Safe Speed in Ice:
An Analysis of Transit Speed and Ice Decision Numerals

December 1996

prepared for

Ship Safety Northern (AMNS), Transport Canada
344 Slater Street,
Ottawa, Ontario, K1A 0N7

prepared by

ENFOTEC Technical Services Inc.
150 Metcalfe Street, 19th Floor
Ottawa, Ontario, K2P 1P1

and

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

and

John McCallum
382 Country Road #23, R.R.#3
Merrickville, Ontario, K0G 1N0

Table of Contents

1.0 INTRODUCTION **1**

1.1 BACKGROUND 1
1.2 OBJECTIVE 2

2.0 METHODS **4**

2.1 ANALYSIS OF ICE CHARTS AND NORDREG DATA 4
2.2 FIELD VALIDATION REPORTS EXAMINATION 7

3.0 RESULTS **8**

3.1 TYPE E VESSELS 8
3.2 TYPE D VESSELS 10
3.3 SPEEDS WITH ICE DAMAGE 10
3.4 COMBINED TYPE B, D, AND E VESSELS 11
3.5 RUSSIAN EXAMPLES OF VOYAGE SPEED-ICE DATA 12

4.0 SAFE SPEED IN ICE **16**

5.0 CONCLUSIONS AND RECOMMENDATIONS **18**

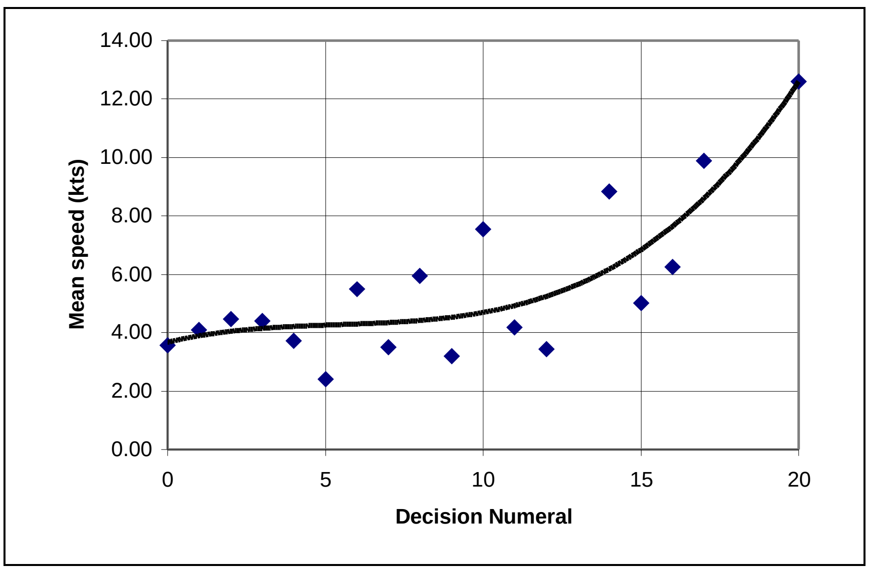
5.1 DATA ANALYSIS METHODOLOGIES 18
5.2 SAFE SPEED 18
5.3 OTHER RESEARCH - FLOE SIZE 19

6.0 REFERENCES **20**

1.0 Introduction

1.1 *Background*

In the Tanker Navigation Safety System (TNSS)[1] study an investigation was made into the relationship between historical transit speeds in ice and the corresponding Ice Decision Numeral as calculated using the Ice Regime Shipping System (IRSS). This study was used to define a safe speed for ship operations in ice needed for the risk model. Past validation trials of the IRSS on Type B vessels, the most active deep sea vessel type in the Canadian Arctic, were analysed to compare ship speed versus Decision Numeral. Since the Ice Decision Numeral is a function of the concentration of ice types and a multiplier for each type of ship, it was successfully demonstrated that ships historically transit ice at a higher safe speed as ice conditions improve, as indicated below in Figure 1. The study documented a positive trend and relationship between Ice Decision Numeral and ship speed. The resulting correlation was used to hypothesize that given the inputs of ship type and Ice Decision Numeral a safe speed could be determined.



Source: Judson, B., J. Shortreed, et al. 1996. *Tanker Navigation Safety System*. Canarctic and Institute for Risk Research for Transportation Development Centre, Transport Canada

Figure 1: Mean Safe Speed (knots) per Decision Numeral, Type B Ships

These values charted in Figure 1 were calculated for transits in conditions where no ice damage occurred. It was reasoned that the Master establishes the safe speed in accordance with the ice and visibility conditions, all other factors (e.g. mechanical

[1] Judson, B., J. Shortreed, et al. 1996. *Tanker Navigation Safety System*. Canarctic and Institute for Risk Research for Transportation Development Centre, Transport Canada.

problems, etc.) being equal or not important. This is part of the “due caution” of mariners that is referred to in the existing CASPPR regulations.

It is well known and accepted that ice damage is often the result of excessive speed in the ice conditions and that damage often occurs in broken ice in low to moderate concentrations where speed was excessive. To clarify this issue, the report *Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992*[2] states “It has been shown that 20 to 30% of damages occur in ice regimes having relatively high positive Ice Numerals. Such damages are usually the result of inadequate caution and/or poor judgement, and frequently occur even when the ship is under the command of a Master experienced in navigating Type vessels through ice.” These damages in low ice concentrations are a direct contrast the many voyages which transit even severe ice conditions (i.e. where the ice numeral is negative) where no damage occurs because the Master has reduced speed to match the conditions.

It is an emerging opinion in the Harmonization of Polar Rules that the Russian ice passport system which defines a safe ship speed and serves as a guideline to the Master navigating in Russian Arctic waters has considerable merit, and that its use should be seriously considered in the Polar Ship rules. A weakness in CASPPR and the IRSS is that no limit to ship speed is imposed. It would be prudent to establish speed limits if there is data to support them, and such speed limits would align CASPPR closer to the Russian ice passport system. Adopting this convention should be based on evidence that there is a relationship between speed and ice conditions, and that this relationship may or may not vary with ship class. The determination of safe ship speed versus Decision Numeral would tie the IRSS to ship speed and, through one relationship, define the operating parameters for vessels navigating in Arctic and possibly Antarctic waters.

1.2 *Objective*

This study analyzes the field validation trial reports[3], 1991 Nordreg reports and ice charts to assess the hypothesis that there is a correlation between Ice Decision Numeral and safe

[2] Wells, D., A. Keinonen and C. Revill. 1993. *Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992*. Report prepared by Norland Science and Engineering Ltd. and AKAC Inc. for Canadian Coast Guard Northern. TP-11691E.

[3] Hagen, D and D Wells. 1994. *Field Validation Trials of the Proposed ASPPR Ice Regime Shipping Control System MT Hubert Gaucher, July 23 to August 1, 1992*. Norland Science & Engineering Ltd.

Nazarenko, D and D Wells. 1994. *Field Validation Trials of the Proposed ASPPR Ice Regime Shipping Control System MV Federal Polaris*. Norland Science & Engineering Ltd.

Norland Science and Engineering. 1995. *Trial Implementation and Verification of the Proposed ASPPR Ice Regime Shipping Control System on Board Fednav Vessels*. Norland Science & Engineering Ltd. and FEDNAV Limited.

speed for Type B, D and E vessels. The objective of this study is to validate the hypothesis of the TNSS study which links safe ship speed and Ice Decision Numerals and to determine a historical safe speed for various vessel types.

