Risk Based Design Method for Aids to Navigation in the St. Lawrence River: MSD Relationships

Prepared for:

Garde Côtière, Aides à la navigation, Region Laurentienne

by

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Relationships within the MSD

Note: Units of measure—feet, metres or cables can be used as the horizontal dimension unit of measure in the MSD tool. Only metres are used to measure water depth. Vessel dimensions can be feet or metres.

1.0 Introduction

Each component in the MSD tool is described in this document. These components are:

- Physical dimensions,
- Shiphandling, and
- Positioning

A hierarchy of subcomponents for each component is also presented with the following format:

- Objective and assumptions
- Functional relationship in the MSD tool
- PIANC comparison
- Comparisons with other sources
- Expert input

Expert input was used to develop, discuss and modify the functional relationships: especially where there was variation in Mariner Best Practice.

2.0 Physical dimensions

The first MSD component adds the reference vessel's beam to estimates of the additional cross section of the vessel as it steers towards wind and current vectors to maintain its track (see Figure 1). Squat is then calculated. Subcomponents include:

- Beam—the vessel's beam in feet,
- the relative current on the bow (for the track section),
- the relative wind on the bow (for the track section), and
- Squat.

2.1 Beam

2.1.1 Objective and assumptions

To add the width of the reference vessel's beam to the MSD and also the secondary vessel's beam for a two-way MSD estimation.

2.1.2 Functional relationship in the MSD tool

None required.

2.1.3 PIANC comparison

Each factor is a function of the reference vessel's beam in PIANC. This is not the case with the MSD.

2.1.4 Comparisons with other sources

Canso 99.9% added the actual beam width of the reference vessel.

2.1.5 Expert input

2.2 The effect of current

2.2.1 Objective and assumptions

To add the width due to an increase in a vessel's horizontal cross-section to the drift angle created by a current.

The calculation of width due to current applies the current speed vector to the vessel speed vector. Vessels become less manoeuverable proceeding downbound when speed is reduced to maintain a safe speed made good (SMG) over the ground. This is due to a reduction in water flow past the rudder. The model predicts the drift angle "B" and the SMG "a". If a decision is made to reduce speed in a downbound simulation, then a reduced vessel speed should be re-entered into the MSD processor and the drift angle is re-calculated which increases the required width. Note that the vessel speed strongly affects all components of the MSD processor.

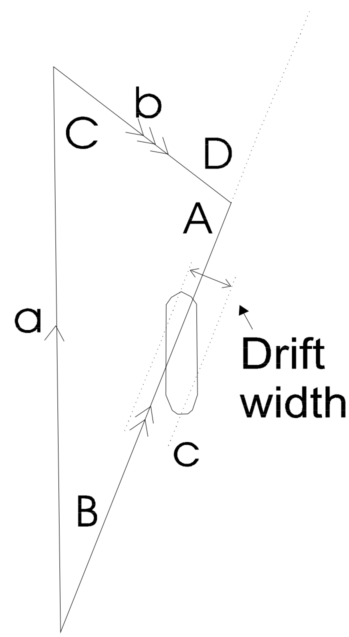


Figure 1 Vessel drift angle

Figure 1 illustrates the various angles and vectors associated with the determination of a course to steer to maintain a track given a wind or current vector.

The task of choosing a course to steer is usually based upon experience, but it can be determined by plotting speed vectors. The MSD processor uses plane trigonometry to accomplish the task of determining the vessel drift angle and the resulting width in the same manner as using a manoeuvering board to plot speed vectors.

2.2.2 Functional relationship in the MSD tool

The following example applies these relationships:

Law of Sines $$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

Law of Cosines $a^2 = b^2 + c^2 - 2bc \cos A$ or $a = \sqrt{b^2 + c^2 - 2bc \cos A}$

Example:

Let the current angle on the bow be 50° "*D*" at 5 knots "*b*", and the vessel's speed be 14 knots "*c*". First calculate "*B*", which is the vessel drift angle used to calculate the width.

Substituting in $\frac{b}{\sin B} = \frac{a}{\sin A}$ then $\frac{5}{\sin B} = \frac{a}{\sin 180 - D}$ (note 1) or $\frac{5}{\sin B} = \frac{a}{\sin 130}$;

Substituting in $a = \sqrt{b^2 + c^2 - 2bc \cos A}$ then $a = \sqrt{5^2 + 14^2 - 2 \times 5 \times 14 \cos 130}$;

Therefore $\frac{5}{\sin B} = \frac{17.6}{0.77}$ or $\frac{5}{\sin B} = \frac{17.6}{0.77}$ or $\frac{5}{\sin B} = 22.9$ or $\sin B = \frac{5}{22.9}$ or a drift angle of 12.6°.

Given a vessel drift angle of 12.6° and a ship length of 750' then the width = sin(12.6°)x ship length, or 0.218 x 750' = 164 feet of width.

2.2.3 PIANC comparison

PIANC applies a width of 0 to 0.4 beams depending on the longitudinal current and 0 to 1.3 beams depending on the cross current.

2.2.4 Comparisons with other sources

Admiralty Manual of Navigation, Volume 1, Chapter III The Ship's Position and Track

2.2.5 Expert input

[1] If D < 90: sin180-D, Else if D > 90: sinD.

2.3 Width due to relative wind

2.3.1 Objective and assumptions

To add the width due to an increase in a vessel's horizontal cross-section to to the drift angle created by a wind. The calculation of width due to wind is less straight-forward. This is because drift is largely influenced by the windage, vessel speed and draught.

