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Incorporating Vessels of Opportunity in Exposure Time Estimates for Polar Regions

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Executive Summary

This report provides a methodology for incorporating the potential impact that Vessels of Opportunity (VOO) could have on exposure times in Polar Regions. This methodology complements the exposure time estimations published by Kennedy et al. in 2013 and the generalized equations developed by Piercey et al. in 2019. The additional calculations for incorporating VOO were implemented into a Python program for estimating the exposure time at any location in the Polar Regions. The method presented to quantify the impact of VOO utilizes the same input variables as presented by Piercey et al. in 2019. The additional calculations added to the methodology require the input of relevant historical Automatic Identification System (AIS) data, which includes the potential VOO's operating in the selected area at the time of year that is considered in the emergency scenario.

This report considers two example scenarios to demonstrate the impact that the inclusion of VOO can have on the resulting ranges for exposure times. The selected example scenarios reflect the same scenario parameters as the general emergency scenario presented by Kennedy et al. in 2013. The scenarios investigated in this report occur at the same location in two different months of interest to illustrate the variability of the presence of vessels of opportunity in relation to the time of the year.

Based on the example scenario results for July, it is not expected that there would be a vessel of opportunity in the area that could assist with Search and Rescue (SAR) efforts as the probability calculated was 0.0%. Therefore, the exposure time ranges that were presented without considering VOO are not reduced and represent the estimated exposure times for July with the consideration of VOO. Meanwhile, for August, a probability of 50.0% was generated for the probability of a vessel of opportunity being closer to the scenario than the nearest marine SAR base. Therefore, updated estimations for exposure time considering VOO's were calculated, which reduced the overall estimated exposure time in August. The probability of a VOO impacting the estimated exposure time can be significantly influenced by a number of variables. Several assumptions were made when estimating the impact that VOO may have exposure time which should be carefully considered when using this methodology. For example: the size of the VOO is not considered when estimating the impact; only that a vessel is in a given area. Vessels that are significantly smaller than the vessel in distress may not be able to affect a rescue. It is the responsibility of the voyage planners to determine what variables and level of probability is sufficient to consider the reduction of exposure times due to the presence of VOO.

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1. Introduction

There has been a notable increase in marine traffic throughout the Polar Regions due to varying ice conditions as a result of climate change. The changing ice conditions in the North have opened up the area to different types of vessels that could not operate in the region previously due to ice restrictions. Due to this increasing traffic, the potential risk of a maritime emergency to occur within remote areas of the Polar Regions has risen as well. As a result of the lack of infrastructure and the overall remoteness of these regions, those that are required to evacuate a ship in these areas may have to wait a significant amount of time before being rescued [1]. The International Code for Ships Operating in Polar Waters (Polar Code) was introduced by the International Maritime Organization (IMO) in 2017 to address the unique risks associated with polar travel. One of the stipulations of the Polar Code indicates that all Life-Saving Appliances (LSA) must be capable of providing safe evacuations for evacuees and remain functional for a maximum expected time of rescue that is not less than five days [2].

In 2013, Kennedy et al. published a report that presented a methodology for estimating the length of time a person may be exposed to the environment while awaiting rescue in the Canadian Arctic [1]. The report evaluates the potential exposure times from a marine emergency scenario occurring in eight different locations in the Canadian North. The results presented by Kennedy et al. [1] indicated that individuals awaiting rescue in the Canadian Arctic might be waiting much longer than the maximum expected time of rescue that is indicated in the Polar Code. In these cases, the individuals may be at risk since the LSA would be required to remain functional for a duration longer than the stipulated five days.

In 2019, an additional report was published by Piercey et al. [3] that generalized the Kennedy et al. methodology [1] for estimated exposure time so that it may be utilized by other Polar Nations to assist with their search and rescue efforts. This methodology includes an equation to calculate estimated exposure time that utilizes variables of: craft speed; distance travelled; proximity of fueling locations; capacity of rescue craft; number of evacuees; rescue craft range; number of survival crafts; and other necessary variables. The generalized methodology presented in the report was submitted for consideration to the seventh meeting of the Ship Safety and Equipment (SSE) subcommittee of the IMO. Feedback from other IMO members suggested that implementing vessels of opportunity (VOO) into the estimated exposure time equations may be useful.

Based on this feedback, this report will present a summary of the original generalized methodology for exposure time along with a new version for implementing VOO into the estimation of exposure time. The methodology incorporates the impact that VOO may have on the calculated exposure time by adjusting the final estimated time. The existing exposure time methodology and the additional calculations for incorporating VOO were converted to a computer program using the programming language Python for ease of use in generating exposure time results for a given scenario. This report will consider two example scenarios within the Arctic region to demonstrate the effect of VOO on the estimation of exposure times using this methodology. The example scenarios also provide the reader with an understanding of the variability of VOO presence at different distances from an emergency event and also at different times of the year.

2. Estimated Exposure Time Methodology

The methodology for estimating exposure times was initially developed by Kennedy et al. [1] for a general scenario at different locations within the Canadian Arctic. In 2019, Piercey et al. [3] generalized the previous methodology into a set of equations that could be applied to all Polar Regions to estimate exposure times in these areas. The following sections will briefly discuss the methodology outlined in the previous reports to provide context towards the vessel of opportunity methodology. The original reports [1, 3] can be referenced for more detailed explanations and rationales behind the methodologies.

2.1. Key Terms

The definition of key terms used throughout this report are provided below. Modifying the definition of these terms would alter the results of this study. As such, it is important that the reader be aware of how these terms are defined in the context of this research.

Exposure Time: Exposure time is defined as the total time that an individual, or individuals, are exposed to the elements following a marine evacuation, including any time spent inside a survival craft. The exposure period begins following the first signal of distress from the stricken ship, and the period concludes upon the placement of the final evacuee onto the rescue resource.

Polar Regions: The Polar Regions are defined as the Arctic waters and the Antarctic area as outlined in Regulation 1 of Safety of Life at Sea (SOLAS) Chapter XIV [4].