Wells, D. 1990. 1989 *Field Validation of the Proposed ASPPR Ice Regime Shipping Control System onboard MV Lucien Paquin*. Report prepared by Norland Science & Engineering Ltd. for Canadian Coast Guard Northern.

Wells, D. A. Keinonen and C. Revill. 1993. *Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992*. Report prepared by Norland Science & Engineering Ltd. and AKAC Inc. for Canadian Coast Guard Northern.

Wells, D. D. Nazarenko and D. Hagen. 1992. *Field Validation Trials of the Proposed ASPPR Ice Regime Shipping Control System MV ARCTIC, 1990 and MV FEDERAL FUJI, 1991*. Report prepared by Norland Science & Engineering Ltd. for Canadian Coast Guard Northern.

2.0 Methods

This study requires the analysis, validation and synthesis of data from field trials, the 1991 Nordreg report, and 1991 ice charts. The use of these data sources is discussed below.

2.1 *Analysis of Ice Charts and Nordreg Data*

Nordreg reports list ship arrival and departure times to within a one minute accuracy and can be used for the determination of average speed. The ice charts enable one to calculate the Ice Decision Numerals for each ice polygon and a proportional average Ice Decision Numeral for an entire voyage.

The process used to produce the data file and map of transits from a Nordreg report is as follows:

1. Scan and OCR Nordreg data and convert to data file. Note: This study used only the port departure and arrival data.
2. Sort by vessel name/month/day/time to get schedule and calculate voyage duration.
3. Plot voyages using most convenient route to get distance; calculate speed as distance in nautical miles/voyage duration in hours (Figure 2). Note: The speeds used for the Type D and E vessels were average speeds from port to port. The speeds used for Type B vessels were average speeds over several ice regimes as documented by Norland[4].
4. Check data for 44 of 135 records which indicated speeds over 15 knots and less than 3 knots to help identify data entry errors. Of these records, 14 errors in Nordreg data were noted as suspect and one obvious Nordreg error in month was corrected.
5. Adjust routes to minimize Ice Decision Numeral. The assumption used here was that the shortest distance between ports was not an accurate representation of the route taken since avoiding heavier ice conditions is not taken into consideration. Therefore, this route adjustment was done to provide a more accurate simulation of voyage transits.
6. Calculate the proportional average Decision Numeral of each voyage. This is accomplished by taking the average of the Decision Numerals in each polygon transited by a single voyage weighted by the distance traveled in each ice regime polygon.

---

[4] Wells, D., A. Keinonen and C. Revill. 1993. *Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992*. Report prepared by Norland Science and Engineering Ltd. and AKAC Inc. for Canadian Coast Guard Northern. TP-11691E.

Classification of Nordreg transits by ASPPR ice class was possible for all but two records. The Nordreg data for 1991 provided a sufficient number of transits for the analysis of Type D, E and B vessels (Table 1). Since Type B were examined in the earlier study, Types E and D were examined further. Of the 42 Type E transits, and 32 Type D transits, 12 suspect records were removed (6 from the Type E sample and 6 from the Type D sample).

Table 1: 1991 Nordreg Transits by ASPPR Class

Type	Count
3	1
B	57
E	42
D	32
Unknown	2

The next requirement was to digitize ice charts for ice conditions covering the closest period to each transit (Figure 3). The polygons demarking the limits of an ice regime were created in MapInfo by digitizing AES ice charts. Only those parts of the ice chart which were transited were digitized. This resulted in the creation of 20 ice charts in vector format used for the analysis of Type D and E transits.

A short algorithm was run which calculated the Ice Decision Numeral for Type E ships for each ice polygon on each chart. The standard ASPPR Ice Multipliers were used in this calculation (See Appendix A). Another short algorithm was run to calculate the proportional average Ice Decision Numeral for each transit[5]. Please note that the method used to calculate the Ice Decision Numeral did not apply a correction for escort and that the use of escort was not recorded in the 1991 Nordreg report data. This process was repeated for Type D transit records.

[5] The proportional average Decision Numeral was calculated by taking the average of the Decision Numerals in each polygon transited by a single voyage proportioned by the distance traveled in each polygon.

