Turn		736		1346
62	Turn	Cutoff, 35 degree	Day	No		conventional	2 buoys				Turn		383		749
63	Turn	Cutoff, 35 degree	Day	No		conventional	3 buoys				Turn		383		815
64	Turn	Cutoff, 35 degree	Day or Night	No		conventional	high-sensitivity range				Turn		1220		2164
65	Turn	Cutoff, 35 degree	Day or Night	No		conventional	low-sensitivity range				Turn		1744		3050
66	Turn	Cutoff, 35 degree	Night	No		conventional	1 buoy				Turn		1053		1881
67	Turn	Cutoff, 35 degree	Night	No		conventional	2 buoys				Turn		597		1111
68	Turn	Cutoff, 35 degree	Night	No		conventional	3 buoys				Turn		597		1111

MNSS-WAMS Comparison
DRAFT (Do not cite or quote)

	1 (WAMS)	2	3	4	5	6	7	8 (MNSS)	9	10	11	12	13	14	15
	Segment Type • Turn • Track	Turn (Type, Angle) • cutoff, noncutoff • 15 or 35 degree	Visibility • Day • Night • Poor	Passing • Yes • No	Environ. Level Crab Angle: I= 0-2 deg. II= 2-5 deg.	NavAids • conventional • conv. + GPS • conv. + ECDIS	Aid to Navigation	Crab Angle & Weather [% level 2, % level 3]	Conv. Aid Category	Pos'n Qual. Type Best, Next best	Chart Label	vessel length = 600' B=85' M600	W600	vessel length = 1000' B=150' M1000	w1000
69	Track	Graphic Display	Poor	No	I=2.7[0,0]	ECDIS	?	2.7[0,0]	low	330, 330	ES	800	300	887	1281
70	Track	Predictor Steering	Poor	No	I	ECDIS	?	2.7[0,0]	low	210, 330	ES	720	414	814	1848
71	Track	Graphic Display	Poor	No	II=5[100,0]	ECDIS	?	5[100,0]	low	330, 330	ES	1025	431	1241	1865
72	Track	Predictor Steering	Poor	No	II	ECDIS	?	5[100,0]	low	210, 330	ES	950	300	1161	1215
73	Turn	Noncut, 35 degrees	Poor	No	I	ECDIS (GD)	?	2.7[0,0]	low	330, 330	ET	1050	589	1313	3437
74	Turn	Noncut, 35 degrees	Poor	No	I	ECDIS (PS)	?	2.7[0,0]	low	210, 330	ET	975	525	1233	2999
75	Turn	Recovery	Poor	No	II	ECDIS (GD)	?	5[100,0]	low	330, 330	ET	1125	641	1427	2408
76	Turn	Recovery	Poor	No	II	ECDIS (PS)	?	5[100,0]	low	210, 330	ET	1050	446	1340	1621
77	Turn		Day	Yes	I	Conventional	2 buoys	2.7[0,0]	med	300	PT	1650	1110	1936	2237
78	Turn		Day	Yes	I	Conventional	3 buoys	2.7[0,0]	m-h(buoys)	200	PT	1550	653	1819	1343
79	Track		Day	Yes	I	Conventional	long-spaced, gates	2.7[0,0]	med	300	PS	1500	593	1661	1017
80	Track		Day	Yes	I	Conventional	short-spaced, gates	2.7[0,0]	m-h(buoys)	200	PS	1400	499	1554	867

Annex B: Calculation of WAMS Results

In order to compare the WAMS method with the MNSS method, it was necessary to express the WAMS results as a minimum channel width required for safe navigation. This calculation of the WAMS channel width results was achieved by first calculating a minimum channel width for a 600' vessel; the second step was to calculate the minimum channel width for a 1 000' vessel by scaling-up the 600' vessel result. The WAMS data used to calculate the WAMS channel width were: the *mean* and the *standard deviation* of the cross track position of the ship's centre of gravity with respect to the channel centreline; and the *slope factor* used to scale up to larger vessels from the three ship models used in the simulator testing. The ship models were as follows:

- a 30,000 dwt tanker, 595 feet long (between perpendiculars), 84 feet in beam, 35 feet in draft, with a 45-foot height of eye;
- a 52,000 dwt tanker, 653 feet long (between perpendiculars), 106 feet in beam, 33 feet in draft, with a 55-foot height of eye;
- a 80,000 dwt tanker, 763 feet long (between perpendiculars), 125 feet in beam, 40 feet in draft, with a 80-foot height of eye;

Step 1) Calculate channel width for 600' vessel: The following formula was used to calculate the channel width required for a 600' vessel for all cases except for passing. The input values for recovery regions and turn/track regions were calculated and compared. The higher of the two values was used as the channel width for a 600' vessel.

(a) Channel Width for vessel length of 600' (all cases except passing)

= *(IMM / 2*) + (6 x SD) + (2 x 9)

Where:

MN = mean from WAMS tables (sea trials, or simulation results)

SD = standard deviation from WAMS tables (sea trials, or simulation results)

B' = half the adjusted beam. (The adjusted beam is larger than the beam to account for

the crab angle of the ship.)

(b) Channel Width for vessel length of 600' (passing case)

= width required for 'Turn/Track' case + width required for 'Recovery' case

= *[(|MN|/ 2) + (6 x SD) + (4 x B')] + [|MN| + (6 x SD) + (2 x B')]*

Step 2) Calculate channel width for 1 000' vessel: The channel width required for a 1 000' vessel was calculated based on the estimate for the 600'. Adjustments were made based on the scaling factors provided in the WAMS manual. The formula used for all cases is as follows:

Channel Width for vessel length of 1000'

= *190("600'width"-(2 x B') x SF) + (2 x B') x (208 / 85)*

Where:

SF = Slope factor from WAMS tables

APPENDIX E: 99.9% AND LOS WORKSHEETS

Table 1. Comparative changes in grounding and collision risk

	Track No.	Channel Width (min feet)	99.9% Track Width (max feet)	Track Length (NM)	x = 99.9% / Channel Width	Estimated Grounding or Collision frequency per ship per mile =.000001x^3	Track Grounding or Collision Modify Rates Multiplier	Total Passage Length (NM)	Total Passage Grounding or Collision Modify Rates Multiplier
Example	1 Status quo	2000	1800	2	0.9	7.29E-07			
	1 Mod #1	2000	1700	2	0.85	6.14E-07	0.84	7.5	0.96
Canso S Turn	S Turn Status quo	2300	1250	3	0.543478	1.61E-07			
	S Turn Less Buoys + ECDIS	2300	1250	3	0.543478	1.61E-07	1.00	7.5	1.00
	S Turn Less Ranges + ECDIS	2300	1300	3	0.565217	1.81E-07	1.12	7.5	1.05
	S Turn Status quo + ECDIS	2300	1200	3	0.521739	1.42E-07	0.88	7.5	0.95
CO320	CO 320 Status quo	4080	1550	4.5	0.379902	5.48E-08			
	CO 320 Less Buoys + ECDIS	4080	1600	4.5	0.392157	6.03E-08	1.10	7.5	1.06
	CO 320 Less Ranges + ECDIS	4080	1650	4.5	0.404412	6.61E-08	1.21	7.5	1.12
	CO 320 + ECDIS	4080	1500	4.5	0.367647	4.97E-08	0.91	7.5	0.94