Vessel of Opportunity (VOO): A VOO is defined as any ship that may be called upon or diverted to assist with a maritime emergency.

2.2. Methodology for Canadian Arctic

The methodology presented by Kennedy et al. [1] provided exposure time equations, specific for the Canadian Arctic, that were developed based on contributions from Canadian Search and Rescue (SAR) experts. The report then summarized the estimated exposure times for selected locations in the Canadian Arctic, as calculated using the exposure time equations that were developed. The analysis was derived from an exposure timeline that includes four main phases of a SAR event: initial communications, travel to location, search period, and rescue activities [1].

Based on the four main phases in the exposure timeline, the following variables were defined in order to calculate exposure time.

- *Communication Time*: This variable is defined as the time elapsed between the initial alert call of the emergency and the departure of the rescue resource(s). This includes the time for the SAR alert to be received at a rescue coordination centre and the time required to identify appropriate rescue resources and collect the required personnel to respond to the emergency. It was noted that at extreme latitudes, this value might be affected by ionospheric and geographical interference with radio waves, resulting in a lag in distress message receipt.

- *Transit Time*: This variable refers to the duration of time between the departure of the rescue resource at its original location to its arrival at the emergency or incident location. This duration of time can vary significantly based on the type of resource, marine, or air, which is responding to the distress call. It includes the time required for the rescue resource to stop and refuel, if necessary, while in transit to an emergency location. Many other factors, such as harsh weather, poor bathymetric data, and inexperience of the crew, significantly increase this duration of time.
- *Search Time*: This variable is defined as the period of time between the arrival of the rescue resource at the incident location and locating the personnel in distress. This duration can vary based on the details of the emergency scenario, such as whether the personnel have abandoned the vessel into survival crafts. The drift speed of the survival crafts based on the wind speed at the incident location is utilized in determining an estimate for this variable.
- *Rescue Time*: This variable refers to the duration of time between locating the distressed personnel and successfully performing rescue operations to get all personnel on board a rescue resource. There are numerous factors that can affect the duration of time for this phase, such as the location of the distressed personnel (aboard the vessel in distress, in a lifeboat, or in the water) and the type of rescue resource performing the rescue operations.

The summation of these four variables was defined by Kennedy et al. [1] as the estimated exposure time for a given incident.

2.3. Generalized Methodology for Polar Regions

The methodology presented by Piercey et al. [3] considered all of the factors that were highlighted by Kennedy et al. [1] that can impact exposure times. Piercey et al. [3] also presented a fifth phase that was added to the exposure timeline that accounts for multiple loads of evacuees, which may be applicable depending on the capacity of the rescue resource(s) available. A number of generalized equations that can be applied to a scenario specified by the user in any location in the Polar Regions were produced. These equations, along with user inputs for the selected scenario, can generate estimates for exposure time for the given maritime emergency.

The combined form of the generalized equations that includes all five phases of exposure time presented by Piercey et al. [3] is shown below. The definitions of the necessary values for the variables are also defined below.

$$t = t_{comm} + t_{prep} + \frac{d_i}{v} + \left(t_{crew} + t_{fuel}\right) \times \beta + t_{search} \times n_l + t_{resc} \times l + \left(t_{shore} + 2\frac{d}{v}\right) \times (l - 1) \quad (1)$$

Where:

$t =$ the total estimated exposure time (h);

$t_{comm} =$ the time elapsed between the stricken ship sending initial communication and SAR personnel receiving it (h);

$t_{prep} =$ the time elapsed between receiving communication and deploying SAR resource (h);

$d_i =$ the distance the rescue resource must travel from its initial location to the last known location of the distressed vessel (nm);

$v =$ the cruising speed of the rescue resource (kt);

$t_{crew} =$ the time for the crew to switch and relaunch (h);

$t_{fuel} =$ the fueling time of the craft (h);

$\beta =$ the number of stops required;
$= \left[\frac{d_i}{r}\right] - 1, \quad \{\beta \in N\}$

$r =$ the range of the rescue craft (nm);

$t_{search} =$ the time elapsed while searching for evacuees to rescue (h);
$= \frac{(t_2) \times v_{drift}}{v_{search}}$

$t_2 =$ the travel time to the incident location, including stops for fuel;
$= \frac{d_i}{v} + (t_{crew} + t_{fuel}) \times \beta$

$v_{drift} =$ the drift speed of the survival craft (kt);

$v_{search} =$ the search speed of the rescue craft (kt);

$n_l =$ the number of lifeboats/life rafts containing the evacuees;

$t_{resc} =$ the total rescue time per rescue attempt (h);
$= t_{r-marine}$
$= t_{r-air} \times cap$

$t_{r-marine} =$ the time elapsed during a rescue for a marine resource (h);

$t_{r-air} =$ the time elapsed during a rescue for an air resource (h);

$cap =$ the total capacity of the rescue resources;

$l =$ the number of loads (rounded to the highest non-decimal number);
$= \left[\frac{n}{cap}\right], \quad \{l \in N\}$

$n =$ the number of evacuees;

$t_{shore} =$ the time spent on shore activities when depositing the evacuees (h);

$d =$ the distance to the nearest safe base to which the evacuees are brought if multiple loads of evacuees are required depending on the capacity of the SAR resource (nm).

The generalized methodology and the resulting equation for exposure time calculations (Equation 1) were incorporated into a computer program using the programming language Python to generate results for exposure time ranges. The results produced by the computer program utilize the existing methodology, user input to define an emergency scenario, and user input to define parameters specific to a given area (e.g., speed of SAR resources) to produce estimations of exposure times.