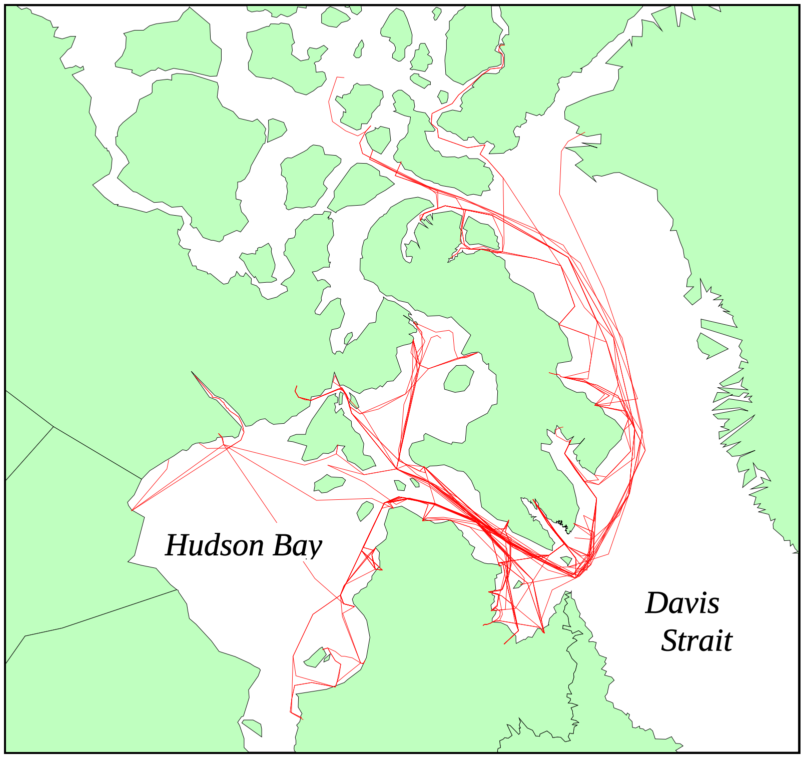


Figure 2: Sample Voyage Routes, Nordreg 1991

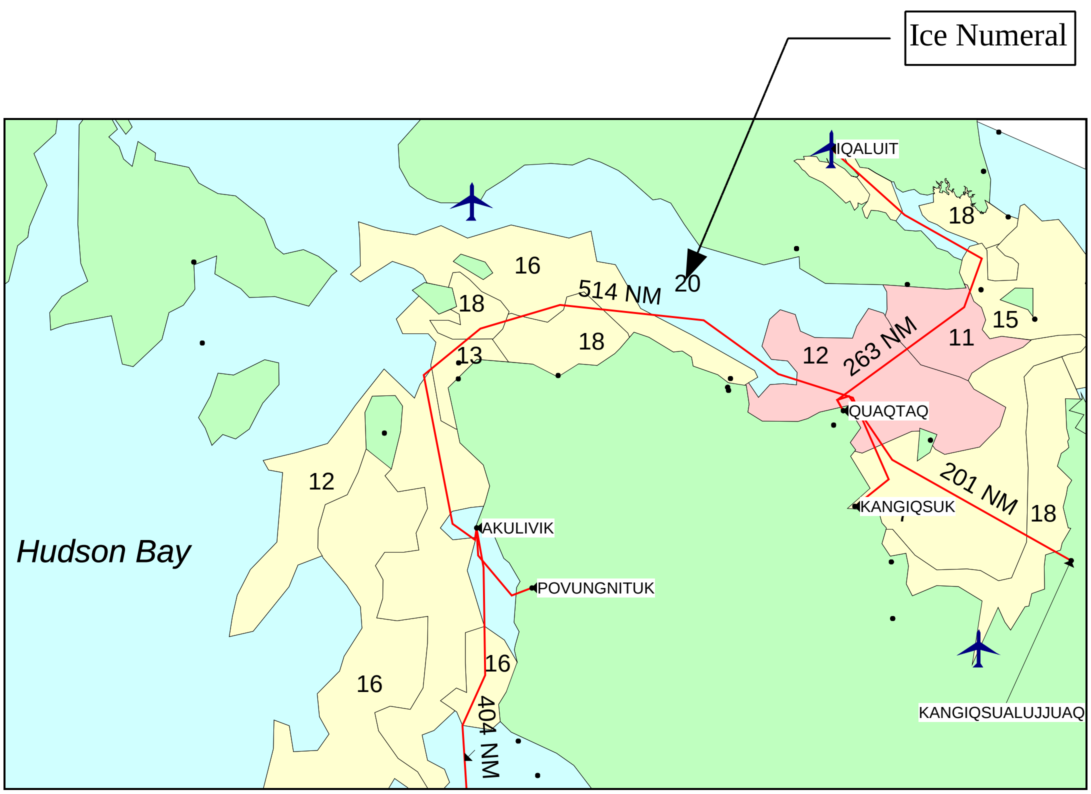


Figure 3: Ice Sheet for July 7, 1991 with Type E Transits (July 3 to 20)

2.2 *Field Validation Reports Examination*

Norland reports were examined for performance data on vessels other than Type B. Other than data on the MV Arctic, only the report *Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992*[6] contained data on vessels other than Type B. This report listed 86 incidents of ice damage but did not provide information on speed. In addition, only five transit records containing ship name, ice conditions and average speeds were available for non-Type B vessels (see Table 2).

Table 2: Non Type B Vessel Data in Field Validation Reports

Date	Vessel Name	ASPPR Ice Class
29-Aug-78	Sir Humphrey Gilbert	A
29-Aug-78	Sir Humphrey Gilbert	A
25-Jun-79	Canmar Explorer III	C
25-Jun-79	Canmar Explorer III	C
31-Jul-84	Evangelia C	E

However, 17 transits resulting in ice damage provided an Ice Decision Numeral, vessel ASPPR Type and average speed. These data were used to assess a correlation between Ice Decision Numeral and *unsafe* speed for the ice circumstances.

[6] Wells, D., A. Keinonen and C. Revill. 1993. *Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992*. Report prepared by Norland Science and Engineering Ltd. and AKAC Inc. for Canadian Coast Guard Northern. TP-11691E.

3.0 Results

3.1 *Type E Vessels*

Most Type E vessels transit in waters where the Ice Decision Numeral is 20. Since in these conditions, speed is relatively unaffected by ice, average transit speeds ranged from 0.2 to 15 knots. Only 10 of 36 transits occurred with a Ice Decision Numeral of less than 20; of these, the lowest Ice Decision Numeral was 10 (Table 3). A linear fit analysis was performed on the 10 transits by Type E vessels with an Ice Decision Numeral of less than 20.

Figure 4 and 5 graph the Type E and B transit speeds respectively. Figure 4 was created using the 10 transits discussed above. Figure 5 was created from data records from the TNSS analysis (Judson, 1996) where the transit Ice Decision Numerals were greater than 10. A comparison between these two figures illustrates the weak but positive relationship between speed and Ice Decision Numeral. This relationship is weak due to the small size of the sample used (90% confidence limits speed 3.9 kts $< \sigma <$ 8.9 kts).
. Further work could be done to clarify this relationship by expanding the data set of this analysis.

Observations:

1. Variation in speed is greater at larger Ice Decision Numerals in both Type B and E samples,
2. Both figures indicate a positive trend, and
3. Vessels travel at about 10 knots in Ice Decision Numeral 19 conditions.