Table 2. Pre-processor 99.9% safe passage buffer widths - "S" Turn

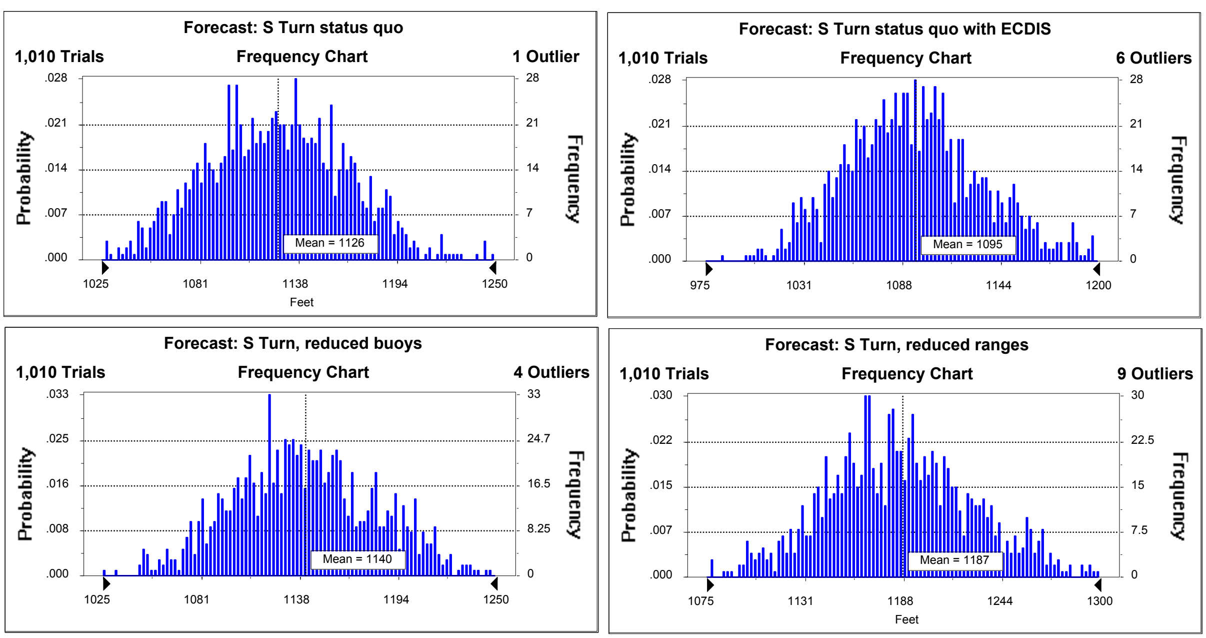
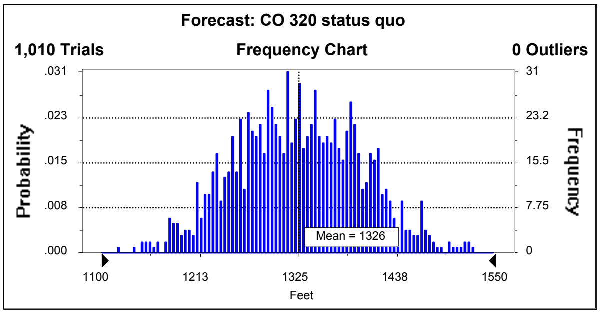
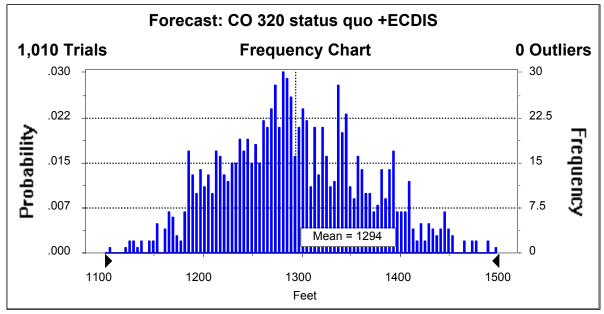
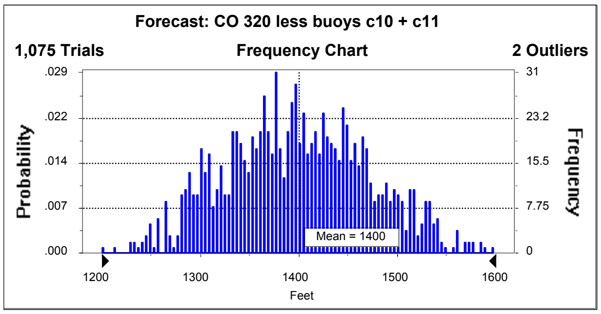
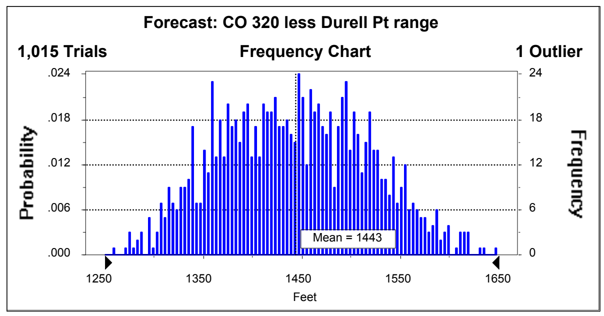


Table 3.Pre-processor 99.9% safe passage buffer widths - Course 320 degrees









Study Area: ***Canso S Turn 52 degrees, no passing, no ECDIS, 760 ft tanker, completely marked***

General Inputs

Category	I
Vessel Beam (feet)	125
Vessel Length (feet)	760
Displacement (GRT)	52049
Speed (Knots)	7
Bridge Experience Multiplier	1

Output (feet)

Beam and Crab	165
Shiphandling	160
Position	257
Turn	439
Weather	86
Passing	0
"99.9%" (average)	**1107**

Format

Reset multipliers to default

LOS

Track/Turn Length (NM)	3
Channel Width (min)	2300
99.9% Width (max)	1250
LOS B	**0.54**

A Beam and Crab

Crab Angle (degrees)	3

B Shiphandling

Course keeping Width (feet)	160

C Positioning Quality

Positioning Quality	Day	Night	Poor Visibility
Conventional: Visual/Radar	50	100	230
Conventional & GPS	50	100	230
Conv. & ECDIS w. DGPS	50	60	150
Chart Accuracy	120	120	120
Best Position Accuracy	50	100	230
Next Best Position Accuracy	50	100	230
Positioning Quality (feet)	170	220	350

Conventional Aids to Nav.: High (completely marked)

Navigation Conditions	Weighted by Visibility Frequency
Sig. Visibility Hazard (NM)	<5.4
Poor Visibility Frequency (%)	40

D Turn Paths

Degree of Turn	52
Turn Path Factor	1

E Weather

Manual Input from Weather Table and WX Data

Reset to Default WX Freq.	1	A	B	C
Level II Frequency (%)	46	61	12	6
Level III Frequency (%)	2	5	1	1
Environmental Sum	86	66	14	6
Multiplier	1			

F Passing, overtaking or crossing Traffic

No — This control affects all worksheets

		From	To
Passing Distance	300	201	399

Study Area: ***Canso S Turn 52 degrees, no passing, with ECDIS, 760 ft tanker, completely marked***