3. Vessels of Opportunity Methodology

The methodology for vessels of opportunity complements the existing equations by adding a means to compute how the estimated exposure times can vary with the consideration of VOO. It was incorporated into the existing Python code to calculate the estimated exposure time. The method requires the user to input relevant historical Automatic Identification System (AIS) data for potential VOO for the selected area and time of year to generate exposure times. The method utilizes the existing equations outlined in the previous section to provide the user with a low and high range of exposure times when VOO are not considered. These exposure times are provided as there may be scenarios or situations in which the probability of VOO within the area is zero or low. The user-supplied AIS data is sorted and filtered to obtain data relevant to the emergency scenario being investigated. The filtering of this data allows for the calculation of the probability that a vessel of opportunity is near the emergency location and the calculation of the adjusted exposure times based on VOO. The adjusted exposure times are calculated using the original exposure time equation (Equation 1) and modifying the transit phase calculation to be based on the location of the responding vessel of opportunity.

3.1. AIS Data Manipulation

The model begins by considering the user-input AIS data and ensures the data is appropriately filtered to only include data within the month of interest for the selected scenario. The type of AIS data provided by the user (satellite-based or terrestrial-based) will affect the number of potential vessels of opportunity being considered for the scenario as the number of vessels can vary depending on the origin of the data. The filtered data is then divided into bins of 1 degree of latitude between -90° and 90°, and 1° of longitude between -180° and 180°. The model then proceeds to check each of the newly formed bins for the presence of a potential VOO. The location coordinates for each of these bins are also adjusted to correspond to the center of the bin as opposed to the edge.

Geographical distances between each of these bins and the provided location of the emergency are then calculated and recorded. The data are then filtered to include only distances that are less than the distance to the nearest SAR resource base. The distance of the nearest SAR resource is based on the home port location of marine SAR resources in a given jurisdiction. This results in only the VOO inside a circular area with a radius equivalent to the distance to the nearest marine SAR base being included.

3.2. Probability of Vessels of Opportunity

The resulting filtered list of potential VOO is then utilized to determine the overall probability of one being closer to the emergency location than the nearest SAR resource. Each day within the month of interest is counted only if there is a vessel within the area on the given day based on the provided AIS data. It should be noted that each unique day is only counted once, even if there are multiple vessels within the area on the same day. The total count of days within the month with a vessel in the area is then used to determine the probability, as shown below.

$$Probability\ of\ VOO = \frac{Total\ Count}{Total\ Days\ in\ Month} \times 100\% \quad (2)$$

Where:

$Total\ Count =$ the total number of days in which a VOO is present (determined based on the AIS data)
$Total\ Days\ in\ Month =$ the total number of days in the month of interest

3.3. Probability of Reducing Areas

The probability of vessels of opportunity being within the area of the emergency is calculated at different distances (radii) from the emergency scenario. The farthest radii considered is the distance to the nearest SAR resource from the emergency event. Each following radii is decreased by a user-defined set amount. The list of decreasing radii terminates once the value of the next radius is zero (at the emergency location) or it is negative (past the emergency location).

For each radius in the list, the AIS data is filtered to only include the VOO that are closer to the emergency event than the radius distance. The filtered list of VOO for each radius is then used to calculate the corresponding probability of a vessel being within the area by the same process as outlined in the previous section. The resulting probabilities are recorded alongside the corresponding radii in the table.

3.4. Adjusting Estimated Exposure Times

The model also produces new estimates for exposure times (considering VOO) at each of the decreasing radii distances from the emergency event. Estimates for exposure time are generated using the adjusted equation shown below..

$$t = t_{comm} + t_{prep} + \frac{r\_voo}{v} + \left(t_{crew} + t_{fuel}\right) \times \beta + t_{search} \times n_l + t_{resc} \times l + \left(t_{shore} + 2\frac{d}{v}\right) \times (l-1) \qquad (3)$$

Where:
$r\_voo =$ the radial distance from the emergency event to a vessel of opportunity (nm).

The equation is adjusted from Equation (1) by reducing the transit time component to account for the closer proximity of the vessel of opportunity. Instead of inputting the distance to the nearest rescue resource (Equation 1 - d_i), the straight line distance to the nearest vessel of opportunity is calculated using AIS data (Equation 3 r_voo). It should be noted that within the equation 3, the transit speed of the vessel of opportunity is assumed to be equivalent to that of the marine SAR resource.

The adjusted exposure times are not calculated for any radii in which the probability of a VOO within the area is zero percent. The adjusted exposure times for these radii are set equivalent to the recalculated exposure times of the last radii in which the probability of a vessel being within the area was greater than zero. The resulting exposure times for the furthest radius considered from the emergency will always be equivalent to the general exposure time calculations (without considering VOO) as the transit distance is unchanged for this case.

3.5. Assumptions Made

The following assumptions were made in adjusting the estimated exposure time equation to account for vessels of opportunity:

1. It is assumed that the VOO responding to the emergency is capable of transiting to the desired location with the same range of transit speeds as a marine SAR resource. The type of VOO can vary significantly, and the type of vessel can restrict the transit speed which will influence its impact on the overall estimated exposure time. Assuming that a VOO is capable of navigating through challenging environments (ice covered waters, high seas, etc.) at the same speed as a SAR resource is an optimistic assumption and should be considered carefully
2. All vessels contained within the AIS database are considered in the exposure time calculation for VOO. Therefore, it is assumed that all of these vessels can navigate in the given area and support a rescue. Vessel size and type are not considered at this stage, though this will have an impact on the ability to affect a rescue, as smaller gross tonnage ships may not be able to rescue a ship that is significantly larger, such as a fishing vessel trying to rescue a cruise ship.
3. It is assumed that the VOO responding to the emergency is capable of effecting a rescue as efficiently as a marine SAR resource. SAR resources are trained to support rescue events, while a VOO may not be. Depending on the capabilities of the vessel, and the training level of the crew, a VOO may be capable of performing a rescue at an equivalent efficiency of a SAR resource, or at possibly at a reduced amount
4. It is assumed that a VOO is capable of rescuing all evacuees in a single load. The size of the VOO may affect the number of evacuees that the vessel can safely transport in a single load
5. It is assumed that the route taken by the vessel of opportunity is a straight line from its original location to the location of the emergency. Depending on the bathymetry and sea conditions in the area, the actual route the VOO would take may be much longer in distance than the straight line simplification.
6. It is assumed that the ranges for communication time and search time as well as the preparation time are unchanged from the marine SAR resource for the VOO. The values of these parameters may be lower or higher depending on the type and location of the VOO.
7. Canadian Coast Guard Auxiliary locations were not considered within the example scenarios demonstrated in this report as only primary search and rescue assets were included. If a Canadian Coast Guard Auxiliary location has the capability of affecting rescue, then it can be included as a primary search and rescue asset by the end user when estimating exposure time.

