Assessing the "buddy system" to enhance cruise vessel safety in the Canadian Arctic: A response time analysis

Floris Goerlandt
Maritime Risk and Safety Research Group,
Department of Industrial Engineering,
Dalhousie University, Halifax, NS, Canada
floris.goerlandt@dal.ca

Kimia Mostaghimi
Maritime Risk and Safety Research Group,
Department of Industrial Engineering,
Dalhousie University, Halifax, NS, Canada
km842497@dal.ca

Ronald Pelot
Maritime Risk and Safety Research Group,
Department of Industrial Engineering,
Dalhousie University, Halifax, NS, Canada
ronald.pelot@dal.ca

ABSTRACT

Climate change has led to increased cruise tourism in the Canadian Arctic. Vast distances, harsh environments, and the limited capacity of the Search and Rescue system, cause major concerns about the time for a rescue asset to arrive on scene in accidents involving large numbers of people. To reduce this risk, the implementation a "buddy system" has been put proposed, i.e. a system where two vessels navigate in each other's vicinity, so that they can assist in case of an emergency. This article explores changes in response time to an incident location between a "buddy system" and independently operating cruise vessels. A quantitative model-based analysis, combining sea ice data, maritime network analysis with cost distance minimization, and data from the Automatic Identification System, is applied. Results indicate that a "buddy system" can have significant safety benefits. Nevertheless, a discussion points to future research needs to fill remaining knowledge gaps.

KEYWORDS

Search and Rescue, Arctic cruise, maritime safety, emergency response, buddy system

INTRODUCTION

Climate change is driving rapid environmental changes, particularly in the Arctic, where its impacts are already being seen through significant decreases in sea ice coverage and increases in dynamic ice conditions (Wang et al., 2022). The rising temperatures contribute to diminishing sea ice, making previously inaccessible waterways more navigable. One major consequence is the increasing maritime accessibility of Arctic waters, leading to a rise in shipping activity. This trend is already evident in the Canadian Arctic, with a growing number of vessels navigating these waters, with especially significant increases in activity of yachts and cruise vessels (Dawson, Copland, et al., 2021). This activity has raised various concerns, including the socio-cultural impacts on Indigenous communities (Stephen, 2018), environmental impacts on vulnerable ecosystems (Qi et al., 2024), protection of seafarer rights (Loot, 2020), and safety of passenger and crew in the harsh Arctic environments (Boileau et al., 2010). Cruise vessels generally have very low accident rates (Eliopoulou et al., 2016) and experienced operators have robust safety management systems (Chaure & Gudmestad, 2020). Likewise, significant research has been dedicated to increasing the safety of Arctic shipping through design and operational measures (Lu et al., 2022), and in understanding the causes of shipping accidents in the Arctic (Fu et al., 2021).

Nevertheless, despite the relatively low numbers of vessels navigating these waters, ship accidents in which large numbers of passengers are crew are in distress have already occurred in the Canadian Arctic (Kikkert et al., 2023).

The remote nature of the Arctic, coupled with extreme and unpredictable weather conditions, further exacerbates the risks to human safety. The presence of dynamic ice conditions can result in vessels getting beset in ice (Lu et al., 2021; Montewka et al., 2015), and the combination of relatively poorly charted areas with the industry's proclivity to venture in remote areas beyond the main corridors of the Northwest Passage (Loot, 2020), can lead to groundings. Other accidents such as shipboard fires can result in even more acute safety risks to passengers and crew. In such scenarios, assistance from other vessels or from aeronautical assets to the people in distress is of vital importance.

The rising risks of such scenarios have caused significant concerns among Inuit communities, whose members often act as first responders to Search and Rescue (SAR) incidents in these areas (Kikkert et al., 2023). The vast distances and harsh conditions pose significant challenges to aerial and marine response authorities to reach people in distress on time (Ash, 2023; Ford & Clark, 2019). Organizing an effective SAR response in the Canadian Arctic remains a formidable challenge. The complexity of governance of SAR in Canada (Cucinelli et al., 2023), vast distances, extreme weather conditions, and limited SAR infrastructure hinder timely interventions. In response to these difficulties, the International Maritime Organization's (IMO) Polar Code (PC) mandates that vessels operating in polar waters be self-sustaining for a specified period, referred to as the 'Maximum Expected Time to be Rescued' (METR), which should be at least five days (IMO, 2017). This requirement acknowledges the reality that help may take significant time to arrive in the event of an emergency . Therefore, cruise operators must ensure their vessels are adequately equipped to handle prolonged isolation while awaiting assistance.