General Inputs	
Category	I
Vessel Beam (feet)	125
Vessel Length (feet)	760
Displacement (GRT)	52049
Speed (Knots)	7
Bridge Experience Multiplier	1

Output (feet)	
Beam and Crab	165
Shiphandling	160
Position	230
Turn	439
Weather	85
Passing	0
"99.9%" (average)	**1079**

Format

Reset multipliers to default

LOS	
Track/Turn Length (NM)	3
Channel Width (min)	2300
99.9% Width (max)	1200
LOS B	**0.52**

A	**Beam and Crab**	
	Crab Angle (degrees)	3

B	**Shiphandling**	
	Course keeping Width (feet)	160

C	**Positioning Quality**	**Day**	**Night**	**Poor Visibility**	**Conventional Aids to Nav.**
	Conventional: Visual/Radar	50	100	230	High (completely marked)
	Conventional & GPS	50	100	230	
	Conv. & ECDIS w. DGPS	50	60	150	
	Chart Accuracy	120	120	120	
	Best Position Accuracy	50	60	150	
	Next Best Position Accuracy	50	100	230	
	Positioning Quality (feet)	170	195	302	

Navigation Conditions	Weighted by Visibility Frequency
Sig. Visibility Hazard (NM)	<5.4
Poor Visibility Frequency (%)	40

D	**Turn Paths**	
	Degree of Turn	52
	Turn Path Factor	1

E **Weather** — Manual Input from Weather Table and WX Data

	1	A	B	C
Reset to Default WX Freq.				
Level II Frequency (%)	46	61	12	5
Level III Frequency (%)	2	5	1	0
Environmental Sum	85	66	14	6
Multiplier	1			

F **Passing, overtaking or crossing Traffic** — No — This control affects all worksheets

		From	To
Passing Distance	300	201	399

Study Area: ***Canso S Turn 52 degrees, no passing, with ECDIS, 760 ft tanker, ranges (Elimination of C13 & C14)***

General Inputs

Category	I
Vessel Beam (feet)	125
Vessel Length (feet)	760
Displacement (GRT)	52049
Speed (Knots)	7
Bridge Experience Multiplier	1

Output (feet)

Beam and Crab	165
Shiphandling	160
Position	276
Turn	439
Weather	86
Passing	0
"99.9%" (average)	**1127**

Format

Reset multipliers to default

LOS

Track/Turn Length (NM)	3
Channel Width (min)	2300
99.9% Width (max)	1250
LOS B	**0.54**

A Beam and Crab

Crab Angle (degrees)	3

B Shiphandling

Course keeping Width (feet)	160

C Positioning Quality

Positioning Quality	Day	Night	Poor Visibility
Conventional: Visual/Radar	75	150	330
Conventional & GPS	150	200	330
Conv. & ECDIS w. DGPS	60	90	210
Chart Accuracy	120	120	120
Best Position Accuracy	60	90	210
Next Best Position Accuracy	75	150	330
Positioning Quality (feet)	187	233	377

Conventional Aids to Nav. Med-High (emphasis on ranges)

Navigation Conditions	Weighted by Visibility Frequency
Sig. Visibility Hazard (NM)	<5.4
Poor Visibility Frequency (%)	40

D Turn Paths

Degree of Turn	52
Turn Path Factor	1

E Weather — Manual Input from Weather Table and WX Data

Reset to Default WX Freq.	1	A	B	C
Level II Frequency (%)	46	61	12	6
Level III Frequency (%)	2	5	1	1
Environmental Sum	86	66	14	7
Multiplier	1			

F Passing, overtaking or crossing Traffic — No — This control affects all worksheets

		From	To
Passing Distance	300	201	399

Study Area: ***Canso S Turn 52 degrees, no passing, with ECDIS, 760 ft tanker, ranges (Elimination of Eddy Point, Thomas Head, Durell Pt ranges)***

General Inputs

Category	I
Vessel Beam (feet)	125
Vessel Length (feet)	760
Displacement (GRT)	52049
Speed (Knots)	7
Bridge Experience Multiplier	1

Output (feet)

Beam and Crab	165
Shiphandling	160
Position	320
Turn	439
Weather	87
Passing	0
"99.9%" (average)	**1171**

Format

Reset multipliers to default

LOS

Track/Turn Length (NM)	3
Channel Width (min)	2300
99.9% Width (max)	1300
LOS B	**0.57**

A Beam and Crab

Crab Angle (degrees)	3

B Shiphandling

Course keeping Width (feet)	160

C Positioning Quality

Positioning Quality	Day	Night	Poor Visibility
Conventional: Visual/Radar	200	300	330
Conventional & GPS	150	200	330
Conv. & ECDIS w. DGPS	120	180	210
Chart Accuracy	120	120	120
Best Position Accuracy	120	180	210
Next Best Position Accuracy	150	200	330
Positioning Quality (feet)	253	309	377

Conventional Aids to Nav. Med-High (emphasis on buoys)

Navigation Conditions	Weighted by Visibility Frequency
Sig. Visibility Hazard (NM)	<5.4
Poor Visibility Frequency (%)	40

D Turn Paths

Degree of Turn	52
Turn Path Factor	1

E Weather Manual Input from Weather Table and WX Data

Reset to Default WX Freq.	1	A	B	C
Level II Frequency (%)	46	61	12	7
Level III Frequency (%)	2	5	1	1
Environmental Sum	87	66	14	8
Multiplier	1			

F Passing, overtaking or crossing Traffic No — This control affects all worksheets

		From	To
Passing Distance	300	201	399

Study Area: ***Course 320 W of Janvrin Is, with passing, no ECDIS, 760 ft tanker, completely marked***

General Inputs

Category	I
Vessel Beam (feet)	125
Vessel Length (feet)	760
Displacement (GRT)	52049
Speed (Knots)	7
Bridge Experience Multiplier	1

Output (feet)

Beam and Crab	330
Shiphandling	320
Position	257
Turn	0
Weather	86
Passing	300
"99.9%" (average)	**1292**

Format

Reset multipliers to default

LOS

Track/Turn Length (NM)	3
Channel Width (min)	4080
99.9% Width (max)	1550
LOS A	**0.38**

A **Beam and Crab**

Crab Angle (degrees)	3

B **Shiphandling**

Course keeping Width (feet)	160

C **Positioning Quality**

Positioning Quality	Day	Night	Poor Visibility
Conventional: Visual/Radar	50	100	230
Conventional & GPS	50	100	230
Conv. & ECDIS w. DGPS	50	60	150
Chart Accuracy	120	120	120
Best Position Accuracy	50	100	230
Next Best Position Accuracy	50	100	230
Positioning Quality (feet)	170	220	350

Conventional Aids to Nav.: High (completely marked)

Navigation Conditions	Weighted by Visibility Frequency
Sig. Visibility Hazard (NM)	<5.4
Poor Visibility Frequency (%)	40

D **Turn Paths**

Degree of Turn	0
Turn Path Factor	1

E **Weather** — Manual Input from Weather Table and WX Data

Reset to Default WX Freq.	1	A	B	C
Level II Frequency (%)	46	61	12	6
Level III Frequency (%)	2	5	1	1
Environmental Sum	86	66	14	6
Multiplier	1			

F **Passing, overtaking or crossing Traffic** — Yes — This control affects all worksheets