2.3.2 Functional relationship in the MSD tool

The vessel drift angle in degrees (*b)* is calculated using the following formula:

$$b = \frac{y_A{}^2 \times A_L}{25 \times T^2 \times V_k{}^2}$$

Where

b	=	vessel drift angle in degrees
Y_A	=	sin(relative wind angle) x true wind speed in m/sec.
A_L	=	windage area (m^2)
T	=	ship draught (m)
V_k	=	ship speed through the water (relative to the undisturbed water) (knots)
25	=	a constant calibrated for VLCCs

Example:

Let the wind be 60° on the port bow at 30 knots with

Y_A	=	sin(60) x 15.4 m/sec. = 13.3 m/sec.
A_L	=	4500 m^2
T	=	15 m
V_k	=	10 knots

Then

$$b = \frac{13.3^2 \times 4500}{25 \times 15^2 \times 10^2}$$

And the vessel drift angle in degrees is 1.4°

Given a wind drift angle of 1.4° and a ship length of 750' then the width = sin(1.4°) x ship length, or 0.024 x 750' = 18 feet of width or about .3B.

Figure 2 illustrates the computed vessel drift angle for various wind speeds and directions. It was based on a vessel with the following characteristics:

Windage = 4500 m^2
Draught = 15 m
Vessel speed = 10 knots

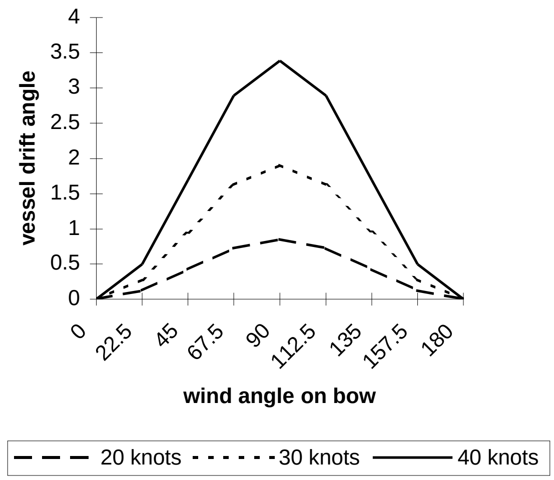


Figure 2 Vessel drift angle due to wind

2.3.3 PIANC comparison

Note that PIANC indicates the following widths for inner channels in protected waters:

- if vessel speed is fast, no effect
- if vessel speed is moderate and wind is >15 or <=33 knots, 0.4B
- if vessel speed is slow and wind is >15 or <=33 knots, 0.5B
- if vessel speed is moderate and wind is >33 or <=48 knots, 0.8B
- if vessel speed is slow and wind is >33 or <=48 knots, 1.0B

The formula described in 2.3.2 compares well with PIANC. For example, given a wind drift angle of 9.9° (48 knot wind on the beam with a slow vessel speed of 7 knots) and a ship length of 750' the calculated width is 130 feet or about 1.0B which is consistent with PIANC which also estimates 1.0B.

2.3.4 Comparisons with other sources

The calculation of vessel drift angle due to wind uses an empirical formula by Dr. Nils Norrbin and Capt. Robert Hofstee, FNI (a European pilot) at the World Maritime University in Malmo, Sweden.

UK Department of Transport[2] scale model trials in 1981/2 showed the wind drift effects for container vessels. Using their method, the estimated drift angle is 1.5°.

2.3.5 Expert input

2.4 *Underkeel Clearance and squat.*

2.4.1 Objective and assumptions

To estimate underkeel clearance given the ship's draught, speed, water depth and squat. The calculation of squat (increase in draught) is a physical dimension used here to determine underkeel clearance and later as a Shiphandling variable due to reduced manoeuverability.

2.4.2 Functional relationship in the MSD tool

The reference vessel variables, including the water depth (from the selected worst plausible case), bank profile for the section, and heel estimates are required.

The calculation of squat uses an empirical formula by Eryuzlu upon which the St. Lawrence River squat tables were produced. The formula was updated in 1994 to allow an adjustment for the effect of channel width.

$$S_b = 0.298 \frac{h^2}{T} \left(\frac{V}{\sqrt{gT}} \right)^{2.289} \left(\frac{h}{T} \right)^{-2.972} K_b$$

Where

S_b	=	sinkage at bow (m), or max sinkage
h	=	water depth (m)
T	=	ship draught (m)
V	=	ship speed through the water (relative to the undisturbed water) (m/s)
g	=	acceleration due to gravity (9.8 m/s^2)
W	=	channel width, measured at bottom (m)
B	=	ship beam (m)

with

[2] Controller Research and Development (1982). *Ship Behaviour in Ports and their Approaches, Part 6. The Determination of Channel Width Requirements Allowing for the Effects of Wind.* UK Dept. of Transport.

$$K_b = \frac{3.1}{\sqrt{\frac{W}{B}}} \quad \text{when} \quad \frac{W}{B} < 9.61$$

or

$$K_b = 1 \quad \text{when} \quad \frac{W}{B} \geq 9.61$$

Example:

Table 1 Example squat calculation

Traverse Nord	
Depth h (m)	17
Draught T (m)	15
Speed V_k (knots)	10
Speed V (m/s)	5.14
h/T	1.13
acceleration due to gravity (m/s^2)	9.8
Channel W (m)	305
Beam (m)	43
K_b	1.16
gT	147
S_b Squat (m)	0.65

Example:

Given the calculated squat, the under-keel clearance is calculated. If negative, then speed or vessel design or channel depth must be modified to enable passage in the given conditions. If positive, then a shiphandling width due to squat is calculated in Section 3.2.