To improve safety and emergency response times, a "buddy system" for vessels operating in Arctic conditions has been proposed (Albrigtsen et al., 2015). Under this system, two or more vessels navigate within each other's vicinity, allowing for immediate assistance in case of an emergency. This system has the potential to significantly enhance safety, as it reduces the time required for assistance to arrive and provides additional resources such as medical aid, provision of additional resources, and evacuation capabilities. Furthermore, a buddy system could alleviate some pressure on Arctic SAR operations, both from Inuit community members and from assets controlled by official SAR organizations such as the Canadian Coast Guard (CCG) and the Royal Canadian Air Force (RCAF), which currently rely heavily on a limited number of vessels with ice-going capability and aircraft for emergency responses.

Despite its apparent advantages, the safety merits of a buddy system for cruise vessels operating in the Canadian Arctic warrant further investigation. This study aims to answer the following research question: how much faster can a vessel in distress receive external assistance by a maritime asset in a buddy system compared to a baseline system where cruise vessels operate independently without coordination for mutual assistance? The findings, while preliminary, aim to provide valuable insights for policymakers, cruise vessel operators, and SAR authorities in shaping future safety regulations and strategies to support sustainable tourism in the Canadian Arctic.

The remainder of this article is organized as follows. The second section provides an overview of the methodology to compare the buddy system with independently operating cruise vessels. The third section provides preliminary results for selected potential incident locations and time periods. In the fourth section, a discussion is provided, highlighting the need for future work to obtain more elaborate results and future research directions. The fifth section concludes.

METHOD

This Section provides an overview of the method to compare the response time of the current operational practice of independent Arctic cruise vessel operation, and cruise operations relying on a buddy system. It first addresses how a buddy system is conceptualized in this analysis, and how the comparison is performed. Then, the approach to estimate the response time in the buddy system is explained. Then, the method to determine the METR for independently operating cruise vessels is outlined.

Conceptualizing an Arctic cruise vessel buddy system

In maritime operations, a buddy system can be conceived as a mechanism by which vessels operate in relative proximity of one another, so that they can provide mutual support in case one of these vessels experiences an emergency. Albrigtsen et al. (2015) described two buddy system concepts: an "active" and a "passive" buddy system. In the active system, two vessels operate in close proximity, so that the vessel's crew actively observe the activities of the other ship, and vessels can even engage in joint activities. In the passive system, vessels maintain close proximity, but vessels perform their activities and operations independently.

In the context of Arctic cruise tourism, the most feasible approach for this would be a passive buddy system, in which the vessels navigate sufficiently far away from one another so that passengers cannot see the other vessel. Especially for expedition cruises, for which passengers have raised the importance of the sense of wilderness adventure and exploration (Manley et al., 2017), it is plausible that passengers prefer that a cruise vessel navigates the pristine and remote areas independently, or at least that any other vessel navigating nearby are beyond the line of sight of the own vessel. For the purposes of the current analysis, different assumptions are made as to how far apart the two cruise vessels would navigate.

Scenario-based comparison: test conditions and key assumptions

The response operation to a vessel in distress can broadly be divided in four phases: i) initial communications, ii) travel to location, iii) search period, and iv) rescue activities (Kennedy et al., 2021). In the current analysis, the focus is exclusively on the second phase, and only maritime responding assets are considered. Thus, it is taken that a responding vessel has been dispatched to the incident location, with the analysis focusing on the time needed for reaching the incident location by this responding vessel. Neither the possible time needed to search the vessel in distress from its last known position, nor the time needed to perform on-site operations (rescue of people in distress, provision of resources, or activities to mitigate risks to the vessel condition).