		From	To
Passing Distance	300	201	399

Study Area: *Course 320 W of Janvrin Is, with passing, no ECDIS, 760 ft tanker, less buoys C10 + C11*

General Inputs

Category	I
Vessel Beam (feet)	125
Vessel Length (feet)	760
Displacement (GRT)	52049
Speed (Knots)	7
Bridge Experience Multiplier	1

Output (feet)

Beam and Crab	330
Shiphandling	320
Position	333
Turn	0
Weather	88
Passing	300
"99.9%" (average)	**1371**

Format

Reset multipliers to default

LOS

Track/Turn Length (NM)	3
Channel Width (min)	4080
99.9% Width (max)	1600
LOS A	**0.39**

A Beam and Crab

Crab Angle (degrees)	3

B Shiphandling

Course keeping Width (feet)	160

C Positioning Quality

Positioning Quality	Day	Night	Poor Visibility
Conventional: Visual/Radar	75	150	330
Conventional & GPS	150	200	330
Conv. & ECDIS w. DGPS	60	90	210
Chart Accuracy	120	120	120
Best Position Accuracy	75	150	330
Next Best Position Accuracy	150	200	330
Positioning Quality (feet)	220	291	450

Conventional Aids to Nav.: Med-High (emphasis on ranges)

Navigation Conditions	Weighted by Visibility Frequency
Sig. Visibility Hazard (NM)	<5.4
Poor Visibility Frequency (%)	40

D Turn Paths

Degree of Turn	0
Turn Path Factor	1

E Weather — Manual Input from Weather Table and WX Data

Reset to Default WX Freq.	1	A	B	C
Level II Frequency (%)	46	61	12	8
Level III Frequency (%)	2	5	1	1
Environmental Sum	88	66	14	8
Multiplier	1			

F Passing, overtaking or crossing Traffic: Yes — This control affects all worksheets

		From	To
Passing Distance	300	201	399

Study Area: ***Course 320 W of Janvrin Is, with passing, no ECDIS, 760 ft tanker, less Durell Pt range***

General Inputs

Category	I
Vessel Beam (feet)	125
Vessel Length (feet)	760
Displacement (GRT)	52049
Speed (Knots)	7
Bridge Experience Multiplier	1

Output (feet)

Beam and Crab	330
Shiphandling	320
Position	375
Turn	0
Weather	89
Passing	300
"99.9%" (average)	**1414**

Format

Reset multipliers to default

LOS

Track/Turn Length (NM)	3
Channel Width (min)	4080
99.9% Width (max)	1650
LOS B	**0.40**

A Beam and Crab

Crab Angle (degrees)	3

B Shiphandling

Course keeping Width (feet)	160

C Positioning Quality

Positioning Quality	Day	Night	Poor Visibility
Conventional: Visual/Radar	200	300	330
Conventional & GPS	150	200	330
Conv. & ECDIS w. DGPS	120	180	210
Chart Accuracy	120	120	120
Best Position Accuracy	150	200	330
Next Best Position Accuracy	200	300	330
Positioning Quality (feet)	291	360	450

Conventional Aids to Nav.: Med-High (emphasis on buoys)

Navigation Conditions	Weighted by Visibility Frequency
Sig. Visibility Hazard (NM)	<5.4
Poor Visibility Frequency (%)	40

D Turn Paths

Degree of Turn	0
Turn Path Factor	1

E Weather — Manual Input from Weather Table and WX Data

Reset to Default WX Freq.	1	A	B	C
Level II Frequency (%)	46	61	12	9
Level III Frequency (%)	2	5	1	1
Environmental Sum	89	66	14	9
Multiplier	1			

F Passing, overtaking or crossing Traffic — Yes — This control affects all worksheets

		From	To
Passing Distance	300	201	399

Study Area: ***Course 320 W of Janvrin Is, with passing, with ECDIS, 760 ft tanker, completely marked***

General Inputs

Category	I
Vessel Beam (feet)	125
Vessel Length (feet)	760
Displacement (GRT)	52049
Speed (Knots)	7
Bridge Experience Multiplier	1

Output (feet)

Beam and Crab	330
Shiphandling	320
Position	230
Turn	0
Weather	85
Passing	300
"99.9%" (average)	**1265**

Format

Reset multipliers to default

LOS

Track/Turn Length (NM)	3
Channel Width (min)	4080
99.9% Width (max)	1550
LOS A	**0.38**

A Beam and Crab

Crab Angle (degrees)	3

B Shiphandling

Course keeping Width (feet)	160

C Positioning Quality

Positioning Quality	Day	Night	Poor Visibility
Conventional: Visual/Radar	50	100	230
Conventional & GPS	50	100	230
Conv. & ECDIS w. DGPS	50	60	150
Chart Accuracy	120	120	120
Best Position Accuracy	50	60	150
Next Best Position Accuracy	50	100	230
Positioning Quality (feet)	170	195	302

Conventional Aids to Nav.: High (completely marked)

Navigation Conditions	Weighted by Visibility Frequency
Sig. Visibility Hazard (NM)	<5.4
Poor Visibility Frequency (%)	40

D Turn Paths

Degree of Turn	0
Turn Path Factor	1

E Weather — Manual Input from Weather Table and WX Data

	1	A	B	C
Reset to Default WX Freq.				
Level II Frequency (%)	46	61	12	5
Level III Frequency (%)	2	5	1	0
Environmental Sum	85	66	14	6
Multiplier	1			

F Passing, overtaking or crossing Traffic: Yes — This control affects all worksheets

		From	To
Passing Distance	300	201	399

APPENDIX F: CANSO RISK ANALYSIS OUTPUT

Table 1. Both S Turn Status Quo & Less Buoys (same results)

Cause Factor	Statistic	Grounding Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Grounding	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Position Fixing	Min	0.0028	$1,735	0.0003	0.0000	0.0002	$12	$3	$1	$28	$7	$842	$842
Position Fixing	Max	0.0084	$27,004	0.0008	0.0001	0.0005	$4,809	$792	$357	$168	$253	$16,837	$3,788
Shiphandling	Min	0.0046	$2,863	0.0004	0.0000	0.0003	$19	$4	$1	$46	$11	$1,391	$1,391
Shiphandling	Max	0.0139	$44,615	0.0013	0.0001	0.0008	$7,945	$1,309	$589	$278	$417	$27,818	$6,259
Engine, power or prop failure	Min	0.0029	$1,808	0.0003	0.0000	0.0002	$12	$3	$1	$29	$7	$878	$878
Engine, power or prop failure	Max	0.0088	$28,179	0.0008	0.0001	0.0005	$5,018	$827	$372	$176	$264	$17,569	$3,953
Steering gear breakdown	Min	0.0017	$1,054	0.0002	0.0000	0.0001	$7	$2	$0	$17	$4	$512	$512
Steering gear breakdown	Max	0.0051	$16,437	0.0005	0.0001	0.0003	$2,927	$482	$217	$102	$154	$10,249	$2,306
Total	Min	0.0122	$7,536	0.0011	0.0001	0.0007	$51	$12	$3	$121	$29	$3,660	$3,660
Total	Max	**0.0366**	**$117,409**	**0.0034**	**0.0004**	**0.0022**	$20,908	$3,444	$1,551	$731	$1,099	$73,205	$16,471