Table 3: Type E Transit Data, 1991

VESSEL	Speed in Knots	Decision Numeral	Distance in NM	FROM	TO	ETD_DTG	ETA_DTG	HOURS	Ice_Chart
JAZ DESGAGNES	4.8	20	66	POVUNGNITUK	AKULIVIK	7/4/91 22:00	7/5/91 11:42	13.7	HUD0707
JAZ DESGAGNES	5.5	20	112	SANIKILUAQ	KUUJJUARAPIK	7/10/91 17:00	7/11/91 13:24	20.4	HUD0707
JAZ DESGAGNES	7.1	20	163	AKULIVIK	INOUCDJOUAC	7/14/91 22:36	7/15/91 21:33	23.0	HUD1407
JAZ DESGAGNES	6.4	20	171	KUUJJUARAPIK	FORT GEORGE	7/21/91 9:15	7/22/91 12:09	26.9	HUD2107
JAZ DESGAGNES	6.3	20	101	SANIKILUAQ	UMIUJAC	7/22/91 19:00	7/23/91 10:57	16.0	HUD2107
JAZ DESGAGNES	3.3	20	91	UMIUJAC	KUUJJUARAPIK	7/24/91 22:00	7/26/91 1:48	27.8	HUD2107
JAZ DESGAGNES	6.4	20	171	KUUJJUARAPIK	FORT GEORGE	7/27/91 13:30	7/28/91 16:18	26.8	HUD2807
JAZ DESGAGNES	6.3	20	66	POVUNGNITUK	AKULIVIK	7/31/91 9:24	7/31/91 20:00	10.6	HUD2807
KEEWATIN	0.2	20	121	CHESTERFIELD INLI	WHALE COVE	7/1/91 17:00	7/29/91 5:00	660.0	HUD1407
KEEWATIN	8.1	20	142	CHURCHILL	ESKIMO POINT	7/5/91 4:30	7/5/91 22:00	17.5	HUD0707
KEEWATIN	5.8	20	166	BAKER LAKE	CHESTERFIELD INLI	7/14/91 11:30	7/15/91 16:00	28.5	HUD1407
KEEWATIN	6.6	20	469	CHURCHILL	BAKER LAKE	7/17/91 0:15	7/19/91 23:00	70.8	HUD2107
KEEWATIN	7.2	20	270	CHURCHILL	RANKIN INLET	7/21/91 3:00	7/22/91 16:45	37.8	HUD2107
MATHILDA DESGAGNES	13.3	20	222	KUUJJUAQ	QUAKTAQ	9/27/91 16:00	9/28/91 8:45	16.8	HUD2909
MATHILDA DESGAGNES	7.0	20	66	POVUNGNITUK	AKULIVIK	7/17/91 8:00	7/17/91 17:30	9.5	HUD1407
MATHILDA DESGAGNES	6.7	20	73	AUPALUK	TASIUJAQ	7/27/91 16:30	7/28/91 3:20	10.8	HUD2807
MATHILDA DESGAGNES	4.2	20	110	TASIUJAQ	KANGIQSUK	7/30/91 16:00	7/31/91 18:00	26.0	HUD2807
MATHILDA DESGAGNES	5.5	20	66	AKULIVIK	POVUNGNITUK	9/3/91 0:30	9/3/91 12:30	12.0	HUD0109
MATHILDA DESGAGNES	9.2	20	154	POVUNGNITUK	INOUCDJOUAC	9/5/91 18:00	9/6/91 10:45	16.8	HUD0109
MATHILDA DESGAGNES	11.2	20	285	INOUCDJOUAC	IVUJIVIK	9/8/91 17:00	9/9/91 18:30	25.5	HUD0109
MATHILDA DESGAGNES	13.4	20	410	IVUJIVIK	KANGIQSUK	9/10/91 9:30	9/11/91 16:00	30.5	HUD1509
MATHILDA DESGAGNES	10.3	20	65	KANGIQSUK	AUPALUK	9/11/91 20:30	9/12/91 2:50	6.3	HUD1509
MATHILDA DESGAGNES	15.0	20	150	GEORGE RIVER	KANGIQSUK	9/14/91 11:00	9/14/91 21:00	10.0	HUD1509
MATHILDA DESGAGNES	10.2	20	64	KANGIQSUK	AUPALUK	9/16/91 11:00	9/16/91 17:15	6.3	HUD1509
MATHILDA DESGAGNES	10.5	20	76	AUPALUK	TASIUJAQ	9/18/91 3:30	9/18/91 10:45	7.3	HUD2209
MATHILDA DESGAGNES	0.6	20	134	TASIUJAQ	KANGIQSUALUJJUA	9/20/91 13:30	9/29/91 14:00	216.5	HUD2209
CATHERINE DESGAGNES	15.7	19	1264	THULE, GREENLANI	IQALUIT	7/27/91 7:35	7/30/91 16:00	80.4	HUD2807, BAF0808
CATHERINE DESGAGNES	16.6	19	460	HALL BEACH	CAPE DORSET	8/18/91 9:00	8/19/91 12:45	27.8	FOX1508,HUD1808
CATHERINE DESGAGNES	2.5	19	308	CAPE DORSET	REPULSE BAY	8/20/91 2:00	8/25/91 4:00	122.0	HUD1808
JAZ DESGAGNES	4.2	19	405	AKULIVIK	KUUJJUARAPIK	7/5/91 12:54	7/9/91 13:00	96.1	HUD0707
MATHILDA DESGAGNES	9.8	18	693	IQALUIT	POVUNGNITUK	7/13/91 13:30	7/16/91 12:00	70.5	HUD1407
CATHERINE DESGAGNES	6.1	17	207	IGLOOLIK	LONGSTAFF BLUFF	8/4/91 18:00	8/6/91 4:00	34.0	BAF0808
CATHERINE DESGAGNES	7.8	16	215	LONGSTAFF BLUFF	HALL BEACH	8/8/91 8:30	8/9/91 12:00	27.5	BAF0808
MATHILDA DESGAGNES	2.1	15	514	AKULIVIK	KANGIQSUK	7/10/91 1:00	7/20/91 9:30	248.5	HUD0707
MATHILDA DESGAGNES	8.9	14	264	QUAKTAQ	IQALUIT	7/11/91 8:00	7/12/91 13:30	29.5	HUD0707
MATHILDA DESGAGNES	1.4	10	202	GEORGE RIVER	QUAKTAQ	7/3/91 23:00	7/9/91 20:30	141.5	HUD0707

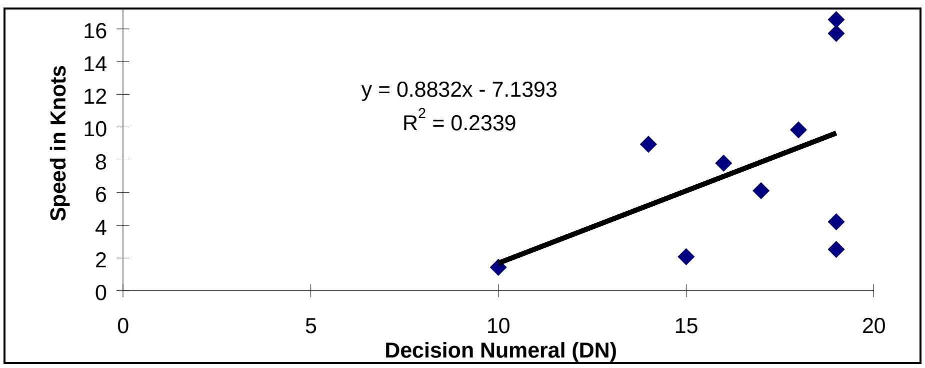


Figure 4: Speed per Decision Numeral, Type E, DN < 20

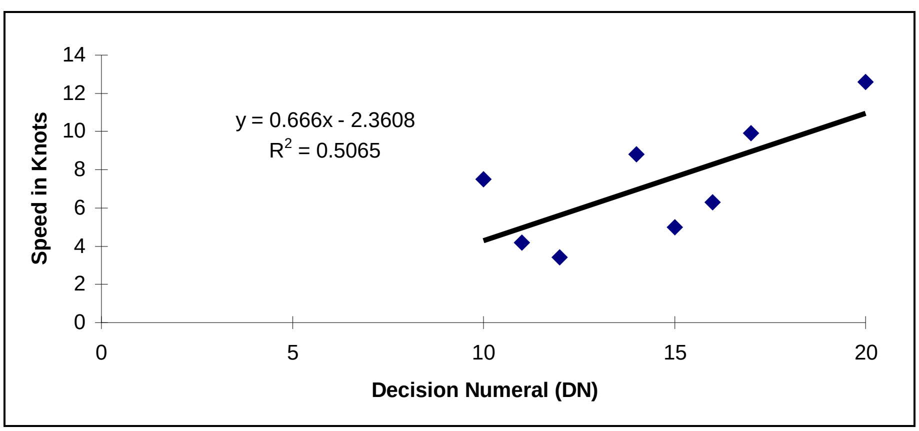


Figure 5: Average Speed per Decision Numeral, Type B, DN > 10

3.2 *Type D Vessels*

Like Type E vessels, most Type D vessels also transit in waters where the Ice Decision Numeral is 20. However, average transit speeds were greater and ranged from 3.5 to 22.7 knots. Only six of 26 transits occurred with a Ice Decision Numeral of less than 20; of these, the lowest Ice Decision Numeral was 15 (Table 4). A trend analysis was not performed on these six transits because of confidence limitations.