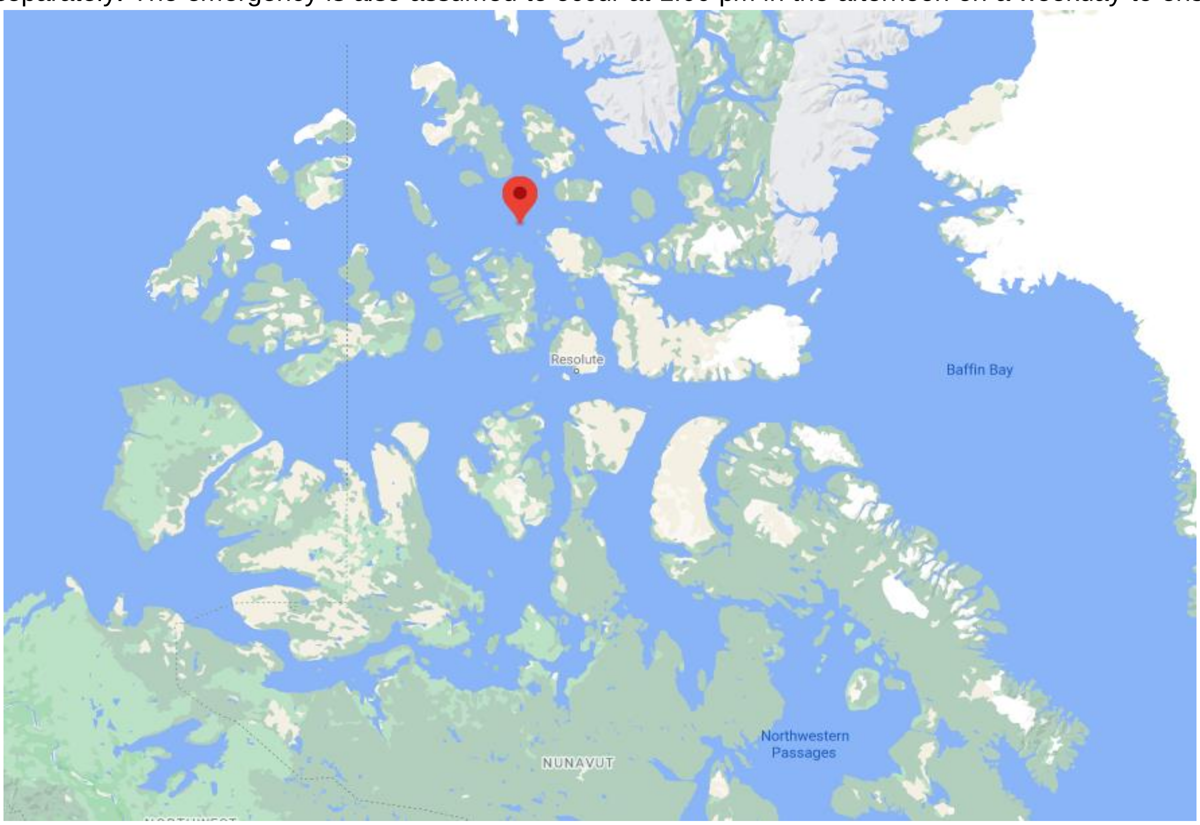
4. Scenario Investigation

A sample scenario was selected to demonstrate the methodology for the inclusion of vessels of opportunity in the estimation of exposure times in Polar Regions. The results produced in the following sub-sections were generated using the computer program developed in Python to produce estimated exposure time ranges for a selected scenario. The selected scenario to be investigated in this section is the same scenario that was selected by Kennedy et al. [1] in their report. The exposure times estimated for this scenario in the 2013 report did not consider VOO. A summary of the scenario inputs is provided in the following section; however, a more detailed explanation concerning the selection of the scenario parameters is provided by Kennedy et al. [1]. This sample scenario was considered for two different months of interest at the same emergency location to investigate how the impact of VOO on exposure times can change at different times throughout the year. The necessary parameters for the selected scenario were used as inputs into the model to return estimates for exposure times with and without the inclusion of VOO.

4.1. Scenario Description

The selected scenario is a marine incident involving the sinking of a vessel with a total of 18 persons on board (POB). The distressed vessel was located at 77.12° N, -98.53° W, which is north of Bathurst Island, Nunavut (

Figure 1). It is assumed that all personnel on board have evacuated successfully into two Totally Enclosed Motor Propelled Survival Craft (TEMPSC) that meet the current SOLAS requirements, but the number of evacuees in each TEMPSC is unknown. All evacuees have donned immersion suits and have not sustained any physical injuries during the evacuation process. It is assumed that this scenario is to occur in the late summer months; thus, the scenario will consider for the months of July and August separately. The emergency is also assumed to occur at 1:00 pm in the afternoon on a weekday to ensure



that potential air SAR resources are on a 30-minute standby as opposed to a two-hour standby.

Based on the location and number of evacuees involved in the emergency scenario, either multiple air resources or one marine resource would be required to effect a rescue of all 18 POB successfully. It is assumed that both of the TEMPSCs are not equipped with an emergency position indicating radio beacon (EPIRB), and the evacuees do not have any means for voice contact with the personnel involved in the SAR efforts. It is assumed that a successful alert was sent out by the distressed vessel prior to sinking that indicated the vessel's location at the time. The two TEMPSCs are equipped with flares that could be used to support the SAR personnel in their search efforts for the evacuees.

Figure 1: Location of sinking vessel when the alert was received by SAR personnel for the selected scenario.