2.4.3 PIANC comparison

2.4.4 Expert input

Note that it was proposed that an increase in draught caused by vessel heel in a turn should be calculated by:

0.5 x beam x sin(heel angle in degrees)

Increase in beam caused by vessel heel in a turn is calculated by:

freeboard x sin(heel angle in degrees)

However, a safety margin is applied in the MSD tool to both turn and straight sections. This safety margin was considered to include an allowance for vessel heel in a turn. The result may be that differences existing between turn and straight sections may not be measured as precisely as they could be.

3.0 Shiphandling

The second MSD component is the Shiphandling width which includes:

- course-keeping in a turn or straight section,
- the effects of squat,
- manoeuverability due to block coefficient,
- the effect of ice concentration and the presence of ice battures,
- one or two way (meeting or overtaking) traffic, and
- bank clearance.

The Shiphandling component is the sum of these six factors. It is increased or decreased by Bridge Performance.

3.1 Course-keeping width in a turn or straight section

3.1.1 Objective and assumptions

To measure the width resulting from a variation in courses chosen by a pilot and the ability of a helmsman to maintain a course for different ship lengths.

3.1.2 Functional relationship in the MSD tool

The turn width formula was developed for Canso. Width = ship length x turn angle/90°
It assumes an independence from vessel speed because the increased width due to a longer advance in a turn with higher speed is offset by increased controllability.

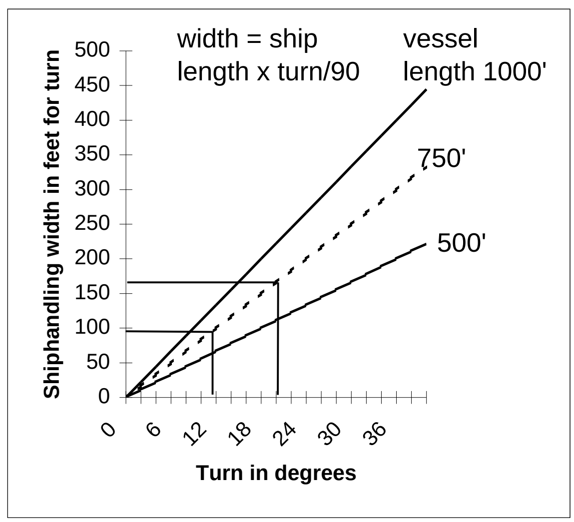


Figure 3 Turn width

Turn width is added to straight section width to estimate total turn width.

Coursekeeping in a straight section is calculated as 0.8 beams.

3.1.3 PIANC comparison

PIANC has inconsistent results for turns and straight tracks. It can estimate a width required for a turn to be less than that for a straight track (PIANC, p28 2nd paragraph)

3.1.4 Comparisons with other sources

The calculation of turn width in the 99.9% pre-processor was based on a function of vessel length and turn angle. It was developed by plotting the track for various advance and transfer lengths.

UK Department of Transport[3] scale model trials in 1981/2 suggest additional widths in Beams for turns:

Depth/Draught	Additional Width
1.5	0.66B
1.4	0.63B
1.3	0.61B
1.2	0.59B
1.1	0.57B

The table was constructed such that the radius of curvature of a bend in a channel should not be less than 10 times the length of the longest ship to be considered.

Assuming a Depth/Draught ratio of 1.1 and a vessel beam of 130 ft then the additional width in a turn would be 74 ft. Add this width to the coursekeeping width in a straight section (0.8B) and the result is about 175 ft. which is the same as that predicted in Figure 3 for a 750 ft. vessel in a 24° turn.

3.1.5 Expert input

Course-keeping in a turn in the river requires a width from about 1.0B to 1.5B. A straight section requires from 0.6B to 1.0B. (MSD concept design workshop, July 1998) . The MSD function yields the same width estimates of 1.0B - 1.5B for a vessel of 750' for a turn of 16° - 24°.

[3] Controller Research and Development (1982). *Ship Behaviour in Ports and their Approaches, Part 6. The Determination of Channel Width Requirements Allowing for the Effects of Wind*. UK Dept. of Transport.

3.2 Width due to squat and heel.

3.2.1 Objective and assumptions

To apply a width due to the decrease in manoeuverability due to squat. Given the calculated squat and a positive underkeel clearance, a shiphandling width due to squat is added.

3.2.2 Functional relationship in the MSD tool

Figure 4 shows the DMS functional relationship, modelled after PIANC, which provides a measure of a shiphandling width as a percentage of the vessel's beam as a function of squat.

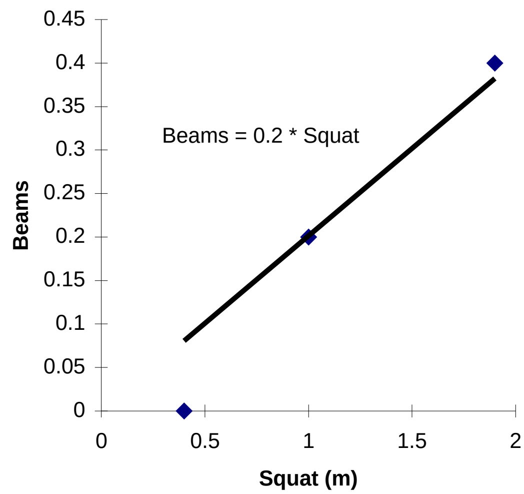


Figure 4 Shiphandling width due to squat

Example:

Squat of 0.65m x .2 = .13B = .13(43m) = 5.6m or 17 feet of shiphandling width.

3.2.3 PIANC comparison

Figure 5 shows the relationship between depth and draught (h/T) and vessel Beam multipliers suggested in PIANC.