Table 4: Type D Transit Data, 1991

VESSEL	Speed in Knots	Decision Numeral	Distance in NM	FROM	TO	ETD_DTG	ETA_DTG	HOURS	Ice_Chart
AIVIK	11.1	20	362	INOUCDJOUAC	SALLUIT/SAGLOUC	7/29/91 0:30	7/30/91 9:00	32.5	HUD2807
AIVIK	11.6	20	135	SALLUIT/SAGLOUC	CAPE DORSET	7/30/91 21:00	7/31/91 8:40	11.7	HUD0707
AIVIK	10.4	20	924	IQALUIT	IGLOOLIK	8/5/91 13:30	8/9/91 6:00	88.5	HUD0408,BAF08
AIVIK	3.5	20	50	IGLOOLIK	HALL BEACH	8/10/91 22:00	8/11/91 12:30	14.5	BAF0808
AIVIK	12.6	20	900	HALL BEACH	BREVOORT	8/12/91 13:50	8/15/91 13:30	71.7	HUD1808, BAF0
AIVIK	17.2	20	732	CLYDE RIVER	ARCTIC BAY	8/21/91 12:15	8/23/91 6:45	42.5	BAF2208
AIVIK	10.8	20	200	ARCTIC BAY	POND INLET	8/24/91 8:30	8/25/91 3:00	18.5	LAN2508,BAF29
AIVIK	11.6	20	1966	POVUNGNITUK	LITTLE CORNWALLIS I	8/25/91 20:35	9/1/91 21:35	169.0	HUD2508,BAF29
AIVIK	13.3	20	514	POND INLET	BROUGHTON ISLAND	8/26/91 23:30	8/28/91 14:00	38.5	BAF2908
AIVIK	12.2	20	287	IQALUIT	LAKE HARBOUR	10/20/91 19:45	10/21/91 19:20	23.6	HUD2010
AIVIK	11.0	20	176	LAKE HARBOUR	SALLUIT/SAGLOUC	10/22/91 15:45	10/23/91 7:50	16.1	HUD2010
AIVIK	12.5	20	266	SALLUIT/SAGLOUC	POVUNGNITUK	10/24/91 2:35	10/24/91 23:55	21.3	HUD2710
ENERCHEM AVANCE	3.6	20	385	REPULSE BAY	IGLOOLIK	8/8/91 20:00	8/13/91 5:40	105.7	BAF0808
LE CEDRE	11.5	20	288	POVUNGNITUK	SALLUIT/SAGLOUC	8/1/91 10:10	8/2/91 11:15	25.1	HUD2807
POLARIS	11.7	20	180	IQALUIT	RESOLUTION ISLAND	8/20/91 19:30	8/21/91 10:50	15.3	HUD1808
POLARIS	16.5	20	379	RESOLUTION ISLAND	CAPE DORSET	8/21/91 15:00	8/22/91 14:00	23.0	HUD2508
POLARIS	11.9	20	200	CAPE DORSET	WALRUS ISLAND	8/22/91 21:00	8/23/91 13:50	16.8	HUD2508
POLARIS	13.2	20	166	WALRUS ISLAND	DIGGES ISLAND	8/23/91 21:30	8/24/91 10:00	12.5	HUD2508
POLARIS	12.7	20	358	DIGGES ISLAND	AKPATOK ISLAND	8/24/91 10:00	8/25/91 14:15	28.3	HUD2508
POLARIS	22.7	20	64	PANGNIRTUNG	KEKERTON HARBOUR	9/6/91 11:40	9/6/91 14:30	2.8	BAF0509
AIVIK	11.6	19	233	BREVOORT	PANGNIRTUNG	8/16/91 0:00	8/16/91 20:00	20.0	FOX1508
LE CEDRE	1.2	19	755	KUUJJUAQ	POVUNGNITUK	7/5/91 8:30	7/31/91 16:00	631.5	HUD2107
POLARIS	13.6	19	245	AKPATOK ISLAND	BUTTERFLY BAY	8/25/91 21:00	8/26/91 15:00	18.0	HUD2508
AIVIK	1.9	18	710	KUUJJUAQ	POVUNGNITUK	7/8/91 0:05	7/23/91 14:00	373.9	HUD1407
AIVIK	3.2	17	162	KANGIQSUK	KUUJJUAQ	7/4/91 9:30	7/6/91 12:00	50.5	HUD0707
AIVIK	6.0	15	290	PANGNIRTUNG	CLYDE RIVER	8/18/91 9:00	8/20/91 9:00	48.0	BAF2208,HUD18

3.3 *Speeds with Ice Damage*

The next step of the analysis was an examination of speeds which resulted in ice damage. The speeds in this analysis were from the Norland report[7] which recorded average speeds leading up to the time damage occurred. The ice damage analysis was then combined with the data records for safe Type B, D, and E vessel transits. Table 5 lists and Figure 6 illustrates the relationship between Ice Decision Numeral and average speeds from the Norland report. Assuming that the strong correlation is representative of unsafe speeds, both high and low, the trendline was then compared to safe speeds in the section following the next analysis of combined data for various Type ships.

[7] Wells, D., A. Keinonen and C. Revill. 1993. *Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992.* Report prepared by Norland Science and Engineering Ltd. and AKAC Inc. for Arctic Ship Safety, Canadian Coast Guard.

Table 5: Decision Numerals and Speeds with Ice Damage

Norland ID	ASPPR	DN	Speed
16	C	-40	0.2
16	C	-40	1.6
78	B	-40	2
35	B	-22	5.5
83	B	-16	7
87	B	-16	0.3
35	B	-6	6.3
47	C	-2	10.3
54	B	-1	4.5
8	A	0	7.5
35	B	4	12.8
8	A	8	9
54	B	8	6
79	B	8	10
35	B	10	13
54	B	20	16.5
54	B	20	17

Source: Appendix C in Norland Science and Engineering Ltd., 1993.

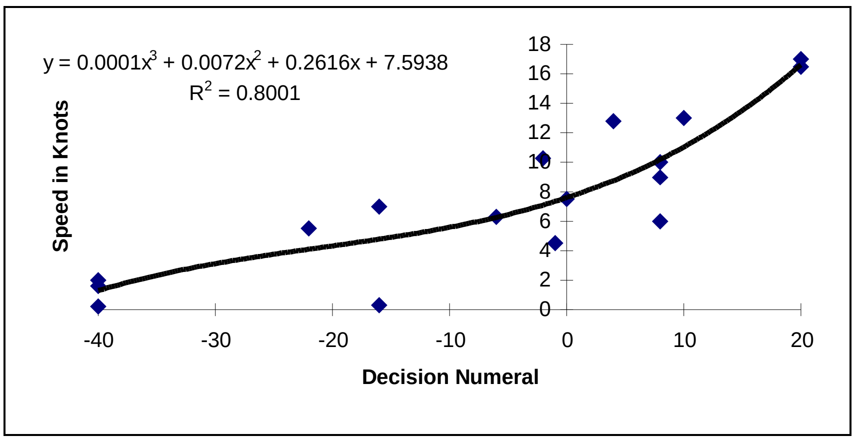


Figure 6: Speeds with Ice Damage

3.4 *Combined Type B, D, and E Vessels*

A total of 362 transit records from Type B, D and E vessels were analyzed to determine if a correlation exists between transit speed and the Ice Decision Numeral (60 records is the required sample size for 95% confidence for a maximum error of ± one knot). An interval data set of average speeds for each Ice Decision Numeral from 0 to 20 was created and plotted with error bars for one standard deviation, Figure 7. A significant correlation would suggest that the Ice Decision Numeral algorithm is a good measure of vessel performance and speed in ice. In theory, these transits represent the range of average safe speeds given the known ice conditions and the unknown weather, seastate, traffic density and presence or not of an escort vessel.

Figure 7 shows a trendline indicating the average safe speed which corresponds to various Ice Decision Numerals for these three Types of vessels. Figure 7 also shows that low positive Ice Decision Numerals are a better predictor of safe speed. More variation in speed is apparent at larger Decision Numerals. These speed variations, particularly those occurring at larger Decision Numerals, are a reflection of the diversity in actual sailing conditions (e.g. weather, mechanical difficulties, etc.). It must be recognized that for Ice Decision Numerals less than 15 ice conditions are the major factor affecting the speed of the vessel - weather and other factors are secondary. For Ice Decision Numerals above 15 ice conditions become secondary and other factors take precedence, hence the larger range of speeds calculated.