4.2. Area of Interest

As indicated in

Figure 1, the location of the selected scenario is within the Canadian Arctic; thus, the required locations of SAR resources will only include those that would respond to a maritime incident in this area. The initial location of SAR resources responding to an emergency are identified based on the base locations of air and marine SAR resources. For marine SAR resources, an assumption is made that the resources are located at a port in the area. In reality, these resources may be on patrol in different locations during the time of the incident and may be closer to the emergency than predicted in this model. The marine port locations in the Canadian Arctic (Appendix B) were used to determine the nearest and furthest marine SAR resource for this scenario.

Air SAR resources are expected to depart from the nearest air force base to the emergency event and then subsequently refuel and unload rescued evacuees at an airport or airstrip near the emergency. The dataset of the locations of the air bases in Canada (Appendix C) was determined from published information from the Royal Canadian Air Force (RCAF). The dataset of locations for airports and airstrips in the Canadian Arctic (Appendix D) was determined from previous research conducted by Kennedy et al. [1] and recent research into additional locations of airports in the area.

4.3. Scenario Inputs

Based on the description of the selected emergency scenario provided in the previous section, a list of scenario-specific inputs were generated (Table 1).

Table 1: Summary of the scenario-specific inputs for the model

Variable	Symbol	Value
Number of Evacuees	n	18
Number of Lifeboats	n_l	2
Latitude of Emergency	sosx	77.12°
Longitude of Emergency	sosy	-98.53°
Wind speed (average)	w	20 knots

Kennedy et al. [1] presented ranges for the specifications of the SAR resources and components of the exposure timeline. These ranges were developed based on the combination of feedback provided by SAR experts and the results obtained from industry surveys and workshops. The ranges were specific to the Canadian Arctic; thus, they are applicable to the emergency scenario being considered in this section.

A summary of the input values selected for this model for both air and marine SAR resources based on the results provided by Kennedy et al. [1] are presented in Table 2.

Table 2: Summary of the input values for the Canadian Arctic [1]

Resource Type	Variable	Symbol	Value	Units
Marine	Craft speed	v	5-15	knots
	Capacity	cap	1000	
	Range	r	50000	nm
	Communication time	t_{comm}	0-4	h
	Prep time	t_{prep}	0.5	h
	Search Time	t_{search}	2 ± 75% [1]	h/lifeboat
	Rescue Time	t_{resc}	0.5-2	h/lifeboat
Air	Craft speed	v	125-175	knots
	Capacity	cap	12	
	Range	r	500	nm
	Communication time	t_{comm}	0-4	h
	Prep time	t_{prep}	0.5	h
	Search Time	t_{search}	0.5 ± 75%[2]	h/lifeboat
	Rescue Time	t_{resc}	0.167-0.5	h/pers

As mentioned in the previous section, the datasets shown in Appendices B through D are user inputs. If emergency events are to be considered in other Polar Regions outside of the Canadian Arctic, the user would need to input data relevant to their jurisdiction. A dataset of anonymized[3] AIS data for vessels traveling through the Arctic Regions for the months of July and August was used for potential vessels of opportunity.

4.4. Scenario Results

The model first returns the resulting ranges of estimated exposure times to the user for the given maritime emergency without taking vessels of opportunity into account. The results for the exposure time

[1] The marine SAR resource search times are estimated from the same methodology as Kennedy et al. (see Appendix A) using an average wind speed of 20 knots at the scenario location. This average wind speed results in a drift speed of 0.4 knots for the lifeboats, meaning during the transit period of the marine resource, they will drift an additional 30 nm based on the average transit time. Therefore, an additional 2 hours of transit is required for the SAR resource.

[2] The air SAR resource search times are estimated from the same methodology as Kennedy et al. (see Appendix A) using an average wind speed of 20 knots at the scenario location. Again, this wind speed results in a drift speed of 0.4 knots for the lifeboats, meaning during the transit period of an air resource, they will drift less than a nautical mile. Thus, the extra search time is approximated to be a half an hour.

[3] The AIS data did not contain any identifying information about the vessels; only the geographical position of the vessel for a given time period.

range using marine resources corresponds to a resource responding to the emergency that is capable of rescuing all evacuees in one load. The results for the exposure time range using air resources corresponds to one resource responding to the emergency and rescuing the evacuees in two loads. For this scenario, the evacuee drop-off and aircraft refueling occurred at the nearest airstrip in Resolute, NU, which was determined from the user input list of nearby airstrips and airports. The low-end of the ranges was found using the nearest SAR base for the given resource type, and the high-end was found using the maximum distance to a SAR base for the given resource type. A summary of the results produced by the model for the selected scenario based on both marine and air SAR resources are shown in Table 3.

Table 3: Summary of the estimated exposure time ranges without including vessels of opportunity

	Exposure Time (h)		
	Low	**Average**	**High**
Marine	25.9	127.3	228.7
Air	17.3	25.2	33.0

The results displayed above have the same low range estimates of exposure time as that indicated in the Kennedy et al. [1] report. The high range is different due to the different approach used to consider the resource location. In Kennedy et al. [1], the marine base location was not considered. Instead, the location of vessels on patrol at the specific time of year considered in the scenario was considered based on input from SAR experts. To generalize the methodology and provide a way to estimate exposure times for different scenarios and locations, the SAR bases were used as a means of estimating the lower and upper exposure time ranges. The following sections investigate the impact that the inclusion of VOO can have on the resulting ranges for exposure times for the selected scenario presented above.

4.4.1. Vessel of Opportunity Results (July)

The AIS data was input as historical data for potential VOO. Figure 2 depicts the locations of these vessels in relation to the location of the selected emergency scenario for the month of July. The blue markers represent the locations of a potential VOO, the pink marker represents the location of the emergency, and the red marker represents the location of the nearest marine SAR base.