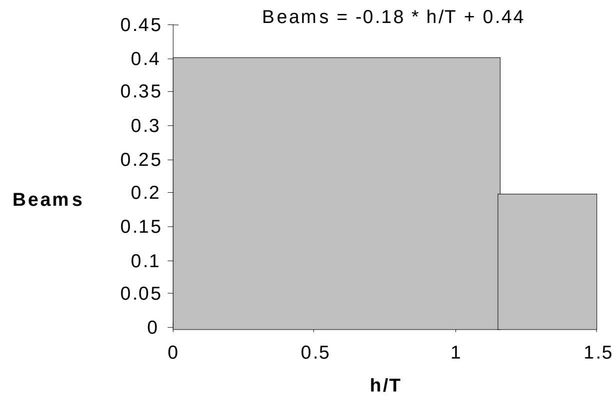


Figure 5 Shiphandling width in Beams due to depth/draught ratio (PIANC)

3.2.4 Comparisons with other sources

3.2.4 Expert input

3.3 Manoeuverability due to block coefficient

3.3.1 Objective and assumptions

To consider a width that reflects the differences in manoeuverability due to hull shape and displacement as measured by the block coefficient.

3.3.2 Functional relationship in the MSD tool

After considering the expert input, no extra width is recommended.

3.3.3 PIANC comparison

3.3.4 Comparisons with other sources

3.3.5 Expert input

Two very different vessels were considered:

- A VLCC (Figure 6 thick line) is more difficult to be set off course by wind and currents but it also takes more time to manoeuver back on track.
- A container vessel (Figure 6 thin line) is easier to be set off its heading and track by wind and currents but is also more easily manoeuvered back on track.

Considering Figure 6, the manoeuvering width is the same.

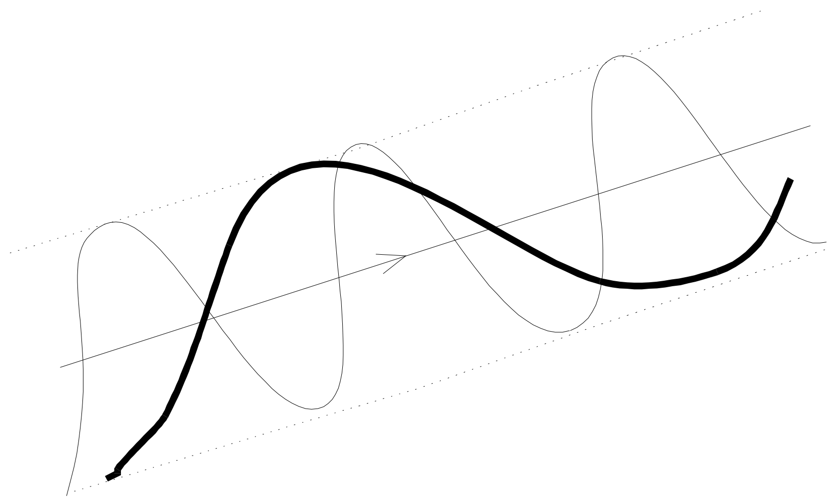


Figure 6 Vessel manoeuvering characteristics

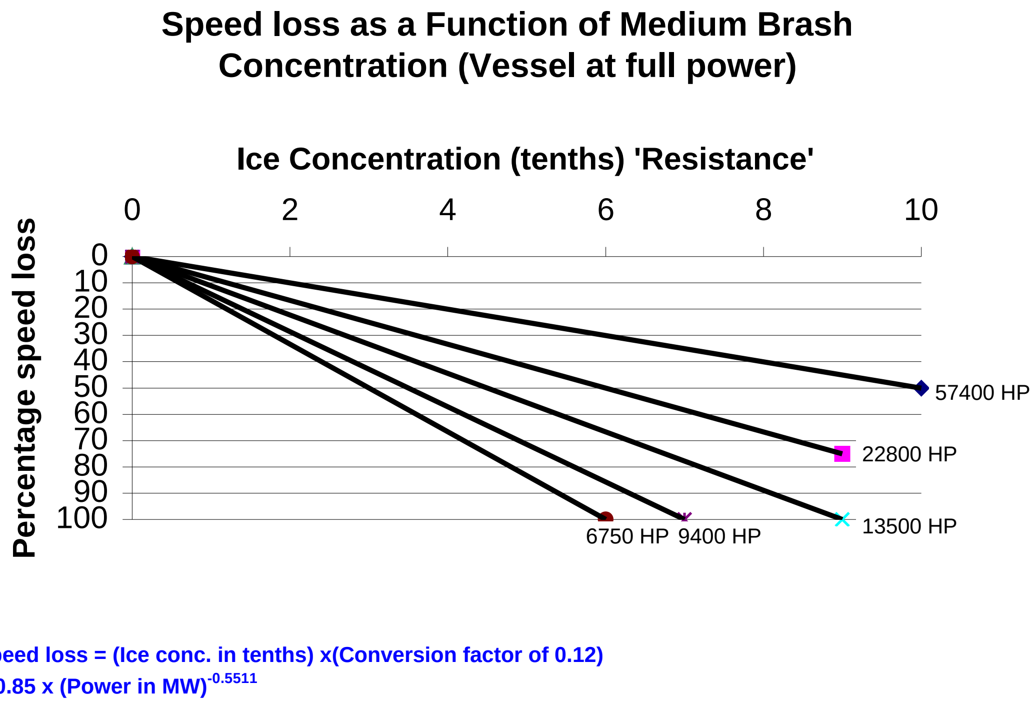
3.4 The effect of ice concentration and the presence of ice battures

3.4.1 Objective and assumptions

To provide a width which reflects the increase in shiphandling as a function of ice concentration.