Cause Factor	Statistic	Collision Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Collision	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Failure to observe vessel	Min	0.0040	$2,480	0.0001	0.0000	0.0002	$7	$1	$0	$40	$10	$1,211	$1,211
Failure to observe vessel	Max	0.0121	$33,985	0.0004	0.0001	0.0007	$3,145	$387	$174	$242	$363	$24,224	$5,450
Shiphandling	Min	0.0213	$13,116	0.0007	0.0002	0.0013	$39	$7	$2	$213	$51	$6,402	$6,402
Shiphandling	Max	0.0640	$179,641	0.0020	0.0006	0.0038	$16,623	$2,047	$921	$1,280	$1,920	$128,041	$28,809
Engine, power or prop failure	Min	0.0017	$1,063	0.0001	0.0000	0.0001	$3	$1	$0	$17	$4	$519	$519
Engine, power or prop failure	Max	0.0052	$14,567	0.0002	0.0001	0.0003	$1,348	$166	$75	$104	$156	$10,382	$2,336
Total	Min	0.0288	$17,722	0.0009	0.0003	0.0017	$52	$10	$2	$287	$69	$8,651	$8,651
Total	Max	**0.0865**	**$242,760**	**0.0028**	**0.0009**	**0.0052**	$22,464	$2,766	$1,245	$1,730	$2,595	$173,029	$38,931

Table 2. S Turn with ECDIS

Cause Factor	Statistic	Grounding Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Grounding	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Position Fixing	Min	0.0027	$1,647	0.0003	0.0000	0.0002	$11	$2	$1	$27	$6	$800	$800
Position Fixing	Max	0.0080	$25,654	0.0008	0.0001	0.0005	$4,568	$753	$339	$160	$240	$15,995	$3,599
Shiphandling	Min	0.0044	$2,719	0.0004	0.0000	0.0003	$18	$4	$1	$44	$10	$1,321	$1,321
Shiphandling	Max	0.0132	$42,385	0.0012	0.0001	0.0008	$7,548	$1,244	$560	$264	$396	$26,427	$5,946
Engine, power or prop failure	Min	0.0029	$1,808	0.0003	0.0000	0.0002	$12	$3	$1	$29	$7	$878	$878
Engine, power or prop failure	Max	0.0088	$28,179	0.0008	0.0001	0.0005	$5,018	$827	$372	$176	$264	$17,569	$3,953
Steering gear breakdown	Min	0.0017	$1,054	0.0002	0.0000	0.0001	$7	$2	$0	$17	$4	$512	$512
Steering gear breakdown	Max	0.0051	$16,437	0.0005	0.0001	0.0003	$2,927	$482	$217	$102	$154	$10,249	$2,306
Total	Min	0.0118	$7,304	0.0011	0.0001	0.0007	$49	$11	$3	$118	$27	$3,548	$3,548
Total	Max	**0.0355**	**$113,829**	**0.0033**	**0.0004**	**0.0021**	$20,270	$3,340	$1,504	$709	$1,065	$70,972	$15,969

Cause Factor	Statistic	Collision Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Collision	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Failure to observe vessel	Min	0.0040	$2,480	0.0001	0.0000	0.0002	$7	$1	$0	$40	$10	$1,211	$1,211
Failure to observe vessel	Max	0.0121	$33,985	0.0004	0.0001	0.0007	$3,145	$387	$174	$242	$363	$24,224	$5,450
Shiphandling	Min	0.0203	$12,460	0.0006	0.0002	0.0012	$37	$6	$2	$202	$49	$6,082	$6,082
Shiphandling	Max	0.0608	$170,657	0.0019	0.0006	0.0036	$15,791	$1,944	$875	$1,216	$1,824	$121,639	$27,368
Engine, power or prop failure	Min	0.0017	$1,063	0.0001	0.0000	0.0001	$3	$1	$0	$17	$4	$519	$519
Engine, power or prop failure	Max	0.0052	$14,567	0.0002	0.0001	0.0003	$1,348	$166	$75	$104	$156	$10,382	$2,336
Total	Min	0.0278	$17,066	0.0009	0.0003	0.0017	$50	$9	$2	$276	$67	$8,331	$8,331
Total	Max	**0.0833**	**$233,776**	**0.0027**	**0.0008**	**0.0050**	$21,632	$2,663	$1,199	$1,666	$2,499	$166,627	$37,490

Table 3. S Turn less ranges

Cause Factor	Statistic	Grounding Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Grounding	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Position Fixing	Min	0.0029	$1,820	0.0003	0.0000	0.0002	$12	$3	$1	$29	$7	$884	$884
Position Fixing	Max	0.0088	$28,354	0.0008	0.0001	0.0005	$5,049	$832	$374	$177	$265	$17,679	$3,978
Shiphandling	Min	0.0049	$3,006	0.0005	0.0000	0.0003	$20	$4	$1	$49	$12	$1,460	$1,460
Shiphandling	Max	0.0146	$46,845	0.0014	0.0001	0.0009	$8,342	$1,375	$618	$292	$438	$29,208	$6,572
Engine, power or prop failure	Min	0.0029	$1,808	0.0003	0.0000	0.0002	$12	$3	$1	$29	$7	$878	$878
Engine, power or prop failure	Max	0.0088	$28,179	0.0008	0.0001	0.0005	$5,018	$827	$372	$176	$264	$17,569	$3,953
Steering gear breakdown	Min	0.0017	$1,054	0.0002	0.0000	0.0001	$7	$2	$0	$17	$4	$512	$512
Steering gear breakdown	Max	0.0051	$16,437	0.0005	0.0001	0.0003	$2,927	$482	$217	$102	$154	$10,249	$2,306
Total	Min	0.0126	$7,764	0.0012	0.0001	0.0008	$52	$12	$3	$125	$30	$3,771	$3,771
Total	Max	**0.0377**	**$120,989**	**0.0036**	**0.0004**	**0.0023**	$21,545	$3,550	$1,597	$754	$1,132	$75,437	$16,974

Cause Factor	Statistic	Collision Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Collision	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Failure to observe vessel	Min	0.0040	$2,480	0.0001	0.0000	0.0002	$7	$1	$0	$40	$10	$1,211	$1,211
Failure to observe vessel	Max	0.0121	$33,985	0.0004	0.0001	0.0007	$3,145	$387	$174	$242	$363	$24,224	$5,450
Shiphandling	Min	0.0224	$13,772	0.0007	0.0002	0.0013	$41	$7	$2	$224	$54	$6,722	$6,722
Shiphandling	Max	0.0672	$188,622	0.0021	0.0007	0.0040	$17,454	$2,149	$967	$1,344	$2,016	$134,443	$30,249
Engine, power or prop failure	Min	0.0017	$1,063	0.0001	0.0000	0.0001	$3	$1	$0	$17	$4	$519	$519
Engine, power or prop failure	Max	0.0052	$14,567	0.0002	0.0001	0.0003	$1,348	$166	$75	$104	$156	$10,382	$2,336
Total	Min	0.0299	$18,378	0.0010	0.0003	0.0018	$54	$10	$2	$298	$72	$8,971	$8,971
Total	Max	**0.0897**	**$251,741**	**0.0029**	**0.0009**	**0.0054**	$23,295	$2,868	$1,291	$1,794	$2,691	$179,431	$40,371