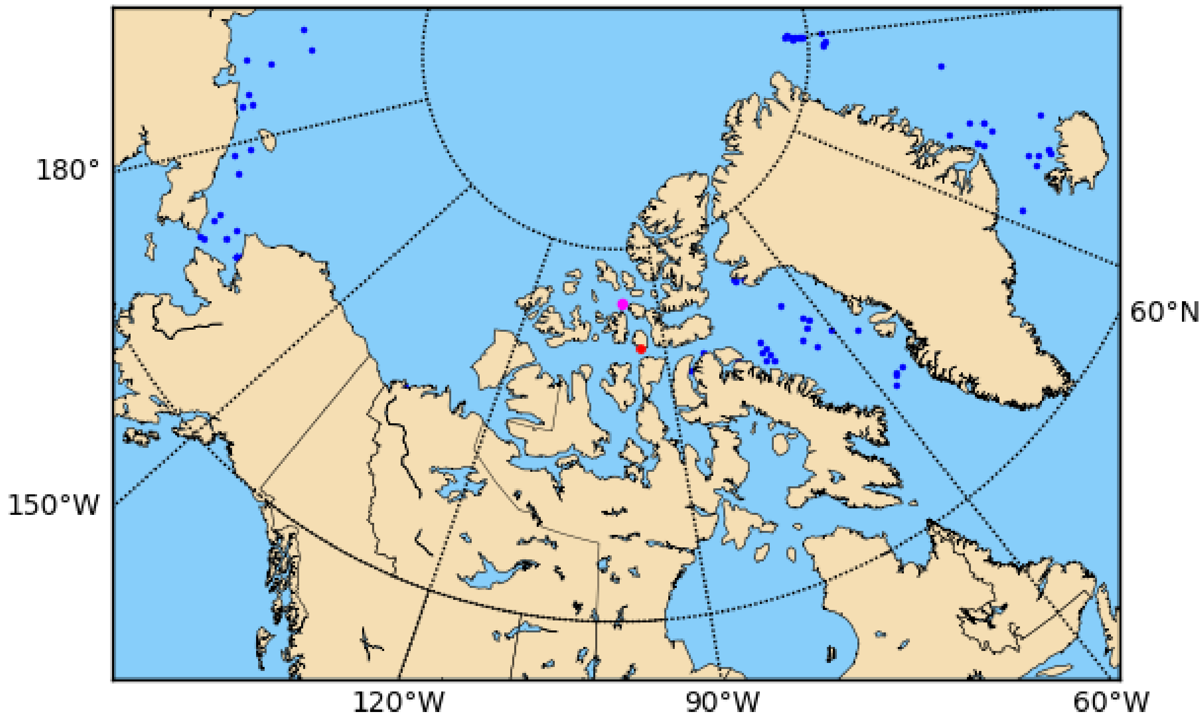


Figure 2: Plot of the vessels of opportunity (blue), the emergency location (pink), and the nearest marine SAR base (red) for the month of July.

Based on the AIS data for potential VOO for the selected scenario, the overall probability of a vessel of opportunity being in closer proximity to the emergency location than the nearest SAR resource produced by the model for July was 0.0%. This indicates that for the month of July, there is a 0% probability that there will be a VOO within the area that could decrease the estimated exposure times for the given scenario. Thus, the estimated exposure time ranges produced in the previous section remain unchanged when considering VOO if the emergency were to occur in July.

4.4.2. Vessel of Opportunity Results (August)

Similar to the previous section, Figure 3 depicts the locations of these vessels in relation to the location of the selected emergency scenario for the month of August.

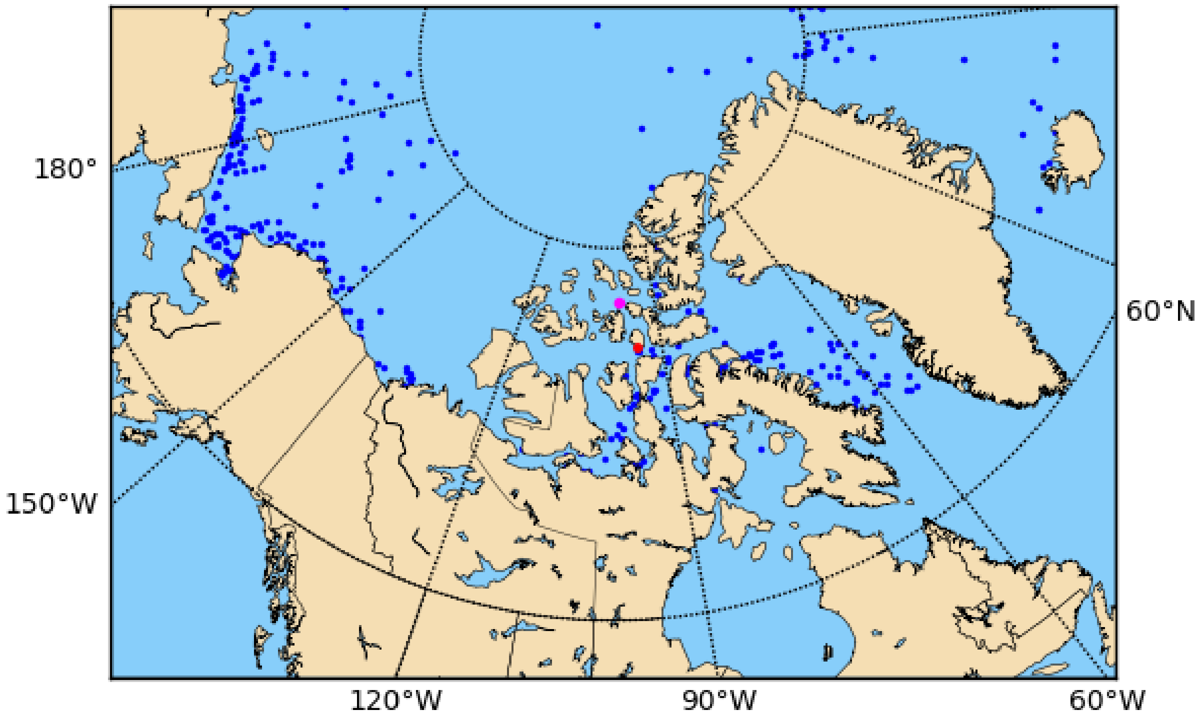


Figure 3: Plot of the vessels of opportunity (blue), the emergency location (pink), and the nearest marine SAR base (red) for the month of August.