3.4.2 Functional relationship in the MSD tool

Speed reduction in ice is estimated as a function of ice resistance, vessel speed and horsepower. This is illustrated in Figure 7. Vessel speed reduction increases the effect of cross currents and wind. Therefore, a MSD width for ice is estimated by applying the new speed of the vessel in an ice condition of 8 tenths brash to the wind and current formulas in Sections 2.2 and 2.3 of this document. The difference in MSD widths calculated for open water vs. ice is the MSD width for ice, speed and horsepower.



Source: see Footnote 5

Figure 7 Speed reduction from full power as a function of ice concentration

3.4.3 PIANC comparison

Not considered in PIANC.

3.4.4 Comparisons with other sources

3.4.5 Expert input

Studies have compared vessel performance in ice. Data from two figures in a 1991 study by Keinonen[4] were input into a spreadsheet as illustrated in Figure 8 below. The only difference from the original figures was that vessel speed loss was compared instead of actual speed, and the set of vessels was reduced.

[4] Figures 4.2.1 and 4.2.2. Keinonen, A.J. et al. (1991) TP10923E Icebreaker Design Syntheses Phase 2 Analysis of Contemporary Icebreaker Performance. Transportation Development Centre.

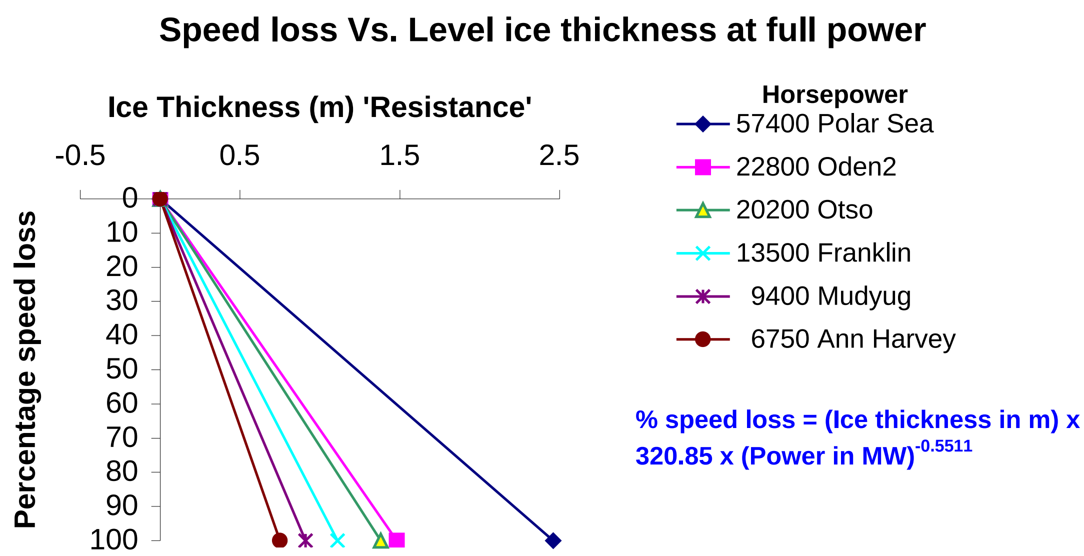


Figure 8 Speed loss as a function of level ice thickness at full power[5]

Notes:

- Consolidated medium brash ice (1 metre in thickness) is considered to be stronger than level ice, l metre in thickness.
- The manoeuvering around ice battures presents two wide a width to be added to the MSD width for comparison of navigation risk between different waterway sections.

3.5 The impact of one or two way traffic

3.5.1 Objective and assumptions

One or two way traffic has three impacts on the MSD:

- redundant bank clearance and redundant shiphandling passing widths are removed,
- overtaking traffic, vessel size and visibility increases shiphandling difficulty and requires a increase in the passing width, and
- a human performance workload flag can be set for sections with high encounter rates.

The passing width should be based on the Threat Rating Guide ‘highly significant’ width and Best Mariner’s Practice.

[5] Function by GeoInfo Solutions from Keinonen, A.J. et al. (1991) TP10923E Icebreaker Design Syntheses Phase 2 Analysis of Contemporary Icebreaker Performance. Transportation Development Centre. Figures 4.2.1 & 4.2.2, pp. 4.18
Note: 1 horsepower = 0.0007456999 MW

3.5.2 Functional relationship in the MSD tool

The MSD method first estimates the required channel width for one way operation and then estimates the MSD for two way operation based on the selection of a “plausible worst case” situation for the reference vessel to be passed

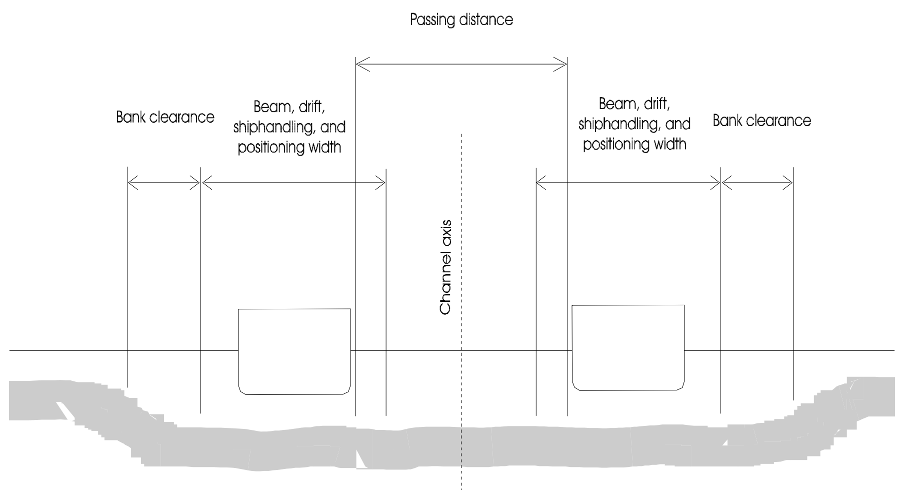


Figure 9 Two way traffic and the MSD

The theoretical passing width is estimated for a channel that is less than 5 cables (3 000 feet) in width.