Table 4. Course 320 Status Quo

Cause Factor	Statistic	Grounding Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Grounding	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Position Fixing	Avg	0.0056	$14,371	0.0005	0.0001	0.0003	$2,411	$398	$179	$98	$130	$8,840	$2,315
Position Fixing	Min	0.0028	$1,735	0.0003	0.0000	0.0002	$12	$3	$1	$28	$7	$842	$842
Position Fixing	Max	0.0084	$27,004	0.0008	0.0001	0.0005	$4,809	$792	$357	$168	$253	$16,837	$3,788
Shiphandling	Avg	0.0093	$23,740	0.0009	0.0001	0.0006	$3,982	$657	$295	$162	$214	$14,605	$3,825
Shiphandling	Min	0.0046	$2,863	0.0004	0.0000	0.0003	$19	$4	$1	$46	$11	$1,391	$1,391
Shiphandling	Max	0.0139	$44,615	0.0013	0.0001	0.0008	$7,945	$1,309	$589	$278	$417	$27,818	$6,259
Engine, power or prop failur	Avg	0.0059	$14,996	0.0006	0.0001	0.0004	$2,515	$415	$187	$103	$136	$9,224	$2,416
Engine, power or prop failur	Min	0.0029	$1,808	0.0003	0.0000	0.0002	$12	$3	$1	$29	$7	$878	$878
Engine, power or prop failur	Max	0.0088	$28,179	0.0008	0.0001	0.0005	$5,018	$827	$372	$176	$264	$17,569	$3,953
Steering gear breakdown	Avg	0.0034	$8,747	0.0003	0.0000	0.0002	$1,467	$242	$109	$60	$79	$5,381	$1,409
Steering gear breakdown	Min	0.0017	$1,054	0.0002	0.0000	0.0001	$7	$2	$0	$17	$4	$512	$512
Steering gear breakdown	Max	0.0051	$16,437	0.0005	0.0001	0.0003	$2,927	$482	$217	$102	$154	$10,249	$2,306
Total	**Avg**	**0.0244**	**$62,474**	**0.0023**	**0.0002**	**0.0015**	$10,480	$1,728	$777	$426	$564	$38,433	$10,066
Total	Min	0.0122	$7,536	0.0011	0.0001	0.0007	$51	$12	$3	$121	$29	$3,660	$3,660
Total	Max	0.0366	$117,409	0.0034	0.0004	0.0022	$20,908	$3,444	$1,551	$731	$1,099	$73,205	$16,471

Collision	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Cause Factor	Statistic	Collision Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Failure to observe vessel	Avg	0.0081	$18,234	0.0003	0.0001	0.0005	$1,576	$194	$87	$141	$187	$12,718	$3,331
Failure to observe vessel	Min	0.0040	$2,480	0.0001	0.0000	0.0002	$7	$1	$0	$40	$10	$1,211	$1,211
Failure to observe vessel	Max	0.0121	$33,985	0.0004	0.0001	0.0007	$3,145	$387	$174	$242	$363	$24,224	$5,450
Shiphandling	Avg	0.0427	$96,381	0.0014	0.0004	0.0026	$8,331	$1,027	$462	$747	$986	$67,222	$17,606
Shiphandling	Min	0.0213	$13,116	0.0007	0.0002	0.0013	$39	$7	$2	$213	$51	$6,402	$6,402
Shiphandling	Max	0.0640	$179,641	0.0020	0.0006	0.0038	$16,623	$2,047	$921	$1,280	$1,920	$128,041	$28,809
Engine, power or prop failur	Avg	0.0035	$7,818	0.0001	0.0000	0.0002	$676	$84	$38	$61	$80	$5,451	$1,428
Engine, power or prop failur	Min	0.0017	$1,063	0.0001	0.0000	0.0001	$3	$1	$0	$17	$4	$519	$519
Engine, power or prop failur	Max	0.0052	$14,567	0.0002	0.0001	0.0003	$1,348	$166	$75	$104	$156	$10,382	$2,336
Total	**Avg**	**0.0577**	**$130,242**	**0.0018**	**0.0006**	**0.0035**	$11,258	$1,388	$624	$1,009	$1,332	$90,840	$23,791
Total	Min	0.0288	$17,722	0.0009	0.0003	0.0017	$52	$10	$2	$287	$69	$8,651	$8,651
Total	Max	0.0865	$242,760	0.0028	0.0009	0.0052	$22,464	$2,766	$1,245	$1,730	$2,595	$173,029	$38,931

Table 5. Course 320 with ECDIS

Cause Factor	Statistic	Grounding Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Grounding	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Position Fixing	Avg	0.0053	$13,507	0.0005	0.0001	0.0003	$2,266	$374	$168	$92	$122	$8,309	$2,176
Position Fixing	Min	0.0026	$1,628	0.0002	0.0000	0.0002	$11	$2	$1	$26	$6	$791	$791
Position Fixing	Max	0.0079	$25,383	0.0007	0.0001	0.0005	$4,520	$745	$335	$158	$237	$15,827	$3,561
Shiphandling	Avg	0.0087	$22,316	0.0008	0.0001	0.0005	$3,743	$618	$278	$153	$201	$13,728	$3,595
Shiphandling	Min	0.0044	$2,691	0.0004	0.0000	0.0003	$18	$4	$1	$44	$10	$1,307	$1,307
Shiphandling	Max	0.0131	$41,937	0.0012	0.0001	0.0008	$7,468	$1,231	$554	$261	$392	$26,148	$5,883
Engine, power or prop failur	Avg	0.0059	$14,996	0.0006	0.0001	0.0004	$2,515	$415	$187	$103	$136	$9,224	$2,416
Engine, power or prop failur	Min	0.0029	$1,808	0.0003	0.0000	0.0002	$12	$3	$1	$29	$7	$878	$878
Engine, power or prop failur	Max	0.0088	$28,179	0.0008	0.0001	0.0005	$5,018	$827	$372	$176	$264	$17,569	$3,953
Steering gear breakdown	Avg	0.0034	$8,747	0.0003	0.0000	0.0002	$1,467	$242	$109	$60	$79	$5,381	$1,409
Steering gear breakdown	Min	0.0017	$1,054	0.0002	0.0000	0.0001	$7	$2	$0	$17	$4	$512	$512
Steering gear breakdown	Max	0.0051	$16,437	0.0005	0.0001	0.0003	$2,927	$482	$217	$102	$154	$10,249	$2,306
Total	**Avg**	**0.0235**	**$60,186**	**0.0022**	**0.0002**	**0.0014**	$10,096	$1,665	$749	$411	$543	$37,025	$9,697
Total	Min	0.0118	$7,257	0.0011	0.0001	0.0007	$49	$11	$3	$117	$27	$3,525	$3,525
Total	Max	0.0353	$113,110	0.0033	0.0004	0.0021	$20,142	$3,319	$1,494	$704	$1,058	$70,525	$15,868