Based on the anonymized AIS data for VOO in the area for the month of August, an overall probability of a vessel being in closer proximity to the emergency than the nearest SAR resource was calculated to be 50.0%.

The resulting exposure times and probabilities relating to the decreasing radius of area surrounding the emergency event are summarized in Table 4.

Table 4: Summary of the results for probabilities and estimated exposure times (with vessels of opportunity) produced by the model for August

Radius (nm)	Probability (%)	Exposure Time (h)		
		Low	Average	High
234	50.0	25.9	32.4	38.9
184	36.7	20.9	27.4	33.9
134	6.7	15.9	22.4	28.9
84	0.0	15.9	22.4	28.9

4.5. Discussion

The effect of vessels of opportunity on the estimated ranges for exposure time in the Arctic were explored through a comparison of the calculated ranges, both with and without the consideration of VOO. Due to the nature of the AIS data available, this work concentrated on Arctic based scenarios and did not explore any scenarios in the Antarctica region. While the methodology proposed here can theoretically be applicable for estimating exposure time including the impact of VOO in Antarctica locations, access to AIS data for this area would be required.

The variation in the effect of VOO on the estimated ranges for exposure time were also analyzed through the comparison of the results of the methodology for both the July and August scenarios. It should be noted that only marine VOO were considered in the results presented previously. Air resources of opportunity are not considered in the current version of the VOO methodology.

As discussed in the results, the probability of a VOO being within the area of the marine emergency scenario presented that is closer than the SAR base for the month of July is 0.0%. Therefore, it is expected that there will be no vessel in close proximity to the emergency that could offer assistance as a means of reducing the exposure time ranges. Thus, the estimated exposure time ranges presented in Table 3 are not reduced below that which would be achieved with existing SAR resources and represent the estimated exposure times for July with the consideration of VOO.

The probability of a VOO being within the area of the marine emergency scenario presented for the month of August is 50.0%. This indicates that there is a 50.0% chance that there is a VOO within the circle of area out to the nearest marine SAR base at 234 nm. A VOO at this transit distance from the emergency would not affect the range of exposure times as the transit time would be unchanged from that of a marine SAR resource. At a radius closer than the nearest SAR base (at 184 nm), there is a probability of 36.7% that a VOO is in the area, which results in a new range of exposure times from 20.9 to 33.9 hours for a marine resource. Following this, there is a probability of 6.7% that a VOO is within 134 nm resulting in exposure times of 15.9 to 28.9 hours for a marine resource. For the given scenario, there is a probability of 0.0% that a vessel of opportunity is within 84 nm of the emergency in the month of August.

The probabilities are provided for each radius considered in Table 4 as a means for planners to decide whether a VOO should be considered in the reduction of exposure time ranges. For example, a VOO located 134 nm from the emergency scenario could reduce the low-end exposure time for the evacuees from 25.9 hours to about 15.9 hours. However, the probability of a VOO being at this location for the month of August is 6.7%. Thus, the probability that there will not be a VOO at this location to respond to the emergency is greater than the probability that there will be a vessel in this area that can offer assistance. Therefore, it may not be reasonable to include the effect of VOO when the probability of one being in the area is so low.

The assumptions listed in section 3.5 that were made when developing these equations may result in an overly optimistic calculation on how VOO can impact estimated exposure time. The AIS data used for the simulated scenarios in this report was sanitized and contained no identifying characteristics of the ships; only that a vessel was in a given area at a specific time. It was assumed that the vessel would be capable of affect a rescue. In reality, vessels of all sizes can be operating in an area of interest, and some of these may be too small, relative to the vessel in distress, to be able to assist. While it would be possible to filter AIS (or equivalent) data to remove ships below a certain size, determining this threshold value is beyond the scope of this report and should be done through discussions with the relevant experts and stakeholders.

It was also assumed that a VOO would be able to transit to the emergency location at a speed equivalent to a SAR resource, and that the path would be a straight line between the two points. These are again optimistic assumptions, and in reality, a VOO would most likely not be able to transit through challenging environments at the same speed as a SAR resource, and its path would not be a straight line. The path a VOO would take to the location of an accident, and the difference in speed between it and a SAR resource, would be dependent on the geographical location, and what ships were in the area to respond to the distress.

Ultimately, it is the responsibility of the end-user to determine what variables, assumptions, and level of probability, are acceptable to include when using these equations to calculate the potential reduction in exposure time due to VOO.

5. Future Work

Additional research and evaluation of the methodology developed to complement the existing exposure time methodology would help to increase the validity of the exposure time estimations in Polar Regions. A summary of the results of external engagements to provide input towards the current methodology, along with some next steps that are being considered for further development are described below.

5.1. Consultations with External Stakeholders

Transport Canada coordinated a correspondence group to solicit feedback on the exposure time methodology. A number of consultation sessions with different members of the correspondence group, including: the Canadian Coast Guard (CCG); the US Coast Guard; Norwegian Maritime Authority and the Coastal Authority; Maritime New Zealand; and various private organizations have taken place and recommendations and comments were gathered. A summary of some of the key recommendations and suggestions are provided below:

1. The ability to restrict the type of VOO being included in the calculations should be considered. Depending on the scenario being considered, only a restricted size of VOO would be capable of responding to the emergency and executing a successful rescue.
2. The inclusion of an additional parameter that accounts for any standby time required to wait to perform a rescue as a result of weather and/or ice conditions should be considered. There are limitations on the weather conditions in which rescues from SAR resources can be performed.
3. The transit speed of the VOO should be reviewed as the assumption that it is equivalent to that of a marine SAR resource may not be valid for all vessels being considered.
4. The type of AIS data being used in the VOO methodology should be considered since depending on the source of data, some vessels may be missing. For example, satellite-based AIS data versus terrestrial-based AIS data.

5. The ice conditions surrounding the emergency should be considered when including VOO's into the exposure time calculation. Many VOO's may not be capable of supporting a marine incident in the presence of sea ice.