i.	Vessel size	Passing width
	a. 50 000 tonnes and greater	300 feet
	b. 251 to 49 999 tonnes	200 feet
	c. less than 251 tonnes	150 feet
ii.	Visibility less than 1 NM	Passing width x 1.5
iii.	Overtaking situation	Passing width x 1.5

Note: DMS widths are determined as separate one-way estimates for channels 5 cables wide and larger, therefore, passing width is not required and is set to zero.

3.5.3 PIANC comparison

PIANC suggests to increase the passing width by 50% in higher traffic areas (see PIANC, P.24).

3.5.4 Comparisons with other sources

UK Department of Transport[6] scale model trials in 1981/2 suggest passing distance in Beams as:

Depth/Draught	Passing Distance
1.5	1.0B
1.4	1.2B
1.3	1.5B
1.2	1.8B
1.1	2.2B

Assuming a Depth/Draught ratio of 1.1 and a vessel beam of 130 ft then passing distance would be 286 ft.

3.5.5 Expert input

Pilots consistently suggest that a passing width of 200 feet is the norm.

[6] Controller Research and Development (1982). *Ship Behaviour in Ports and their Approaches, Part 6. The Determination of Channel Width Requirements Allowing for the Effects of Wind.* UK Dept. of Transport.

3.6 Bank clearance

3.6.1 Objective and assumptions

To provide a width estimation as a function of channel profile and bottom type or composition.

3.6.2 Functional relationship in the MSD tool

Bank clearance is estimated for each vessel using a formula developed from PIANC (p22). The relationship is a function of bottom and bank type as well as profile and vessel speed.

Channel bottom and bank profile and type	**Width for bank clearance**
Sloping channel edges and shoals:	Beam x speed in knots x 0.048
Steep and hard embankments, structures	Beam x speed in knots x 0.089
No channel edge	0

3.6.3 PIANC comparison

Channel bottom and bank profile and type	**Vessel speed**	**Width for bank clearance**
Sloping channel edges and shoals:	fast >12 moderate 8-12 slow 5-8	0.7B 0.5B 0.3B
Steep and hard embankments, structures	fast >12 moderate 8-12 slow 5-8	1.3B 1.0B 0.5B

Source: PIANC (p22)

3.6.4 Comparisons with other sources

3.6.5 Expert input

No bank clearance is required for waterways where the channel edge is far from the vessel.

4.0 Positioning

4.1 Radar and visual navigation

4.1.1 Objective and assumptions

This section presents the details of how the MSD tool estimates a positioning quality width given the navigation aids, vessel type, vessel speed, and environmental factors.

4.1.2 Functional relationship in the MSD tool

Figure 10 represents the positioning quality decision-tree developed from the sample of over 100 navigation situations and/or sections in the Saint Lawrence River study areas. This decision-tree was programmed to automatically calculate the estimated position quality in the MSD tool—this eliminated the need for a look-up table.

The label in Figure 10 to 'Rules' 2 through 10 refer to rules developed to be consistent with the criteria and positioning quality estimates produced by navigation experts. These rules were replicated in the decision-tree as a unique flow path with explicit criteria requirements. References to the term 'Guess' indicate possible outcomes that require substantiation. In the mean time, an intuitive value is provided that is internally consistent.

4.1.3 PIANC comparison

The PIANC document indicates that aids to navigation are "of crucial importance" to "define the width and alignment of the channel" but the PIANC design process suggests otherwise. Specifically, the range from moderate to excellent aid provision is from 0.5B to 0.0B (i.e., only a 50' range from moderate to excellent aids).

4.1.4 Comparisons with other sources

IALA indicates that a 95% accuracy in a gyro bearing is equivalent to 1° which at one mile distance represents 100' in uncertainty in lateral position.[7] IALA also indicates that the 95% radial error in radar should be better than 1.5% of the maximum range of the scale in use or 70 metres whichever is greater.

4.1.5 Expert input

Over the course of the project, many sections, time periods and aids to navigation configurations were examined and estimate positioning qualities provided. Experts with local navigation knowledge were able to examine the design of the

[7] International Association of Lighthouse Authorities (IALA*), 1993 IALA Aids to Navigation Guide (Navguide)*

MSD tool at several stages in workshops. While Figure 10 was only reviewed once by pilots, masters and marine organizations, more review is planned as the MSD tool is released to workshop members for further review.