Collision	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Cause Factor	**Statistic**	**Collision Frequency**	**Total Cost**	**Oil Spill Frequency**	**Death Frequency**	**Injury Frequency**	**Oil Spill Clean**	**Fines**	**Civil Damage**	**Death**	**Injury**	**Ship Cargo Loss**	**Opportunity Cost**
Failure to observe vessel	Avg	0.0081	$18,234	0.0003	0.0001	0.0005	$1,576	$194	$87	$141	$187	$12,718	$3,331
Failure to observe vessel	Min	0.0040	$2,480	0.0001	0.0000	0.0002	$7	$1	$0	$40	$10	$1,211	$1,211
Failure to observe vessel	Max	0.0121	$33,985	0.0004	0.0001	0.0007	$3,145	$387	$174	$242	$363	$24,224	$5,450
Shiphandling	Avg	0.0401	$90,596	0.0013	0.0004	0.0024	$7,831	$965	$434	$702	$927	$63,188	$16,549
Shiphandling	Min	0.0201	$12,329	0.0006	0.0002	0.0012	$37	$6	$2	$200	$48	$6,018	$6,018
Shiphandling	Max	0.0602	$168,861	0.0019	0.0006	0.0036	$15,625	$1,924	$866	$1,203	$1,805	$120,358	$27,080
Engine, power or prop failur	Avg	0.0035	$7,818	0.0001	0.0000	0.0002	$676	$84	$38	$61	$80	$5,451	$1,428
Engine, power or prop failur	Min	0.0017	$1,063	0.0001	0.0000	0.0001	$3	$1	$0	$17	$4	$519	$519
Engine, power or prop failur	Max	0.0052	$14,567	0.0002	0.0001	0.0003	$1,348	$166	$75	$104	$156	$10,382	$2,336
Total	**Avg**	**0.0551**	**$124,459**	**0.0018**	**0.0006**	**0.0033**	$10,758	$1,326	$596	$964	$1,273	$86,807	$22,735
Total	Min	0.0276	$16,935	0.0009	0.0003	0.0017	$50	$9	$2	$274	$66	$8,267	$8,267
Total	Max	0.0827	$231,980	0.0026	0.0008	0.0050	$21,466	$2,643	$1,190	$1,653	$2,480	$165,346	$37,202

Table 6. Course 320 with ECDIS and less ranges

Cause Factor	Statistic	Grounding Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Grounding	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Position Fixing	Avg	0.0059	$15,233	0.0006	0.0001	0.0004	$2,555	$422	$190	$104	$138	$9,370	$2,454
Position Fixing	Min	0.0030	$1,837	0.0003	0.0000	0.0002	$12	$3	$1	$30	$7	$892	$892
Position Fixing	Max	0.0089	$28,624	0.0008	0.0001	0.0005	$5,097	$840	$378	$178	$268	$17,847	$4,016
Shiphandling	Avg	0.0098	$25,165	0.0009	0.0001	0.0006	$4,221	$696	$313	$172	$227	$15,481	$4,055
Shiphandling	Min	0.0049	$3,034	0.0005	0.0000	0.0003	$20	$4	$1	$49	$12	$1,474	$1,474
Shiphandling	Max	0.0147	$47,293	0.0014	0.0001	0.0009	$8,422	$1,388	$624	$295	$442	$29,487	$6,635
Engine, power or prop failur	Avg	0.0059	$14,996	0.0006	0.0001	0.0004	$2,515	$415	$187	$103	$136	$9,224	$2,416
Engine, power or prop failur	Min	0.0029	$1,808	0.0003	0.0000	0.0002	$12	$3	$1	$29	$7	$878	$878
Engine, power or prop failur	Max	0.0088	$28,179	0.0008	0.0001	0.0005	$5,018	$827	$372	$176	$264	$17,569	$3,953
Steering gear breakdown	Avg	0.0034	$8,747	0.0003	0.0000	0.0002	$1,467	$242	$109	$60	$79	$5,381	$1,409
Steering gear breakdown	Min	0.0017	$1,054	0.0002	0.0000	0.0001	$7	$2	$0	$17	$4	$512	$512
Steering gear breakdown	Max	0.0051	$16,437	0.0005	0.0001	0.0003	$2,927	$482	$217	$102	$154	$10,249	$2,306
Total	**Avg**	**0.0253**	**$64,760**	**0.0024**	**0.0003**	**0.0015**	$10,863	$1,792	$805	$442	$585	$39,839	$10,434
Total	Min	0.0126	$7,809	0.0012	0.0001	0.0008	$52	$12	$3	$126	$30	$3,793	$3,793
Total	Max	0.0379	$121,707	0.0036	0.0004	0.0023	$21,673	$3,571	$1,607	$758	$1,139	$75,884	$17,075

Collision	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Cause Factor	Statistic	Collision Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Failure to observe vessel	Avg	0.0081	$18,234	0.0003	0.0001	0.0005	$1,576	$194	$87	$141	$187	$12,718	$3,331
Failure to observe vessel	Min	0.0040	$2,480	0.0001	0.0000	0.0002	$7	$1	$0	$40	$10	$1,211	$1,211
Failure to observe vessel	Max	0.0121	$33,985	0.0004	0.0001	0.0007	$3,145	$387	$174	$242	$363	$24,224	$5,450
Shiphandling	Avg	0.0452	$102,164	0.0014	0.0005	0.0027	$8,831	$1,089	$490	$792	$1,045	$71,255	$18,662
Shiphandling	Min	0.0226	$13,903	0.0007	0.0002	0.0014	$42	$7	$2	$226	$54	$6,786	$6,786
Shiphandling	Max	0.0679	$190,420	0.0022	0.0007	0.0041	$17,620	$2,170	$977	$1,357	$2,036	$135,723	$30,537
Engine, power or prop failur	Avg	0.0035	$7,818	0.0001	0.0000	0.0002	$676	$84	$38	$61	$80	$5,451	$1,428
Engine, power or prop failur	Min	0.0017	$1,063	0.0001	0.0000	0.0001	$3	$1	$0	$17	$4	$519	$519
Engine, power or prop failur	Max	0.0052	$14,567	0.0002	0.0001	0.0003	$1,348	$166	$75	$104	$156	$10,382	$2,336
Total	**Avg**	**0.0602**	**$136,026**	**0.0019**	**0.0006**	**0.0036**	$11,758	$1,450	$652	$1,054	$1,392	$94,873	$24,847
Total	Min	0.0301	$18,509	0.0010	0.0003	0.0018	$55	$10	$2	$300	$72	$9,035	$9,035
Total	Max	0.0904	$253,539	0.0029	0.0009	0.0054	$23,461	$2,889	$1,301	$1,807	$2,711	$180,711	$40,659