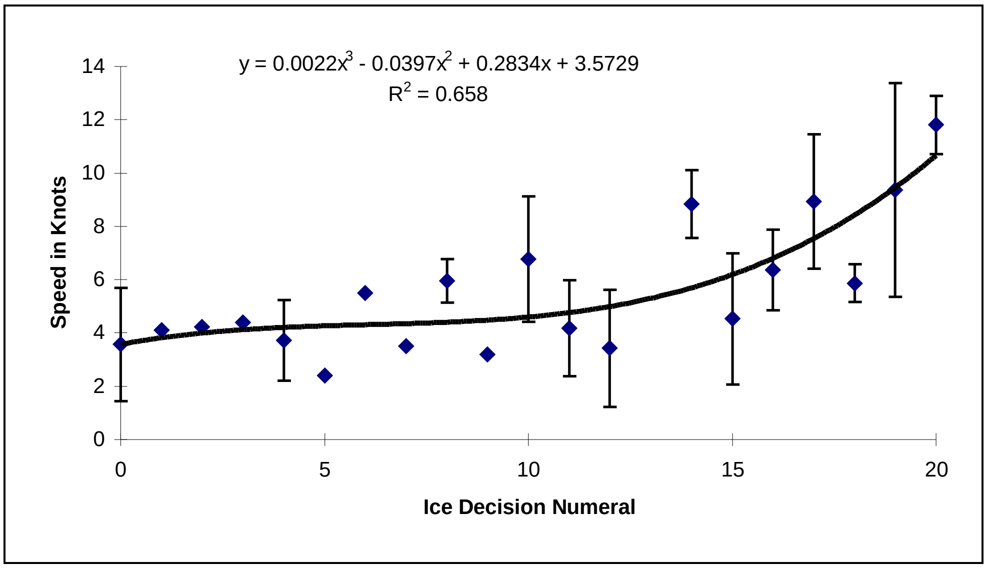


Figure 7: Mean Speeds with 1 SD, Type B, D, and E Ships

3.5 *Russian Examples of Voyage Speed-Ice Data*

In the report *Ice Regime Shipping Control System* **-** *Verification of the System as Applied to the Navigation of Russian Ships in the Arctic*[8] six past voyages in the Arctic were studied. In Part 2 which is a discussion of that report by J. McCallum four graphs are presented (Figures 8 to 11 below). These graphs plot speed against Ice Decision Numeral and there is a broad trend of reduced speed with decreasing Ice Numerals. These Russian voyages were for icebreaker escorted transits of higher ice class vessels (UL and ULA)

[8] Canarctic and Central Marine Research and Design Institute. 1996. *Ice Regime Shipping Control System* **-** *Verification of the System as Applied to the Navigation of Russian Ships in the Arctic* . Final report prepared for Ship Safety, Prairie and Northern Region, Transport Canada submitted April 1996.

and are therefore not directly comparable to the Type B, D and E transits examined in this study. However, the speed - Ice Numeral trend results are similar to those obtained in the analysis of Types B, D and E ships.

The Russian voyages are noteworthy because they demonstrate the relationship between speed and Ice Decision Numeral for actual voyages where detailed data was collected. It can readily be seen from the graphs that the ships sometimes moved at considerable speeds in areas with negative numerals and high concentrations. This likely happens because there is less than 10/10ths concentration with a passage through between the floes. For example, at one point the Kapitan Myshevsky (Figure 8) was moving at 10 knots in 9/10ths thick first-year ice and 1/10th open water where the Ice Numeral was -16. The 1/10th open water consisted of leads (fractures) which allowed the vessel to navigate through the floe at a quick speed. It can also be seen that the ships often proceeded slowly in ice regimes with positive numerals. An ice type with a positive multiplier may slow the ship because it is thick or under pressure. Obviously speed is influenced by many different factors.

Figure 8: Plot of Speed Against Ice Numeral for Kapitan Myshevsky

Escorted by Icebreaker Sibirj

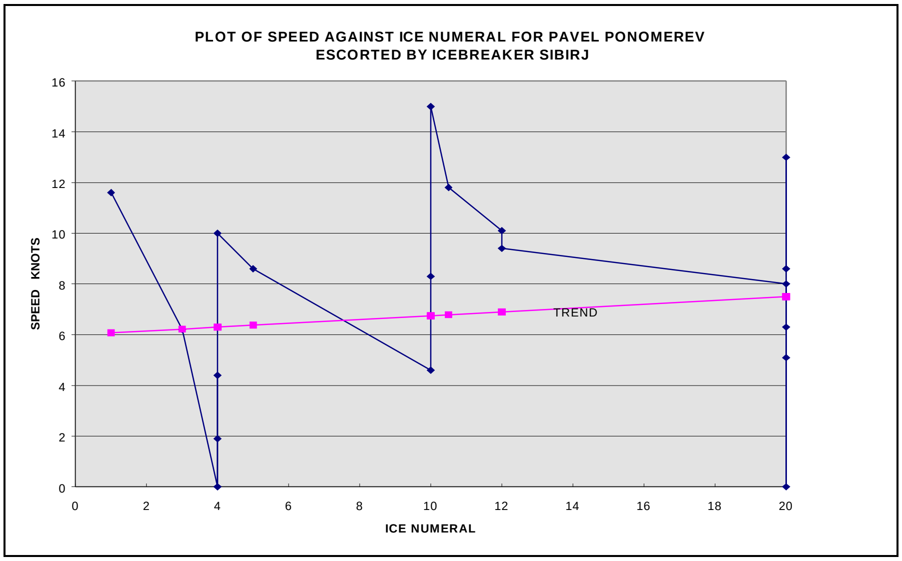


Figure 9: Plot of Speed Against Ice Numeral for Pavel Ponomerev Escorted by Icebreaker Sibirj

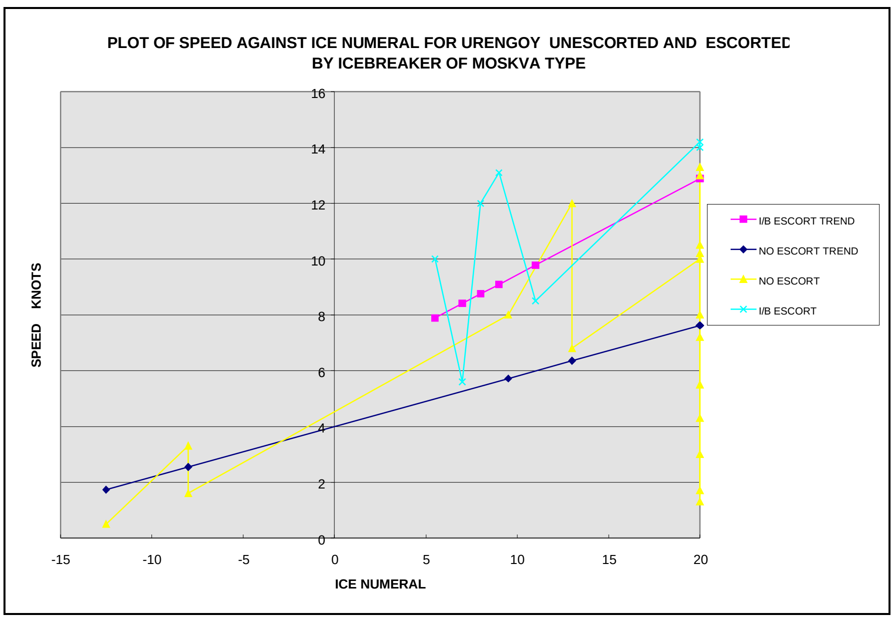


Figure 10: Plot of Speed Against Ice Numeral for Urengoy Unescorted and Escorted by Icebreaker of Moskva Type