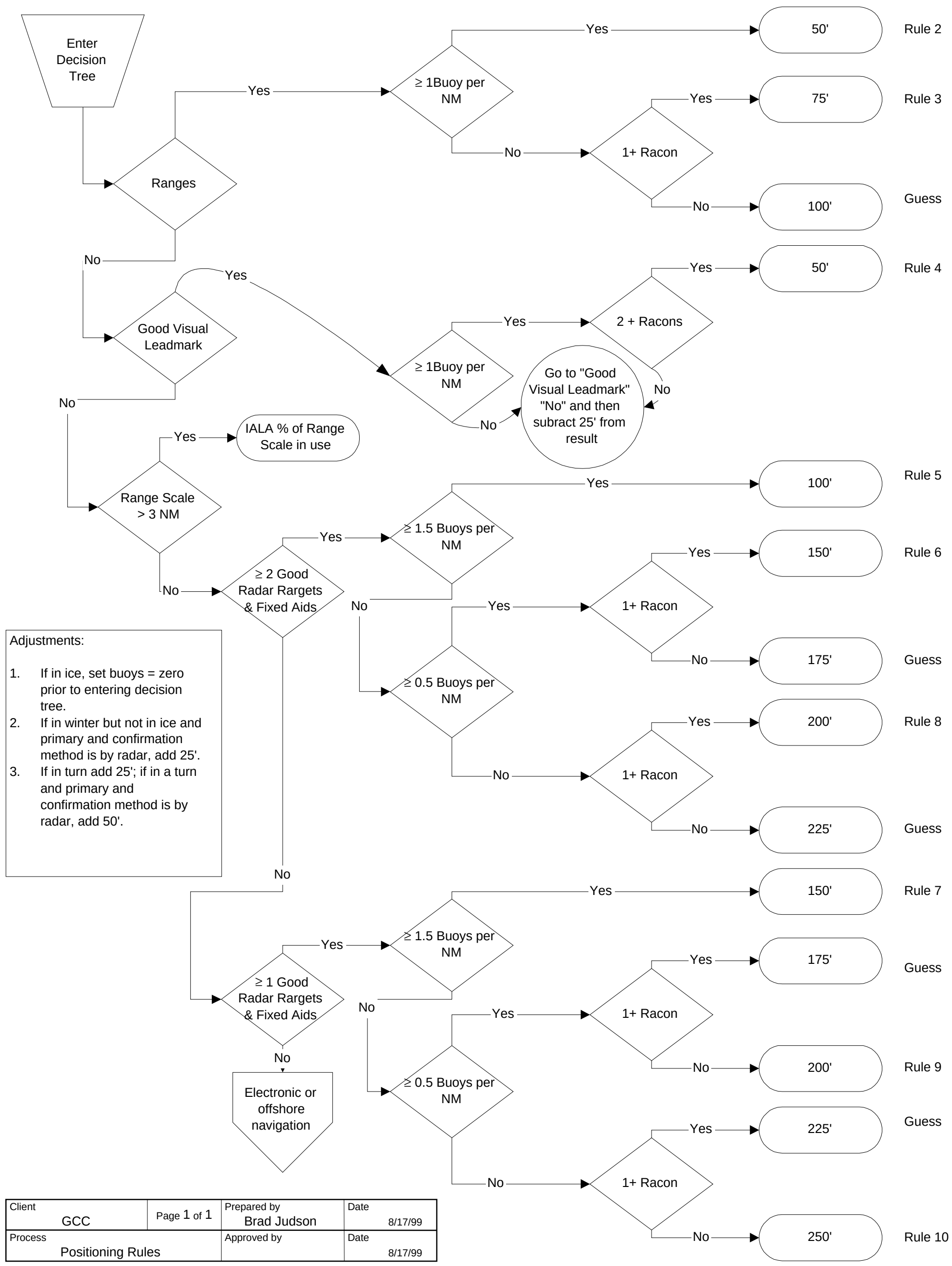


Figure 10 Positioning quality decision-tree

5.0 Bridge performance

The option to automate certain human performance processes versus providing a check list in the MSD tool was considered after examining the possible functional relationships that could be automated in the MSD tool.

At present, the MSD tool has some workload and human performance factors built into its design. For example, the positioning quality estimates are only considered valid for existing level of pilotage service in 1999 (i.e., the correct number of pilots for the situation according to the Laurentian Pilotage Authority Regulations). Also, workoad is indirectly measured by the factors that affect workload, i.e., vessel speed, environmental conditions, size and type of the a passing vessel.

Other human performance factors such as fatigue are not directly measured in the DMS tool. These factors are considered on a section by section basis where there is a minimum of manoeuvering room (CW/MSD $\approx$1). They are logged in the DMS worksheet by ticking a check box.

Bridge performance includes three shaping factor groups:
1. Bridge navigation aids & ergonomics,
2. Navigation and collision avoidance workload, fatigue, & experience/qualification, and
3. Bridge Resource Management: ship to ship & VTS communications, language, helmsman.

5.1 Navigation aids and ergonomics

5.1.1 Objective and assumptions

To investigate whether or not the scientific literature has considered a measure that accounts for the existence of a variation in the quality and user friendliness of the equipment from ship to ship. This variation affects the workload and fatigue of the pilot or officer in control, as well as the accuracy of positions estimated by radar. The scientific ergonomic literature should address the following questions: What procedure will be used to evaluate the existence and the extent of user-friendly qualities of different equipment on a ship by ship basis? How can we then map these differences into differences in workload? How will workload be defined and measured? How can we map these differences into fatigue? How will fatigue be defined and measured?

5.1.2 Functional relationship in the MSD tool

None implemented.

5.1.3 PIANC comparison

5.1.4 Comparisons with other sources

In the Canso model, bridge performance was modeled using a Monte Carlo simulation using a multiplier with a mean of 1 and a range of $\pm$ 0.1.

5.1.5 Expert input

The quality of equipment and charts encountered varies from ship to ship. For example:

- redundant radars provide a benefit of concurrent monitoring of position and traffic at two range scales
- tuning of radar affects target position accuracy
- gyro and index errors require the application of corrections
- charts range from corrected CHS at the best scale to British Admiralty small scale 1:125 000 with no indication of buoys.