5.2. National Research Council of Canada Next Steps

The National Research Council of Canada (NRC) intends to continue working on the methodology presented in this report for the implementation of VOO into estimated exposure time calculations. One of the upcoming steps in progressing this new methodology is the development of a graphical user interface (GUI) for the python code that was used to generate the results in this report. The intent of the development of this GUI is to distribute it to stakeholders to provide them with the opportunity to evaluate the methodology for other jurisdictions and to provide additional suggestions or feedback on improvements that can be made.

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Appendix A

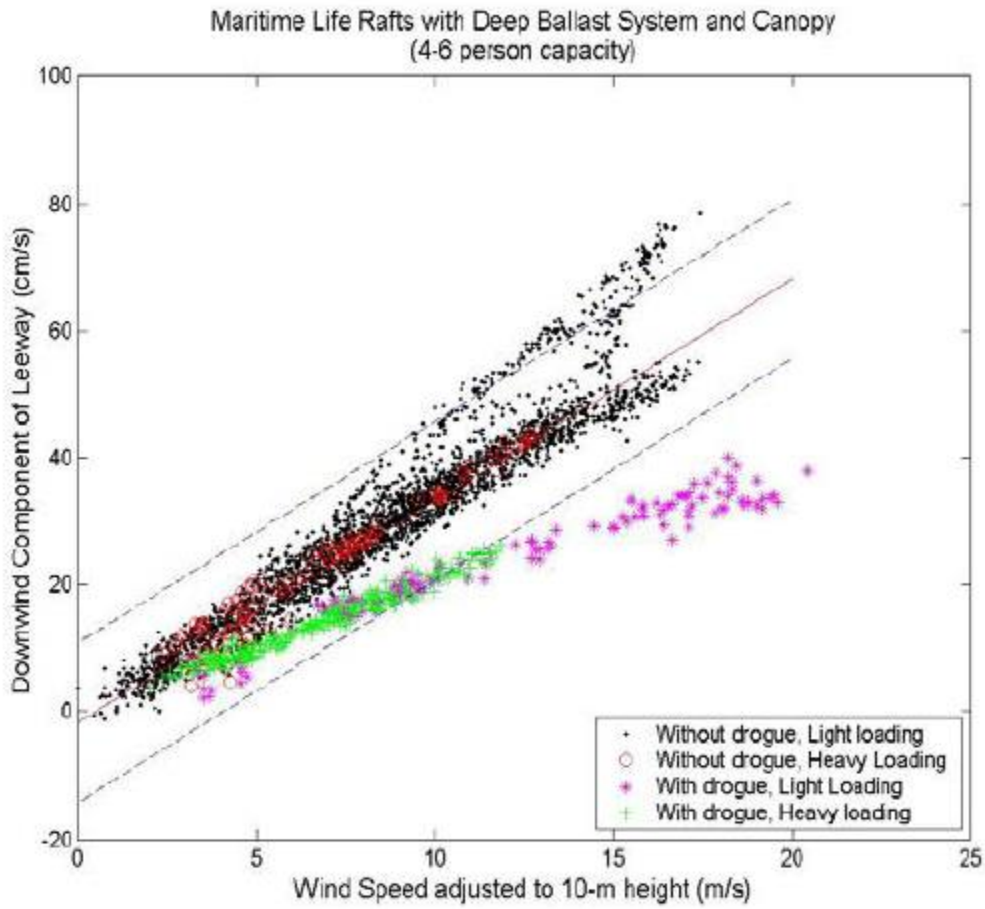

Figure 4: Wind speed and subsequent drift speed of life rafts [5].

Appendix B

Table 5: List of marine ports used as locations for marine SAR bases

Latitude [°]	Longitude [°]	Location
62.1453751	-74.6931	Deception Bay
63.7244493	-68.5109	Iqaluit
67.8252951	-115.135	Kugluktuk/Coppermine
74.6846024	-94.8425	Resolute
69.4363017	-132.984	Tuktoyaktuk
69.1135009	-105.061	Cambridge Bay
47.56494	-52.7093	St. John's
46.819868	-71.2027	Quebec City
44.633102	-63.5641	Halifax

Appendix C

Table 6: List of RCAF bases in Canada used as locations of air SAR bases [6]

Latitude [°]	Longitude [°]	Location
48.94	-54.58	Gander, NL
44.98	-64.92	Greenwood , NS
44.12	-77.53	Trenton, ON
49.71	-124.91	Comox, BC
49.89	-97.25	Winnipeg, MB
48.32	-70.99	Bagotville, QC
44.16	-79.54	Borden, ON
54.27	-110.1	Cold Lake, AB
45.5	-66.26	Gagetown, MB
53.31	-60.42	Goose Bay, NL
45.55	-77.17	Petawawa, ON
45.3	-73.25	Saint-Hubert, QC
46.54	-71.3	Valcartier, QC

Appendix D

Table 7: List of airports in the Canadian Arctic used as potential safe bases for evacuee drop-offs and refueling [1, 7]

Latitude [°]	Longitude [°]	Location
76.14	-119.19	Mould Bay Airport
81.24	-76.52	Tanquary Fiord Airport
74.43	-94.58	Resolute Bay Airport
74.04	-93.47	Arctic Watch Lodge Aerodrome
82.31	-62.16	Alert Airport
72.41	-77.58	Pond Inlet Airport
72.58	-84.36	Nanisivik Airport
73	-85.02	Arctic Bay Airport
69.21	-81.48	Igloolik Airport
68.46	-81.14	Hall Beach Airport
70.29	-68.31	Clyde River Airport
67.32	-64.01	Qikiqtarjuaq Airport
70.45	-117.48	Ulukhaktok Airport
69.21	-124.04	Paulatuk Airport
69.07	-105.01	Cambridge Bay Water Aerodrome
68.07	-106.35	Doris Lake Aerodrome
68.09	-106.36	Hope Bay Aerodrome
66.39	-91.32	Hayes Camp Aerodrome