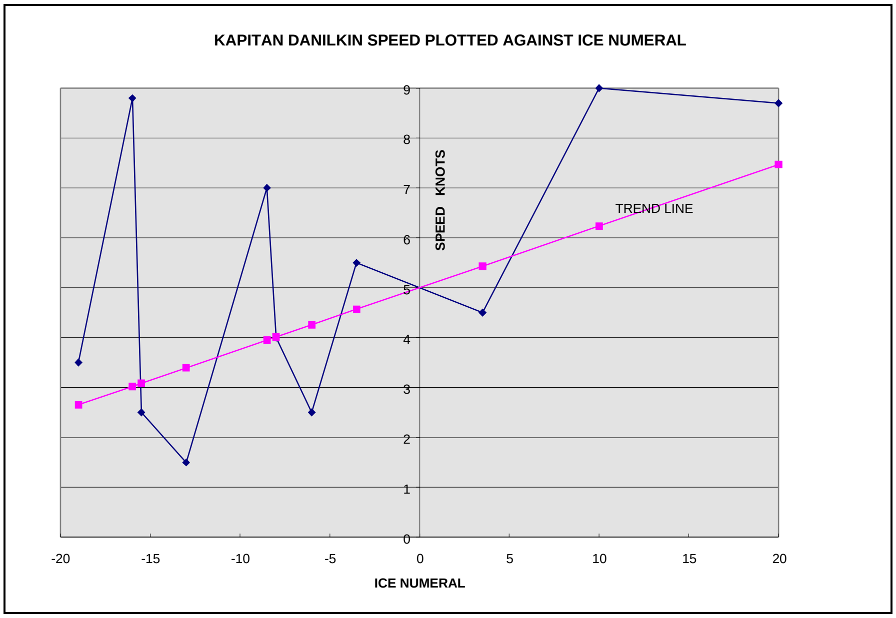


Figure 11: Kapitan Danilkin Speed Plotted Against Ice Numeral

4.0 Safe Speed in Ice

Figure 12 is provided as a preliminary guideline for establishing safe speeds in different ice conditions for Type ships. It reflects successful transit speeds as it was created from the TNSS transit records and applies an upper and lower safe speed boundary of one standard deviation to the trendline illustrated in Figure 7. It also shows a trendline from Figure 6 which illustrates unsafe speeds where damage was sustained by the vessel. The standard deviation applied ranged from ± 2 for Ice Decision Numeral 0 and ± 4 for Ice Decision Numeral 20. The lower boundary would be suitable for poor visibility or seastates and the upper boundary would be applicable for optimum weather conditions. Speeds are listed in Table 6.

Table 6: Historical Speed in Knots for Decision Numerals

DN	Mean	Low	High	Unsafe
0	4	2	6	7.6
1	4	2	6	7.9
2	4	2	6	8.1
3	4	2	6	8.4
4	4	2	7	8.8
5	4	2	7	9.1
6	4	2	7	9.4
7	4	2	7	9.8
8	4	2	7	10.2
9	5	2	7	10.6
10	5	2	8	11.0
11	5	2	8	11.5
12	5	2	8	11.9
13	5	2	9	12.4
14	6	2	9	12.9
15	6	3	10	13.5
16	7	3	11	14.0
17	8	4	11	14.6
18	9	5	12	15.2
19	10	6	14	15.8
20	11	7	15	16.5

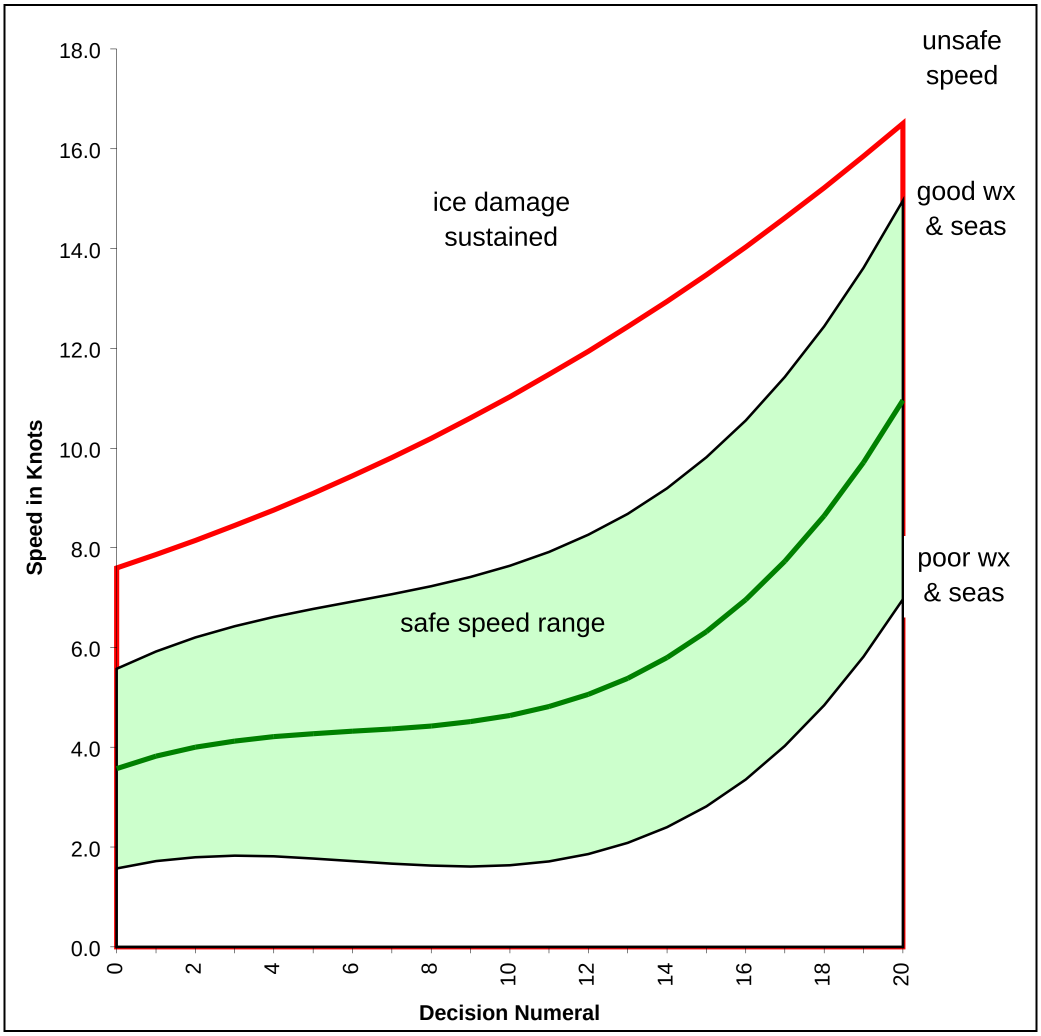


Figure 12: Safe Speeds in Ice and Weather Conditions

5.0 Conclusions and Recommendations

5.1 *Data Analysis Methodologies*

The analysis of Nordreg data was possible because the data records for 1991 included place and time to the nearest minute. By digitizing ice charts, feasible routes were plotted in MapInfo and Ice Decision Numeral and transit distances were estimated. Without detailed time information, average speeds could not be calculated from this source. Other Nordreg reports only included day of arrival and departure.