5.2 Navigation and collision avoidance workload, fatigue, & experience/qualification

5.2.1 Workload

5.2.1.1 Objective and assumptions

To provide a measure which accounts for changes in workload throughout a passage.

The most important factor affecting workload is the speed of the vessel which defines the time to plan and execute all navigation and collision avoidance tasks.

The workload of the pilots increases in narrow channels, turns, adverse weather and lighting conditions, ice with pressure, and in high traffic areas. The workload is affected by the number of pilots (e.g., one in summer; two in winter).

5.2.1.2 Functional relationship in the MSD tool

Workload is indirectly measured for all factors indicated in section 5.2.1.1 above except that:

- Vessel encounter rates are not automated. They are considered for higher risk sections and logged by ticking a check box.
- The positioning quality values are based on current pilotage requirements.

5.2.1.3 PIANC comparison

5.2.1.4 Comparisons with other sources

5.2.1.5 Expert input

Future work might consider expert mariner input to evaluate the relationship between workload and the number of pilots. This could begin with an examination of positioning qualities.

5.2.2 Fatigue

5.2.2.1 Objective and assumptions

To consider the variation of fatigue along a traverse.

The level of fatigue is affected by the number of pilots (e.g., one in summer; two in winter).

During a passage, it is suggested that fatigue probably slowly increases in an oscillating pattern where there are peaks following sections with a higher workload with some recovery during less demanding sections. Since passages are in both directions along the river, fatigue is higher on either side of demanding sections and with proximity to origin and destination.

It is important to note that fatigue will be affected in a major way by the time of day, by the length of the duty period, and by the length of the voyage and other associated factors (environmental conditions).

5.2.2.2 Functional relationship in the MSD tool

Fatigue is not automated. It is considered for higher risk sections and logged by ticking a check box.

5.2.2.3 PIANC comparison

5.2.2.4 Comparisons with other sources

5.2.2.5 Expert input

Fatigue is greatest following demanding tasks or sections of the passage. An awareness to not let one's guard down after a tight section was expressed by the pilots. After eight hours of continuous pilotage, fatigue probably peaks just after the pilot turns over the navigation to another pilot or completes the berthing of a vessel.

5.2.3 Experience/qualification

5.2.3.1 Objective and assumptions

To measure the impact on experience and qualification on the MSD.

5.2.3.2 Functional relationship in the MSD tool

Since the qualification and presence of the correct number of pilots was considered when the positioning quality widths were estimated, the experience factor is already present in the positioning quality estimates in the MSD tool.

5.2.3.3 PIANC comparison

5.2.3.4 Comparisons with other sources

5.2.3.5 Expert input

Observations of the pilot/OOW workload suggests that experience factor in the MSD tool should consider the number and type of hands-on pilotage passage experiences in a particular waterway in a range of environmental conditions, not just years of experience or number of transits while on the bridge.

5.3 Bridge Resource Management: ship to ship & VTS communications, helmsman

5.3.1 Objective and assumptions

To examine the variation in Bridge Resource Management from ship to ship and sector to sector (See comments in Section 5.3.5 below).

Pilots are the factor which minimizes the variation between ships and account for the relatively low proportion of accidents caused by human error on the St. Lawrence River.

5.3.2 Functional relationship in the MSD tool

Ship to ship and VTS communications is important to the coordination of vessel passing (See comments in Section 5.3.5 below). With sufficient information on another vessels position, course and speed, masters and pilots can choose to avoid passing in higher risk sections of the river. This results in one-way sections according to best mariners practice. One and two-way MSD widths are provided in the MSD tool.

The benefit of the OOW, ship master and helmsman to a pilot is not measured in the MSD tool at this time.

5.3.3 PIANC comparison

PIANC groups VTS as an aid to navigation. The range of positioning widths in PIANC is from 0 to 0.5 beams (perhaps 0 to 65 feet).

5.3.4 Comparisons with other sources

An example of VTS effectiveness percentages for complex confined waters used in the CCG VTS Update Study (1991) was considered.

Level of VTS	% Reduction in collisions between participating vessels	% Reduction in groundings for participating vessels
VHF Only	15	10
Basic Radar	50	50
Advanced Radar	60	60

Notes:

- Since *basic radar* VTS was estimated by the CCG study to result in a 50% reduction in collisions and groundings, 50% of vessels would not be helped by the VTS. Therefore, vessels that have misidentified their position appear to have a 50-50 chance of benefiting from shore-based VTS advice on their position. This means that
- VTS can provide a vessel with position confirmation only. There are very few sections in the study areas where position confirmation is not already available by other means. Therefore, VTS positioning benefit was not given further consideration as a measurable component in estimating the MSD width.
- Vessels in a collision-risk situation appear to have a 50-50 chance of benefiting from shore-based advice on collision-avoidance information.
- VTS has a primary benefit in collision prevention in the study areas. VTS provides more current vessel movement information which assists masters to avoid encounters in difficult sections of the river. VTS uses Calling-in-points to collect and provide information.
- VTS may reduce the width needed for passing another vessel if best mariners practice is to avoid passing in a particular section.

5.3.5 Expert input

A good helmsman requires less intervention of a pilot and reduces the pilots shiphandling *workload*. The benefit of this is more apparent in turns. Due to the intensity of work by the helmsman when the ship is in a river passage, helmsmen are rotated more frequently when the ship is in the river compared to open ocean. Canadian helmsmen are probably more *experienced* with the river and would have better English.

Ship to ship communication is rarely needed since the pilots are made aware through VTS or the pilotage authority of who the pilot is on vessels that they will be encountering. VTS helps to confirm the identify of other traffic which enhances the coordination of collision avoidance decisions and communication.