Table 7. Course 320 with ECDIS and less buoys

Cause Factor	Statistic	Grounding Frequency	Total Cost	Oil Spill Frequency	Death Frequency	Injury Frequency	Oil Spill Clean	Fines	Civil Damage	Death	Injury	Ship Cargo Loss	Opportunity Cost
Grounding	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Position Fixing	Avg	0.0063	$16,093	0.0006	0.0001	0.0004	$2,700	$445	$200	$110	$145	$9,900	$2,593
Position Fixing	Min	0.0031	$1,941	0.0003	0.0000	0.0002	$13	$3	$1	$31	$7	$943	$943
Position Fixing	Max	0.0094	$30,244	0.0009	0.0001	0.0006	$5,386	$887	$399	$189	$283	$18,857	$4,243
Shiphandling	Avg	0.0104	$26,590	0.0010	0.0001	0.0006	$4,460	$736	$331	$182	$240	$16,357	$4,284
Shiphandling	Min	0.0052	$3,207	0.0005	0.0001	0.0003	$21	$5	$1	$52	$12	$1,558	$1,558
Shiphandling	Max	0.0156	$49,969	0.0015	0.0002	0.0009	$8,898	$1,466	$660	$312	$467	$31,156	$7,010
Engine, power or prop failur	Avg	0.0059	$14,996	0.0006	0.0001	0.0004	$2,515	$415	$187	$103	$136	$9,224	$2,416
Engine, power or prop failur	Min	0.0029	$1,808	0.0003	0.0000	0.0002	$12	$3	$1	$29	$7	$878	$878
Engine, power or prop failur	Max	0.0088	$28,179	0.0008	0.0001	0.0005	$5,018	$827	$372	$176	$264	$17,569	$3,953
Steering gear breakdown	Avg	0.0034	$8,747	0.0003	0.0000	0.0002	$1,467	$242	$109	$60	$79	$5,381	$1,409
Steering gear breakdown	Min	0.0017	$1,054	0.0002	0.0000	0.0001	$7	$2	$0	$17	$4	$512	$512
Steering gear breakdown	Max	0.0051	$16,437	0.0005	0.0001	0.0003	$2,927	$482	$217	$102	$154	$10,249	$2,306
Total	**Avg**	**0.0262**	**$67,047**	**0.0025**	**0.0003**	**0.0016**	$11,246	$1,855	$834	$458	$605	$41,246	$10,803
Total	Min	0.0131	$8,086	0.0012	0.0001	0.0008	$54	$13	$3	$130	$30	$3,928	$3,928
Total	Max	0.0393	$126,003	0.0037	0.0004	0.0024	$22,438	$3,696	$1,664	$786	$1,179	$78,563	$17,677

Collision	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Cause Factor	**Statistic**	**Collision Frequency**	**Total Cost**	**Oil Spill Frequency**	**Death Frequency**	**Injury Frequency**	**Oil Spill Clean**	**Fines**	**Civil Damage**	**Death**	**Injury**	**Ship Cargo Loss**	**Opportunity Cost**
Failure to observe vessel	Avg	0.0081	$18,234	0.0003	0.0001	0.0005	$1,576	$194	$87	$141	$187	$12,718	$3,331
Failure to observe vessel	Min	0.0040	$2,480	0.0001	0.0000	0.0002	$7	$1	$0	$40	$10	$1,211	$1,211
Failure to observe vessel	Max	0.0121	$33,985	0.0004	0.0001	0.0007	$3,145	$387	$174	$242	$363	$24,224	$5,450
Shiphandling	Avg	0.0478	$107,945	0.0015	0.0005	0.0029	$9,331	$1,150	$517	$837	$1,104	$75,288	$19,718
Shiphandling	Min	0.0239	$14,689	0.0008	0.0002	0.0014	$44	$7	$2	$239	$57	$7,170	$7,170
Shiphandling	Max	0.0717	$201,198	0.0023	0.0007	0.0043	$18,617	$2,292	$1,032	$1,434	$2,151	$143,406	$32,266
Engine, power or prop failur	Avg	0.0035	$7,818	0.0001	0.0000	0.0002	$676	$84	$38	$61	$80	$5,451	$1,428
Engine, power or prop failur	Min	0.0017	$1,063	0.0001	0.0000	0.0001	$3	$1	$0	$17	$4	$519	$519
Engine, power or prop failur	Max	0.0052	$14,567	0.0002	0.0001	0.0003	$1,348	$166	$75	$104	$156	$10,382	$2,336
Total	**Avg**	**0.0628**	**$141,809**	**0.0020**	**0.0006**	**0.0038**	$12,258	$1,511	$679	$1,099	$1,451	$98,907	$25,904
Total	Min	0.0314	$19,295	0.0010	0.0003	0.0019	$57	$10	$2	$313	$75	$9,419	$9,419
Total	Max	0.0942	$264,317	0.0030	0.0009	0.0057	$24,458	$3,011	$1,356	$1,884	$2,826	$188,394	$42,388

APPENDIX G: DATA CONVERSION & CLEANING

1.0 Classification of MARSIS casualty data

A new field 'Casualty Type' in the MNSS casualty data base includes entries classified by many similar MARSIS casualty types (see Table 1).

Table 1. Casualty type classification in the MNSS data base

MNSS Casualty Type	MARSIS Casualty Type Codes included in MNSS Casualty Type Category
GROUNDING	1120-1128, 1242, 1249, 1312, 1411-1412, 2271-2272
COLLISION	1010-1027, 1237-1240, 1313-1314
SINKING	1130, 1244, 1413, 1510-1516, 1810-1811
FLOODING/FOUNDERING	1410, 1812, 2211-2212, 2281
FIRE/EXPLOSION	1129, 1610-1733
MACHINERY/MECHANICAL FAILURE	2136-2161, 2172-2175, 2251-2262
HULL/STRUCTURAL FAILURE	2182
STRIKING	1231-1236, 1241, 1243, 1248, 1250, 1310-1311, 1315
ICE DAMAGE	1910, 1911
OTHER	2110--2135, 2162-2171, 2181, 2184, 2273-2275

2.0 Conversion of VTS traffic volume data

In the Montreal, Quebec and Les Escoumins VTS Zones, vessel movements are counted as arrivals from the east and west, departures to the east and west, in-zone and out-of-zone movements. For the purposes of comparing a single vessel transit in either of these zones to another zone, e.g., Halifax VTS, a single passage through a zone was counted as one movement in the MNSS data base. To accomplish this conversion of traffic movement records for the Laurentian region, the volume of arrivals and departures were cut in half. A percentage was then determined for each Laurentian VTS Zone as follows:

$$\frac{TotalMovements - Departures}{TotalMovements}$$

Table 2 Percentage of total Montreal Zone traffic volume applied to counts in MNSS data base

Type de Navire	Percentage of total Montreal Zone traffic volume used
Nav.-Cit.<50 000T PL	78
Nav.-Cit.>50 000T PL	78
Traversier	100
Cargo - general	64
Cargo - Vrac	62
Conteneur	53
Remorqueur	99
Rem/Trans/Hydrocar.	90
Remorqueur/Remorque	91
Navire d'Etat	96
Bateau de Peche	100
Naviere a Passagers	97
Autres (Navires>20m)	97
Navires <20m	100

Table 3 Percentage of total Les Escoumins Zone traffic volume applied to counts in MNSS data base

Type de Navire	Percentage of total Les Escoumins Zone traffic volume used
Nav.-Cit.<50 000T PL	56
Nav.-Cit.>50 000T PL	55
Traversier	100
Cargo - general	61
Cargo - Vrac	62
Conteneur	51
Remorqueur	99
Rem/Trans/Hydrocar.	80
Remorqueur/Remorque	97
Navire d'Etat	98
Bateau de Peche	99
Naviere a Passagers	97
Autres (Navires>20m)	77
Navires <20m	99

Table 4 Percentage of total Quebec Zone traffic volume applied to counts in MNSS data base

Type de Navire	Percentage of total Quebec Zone traffic volume used
Nav.-Cit.<50 000T PL	56
Nav.-Cit.>50 000T PL	64
Traversier	100
Cargo - general	54
Cargo - Vrac	53
Conteneur	51
Remorqueur	99
Rem/Trans/Hydrocar.	50
Remorqueur/Remorque	85
Navire d'Etat	94
Bateau de Peche	50
Naviere a Passagers	92
Autres (Navires>20m)	97
Navires <20m	99