More confidence could be provided to this analysis by further work accessing other Nordreg data with details of departure and arrival times. Noon position reports could be used to provide more accurate route and speed calculations. The Ice Regime Validation Voyages should be searched for further detailed data. In further work the temporal scope of the work should be expanded and an emphasis should be placed on finding valid data for transits occurring in many different years, particularly those recorded as heavy ice years.

More emphasis needs to be placed on finding valid data for different Types of ships in order to ascertain whether the Ice Decision Numeral - Transit Speed curve is the same shape for different Type vessels. It would also be beneficial to test the curve against detailed data from actual transits similar to those discussed in the Russian example. This type of analysis would provide a reality check of the curves derived through this and subsequent studies.

5.2 *Safe Speed*

Field studies provided the most data for analysis, but this was predominantly for Type B vessels. Studies of transits with ice damage proved useful for setting an unsafe speed boundary given an Ice Decision Numeral. It is suggested that variation in transits speeds is partially explained by weather conditions and vessel operational speeds.

The Figure 12 summary could provide the necessary basis for establishing preliminary safe speed guidelines for navigation in ice covered waters when using the ASPPR system. Most vessels transit at speeds within one standard deviation of the predicted average safe speed. As speeds approach the unsafe speed line, the probability of an accident would increase dramatically.

Further work to sample vessels and distinct weather conditions would enable increased confidence in the Ice Decision Numeral—Transit Speed correlation and propose safe speed ranges in different visibility, weather and other hazards.

5.3 *Other Research - Floe Size*

Work should be undertaken to consider the impact of floe size on transit speed and to integrate the floe size variable into the Ice Regime Shipping System. Floe size, like ice concentration, has a direct impact on the number of contacts the vessel will make with the ice. Floe sizes larger than the turning radius of the ship facilitate reduced contact between the vessel and the ice thereby reducing the potential for damage.

The impact of floe size is seen particularly in lower concentrations of ice (6/10 and lower) where the ship should have the ability to maneuver around the floes. However, if the floe size is smaller than the turning radius of the ship maneuvering around these floes becomes increasingly difficult. In these lower concentration small floe size situations the ship will experience more ship-ice interactions. In Canadian waters where multi-year ice is often present in the floes this increase in ship-ice contact makes the ship more vulnerable to damage regardless of the speed of impact. The potential for damage is significantly increased for lower class ships traveling at accelerated speeds.

Investigating the impact of floe size on transit speed and ship-ice interactions should be done in two ways. First, damage reports should be searched and analysed to specifically consider the floe size of the ice regime the ship was transiting at the time of damage. Secondly, the ship-ice interaction for various floe sizes and concentrations should be simulated. This combination of observed and simulated results would provide a solid basis for defining the impact of floe size on safe ship speeds.

6.0 References

Canadian Coast Guard. 1989. *Proposed Revisions to the Arctic Shipping Pollution Prevention Regulations - Volume 1 - Background.* TP-9981.

Canarctic and Central Marine Research and Design Institute. 1996. *Ice Regime Shipping Control System - Verification of the System as Applied to the Navigation of Russian Ships in the Arctic*. Final report prepared for Ship Safety, Prairie and Northern Region, Transport Canada submitted April 1996.

Canarctic, Central Marine Research and Design Institute and S. Frolov. 1995. *Canadian Participation in the INSROP Demonstration Voyage through the Northern Sea Route*. Report prepared for Ship Safety Northern (AMNS), Transport Canada.

Canarctic and N&R Consult. 1994. *Greenland/Northwest Territories Oil Distribution Plan*. Prepared for the Government of the Northwest Territories and KNI: Canarctic Shipping Company Limited, Ottawa and N&R Consult, Copenhagen.

Hagen, D. and T. Paterson. 1995. *Trial Implementation and Verification of the Proposed ASPPR Ice Regime Shipping Control System On Board FEDNAV Vessels.* Report prepared by Norland Science and Engineering Ltd. and FEDNAV International Ltd. for Canadian Coast Guard Northern. TP-12431E.

Hagen, D. and D. Wells. 1994. *Field Validation Trial of the Proposed ASPPR Ice Regime System, MT Hubert Gaucher, July 23 to August 1, 1992.* Report prepared by Norland Science and Engineering Ltd. for Canadian Coast Guard Northern. TP-11951.

Judson, B., J. Shortreed, et. al. 1996. *Tanker Navigation Safety System.* Canarctic and Institute for Risk Research for Transportation Development Centre, Transport Canada.

Lowings, M.G. 1993. *1982 Navigability Study - MS Columbialand*. Report prepared by Martec Ltd. for Arctic Ship Safety, Canadian Coast Guard.

Nazarenko, D and D Wells. 1994. *Field Validation Trials of the Proposed ASPPR Ice Regime Shipping Control System MV Federal Polaris.* Norland Science & Engineering Ltd.

Norland Science and Engineering. 1995. *Trial Implementation and Verification of the Proposed ASPPR Ice Regime Shipping Control System on Board Fednav Vessels.* Norland Science & Engineering Ltd. and FEDNAV Limited.

Polar Sea Research. 1990. *1989 Field Trial of Proposed Ice Regime Shipping Control System (Escort to/from Eureka Conducted by CCGS Henry Larsen).* Report prepared for Coast Guard Northern, Transport Canada.

Wells, D. 1990. *1989 Field Validation of the Proposed Ice Regime Shipping Control System On Board MV Lucien Paquin.* Report prepared by Norland Science and Engineering Ltd. for Canadian Coast Guard Northern. TP-10060E.

Wells, D., D. Hagen and S. Thomas. 1994. *Field Validation Trial of the Proposed ASPPR Ice Regime System, MV Federal Agno, July 26 to August 6, 1993.* Report prepared by Norland Science and Engineering Ltd. for Canadian Coast Guard Northern. TP-11924.

Wells, D., D. Hagen and S. Thomas. 1994. *Field Validation Trial of the Proposed ASPPR Ice Regime System, MV Federal Polaris, September 7 to 13, 1993.* Report prepared by Norland Science and Engineering Ltd. for Canadian Coast Guard Northern. TP-11925.

Wells, D., A. Keinonen and C. Revill. 1993. *Analysis of Ice Damages Sustained by ASPPR Type Vessels in the Canadian Arctic 1976 to 1992*. Report prepared by Norland Science and Engineering Ltd. and AKAC Inc. for Canadian Coast Guard Northern. TP-11691E.

Wells, D., D. Nazarenko and D. Hagen. 1992. *Field Validation Trials of the Proposed ASPPR Ice Regime Shipping Control System, MV Arctic, 1990, MV Federal Fuji, 1991*. Report prepared by Norland Science and Engineering Ltd. for Canadian Coast Guard Northern. TP-11321E.