The current analysis uses a scenario-based approach to compare the response time of independently operating cruise vessels versus vessels operating in a buddy system. Three possible incident locations are investigated in three time periods, in which an accident involving a cruise vessel may plausibly occur given the characteristics of the tourism season in the Canadian Arctic, and typical vessel movement patters as reported by Dawson et al. (2021). All combinations of {'buddy system', 'independent navigation'}, {'Zone 13', 'Zone 7', 'Zone 12'}, and {'mid-July', 'mid-August', 'mid-September'} are compared. The possible incident locations in the zones are indicated in Figure 1, which shows the Shipping Safety Control Zones, i.e. designated areas in the Canadian Arctic where special safety measures and controls are implemented to ensure the safe navigation of vessels. The above-mentioned time periods correspond to weeks 29-30, weeks 33-34, and weeks 37-38, respectively.

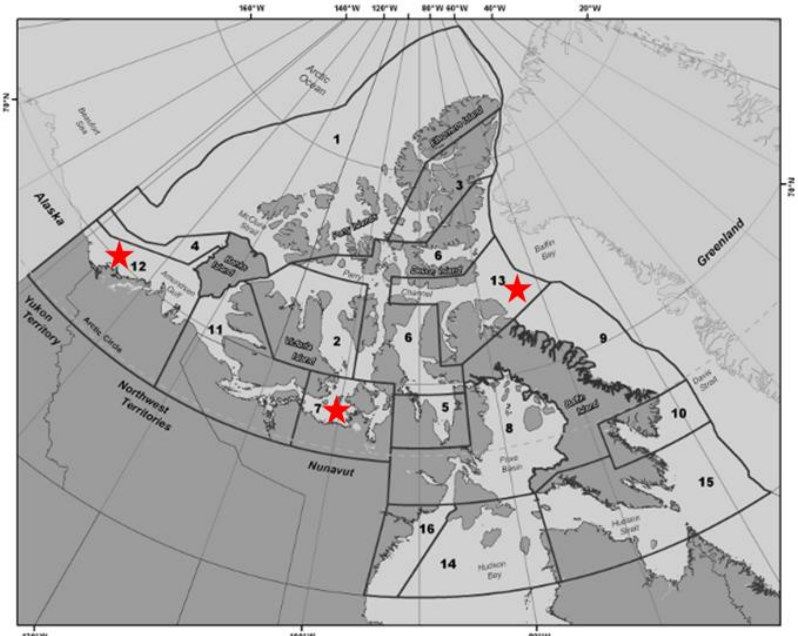

Figure 1. Plausible cruise vessel incident locations in Zone 13, Zone 7, and Zone 12, based on Government of Canada (2024)

Several other assumptions are made. First, it is assumed that a responding vessel will navigate at the maximum safe speed attainable in the prevailing ice conditions, and that it has no range limitations due to fuel availability. Second, data from the Automatic Identification System (AIS) obtained through Spire (2024) for the years 2018 and 2019 are taken as representative for the plausible traffic conditions in the Canadian Arctic. Third, historical sea ice chart data from United States National Ice Centre (USNIC, 2025) over the climatological period from 1991 to 2020, from which a representative median statistical aggregation is selected, see Stoddard et al. (2024). This is taken as representative of the plausible ice conditions in the above-mentioned two-week periods. Fourth, for the response time of a 'buddy system', given the variability of local ice conditions, instead of using historical sea ice data directly, different distances between the two cruise vessels and attainable speeds in plausible ice conditions are assumed. Further details about this are provided in the next section. Finally, the calculation of the METR in the 'independent navigation' scenarios only considers CCG vessels and other cruise vessels operating elsewhere in the Canadian Arctic. This is because of the limited capacity of aeronautical assets and other commercial vessels which could act as vessels of opportunity to rescue and accommodate people in distress (Fernandes, 2024).

Determining response time for cruise vessels in buddy system scenarios

As mentioned in the previous section, the response time for cruise vessels engaged in a buddy system operational setup is based on a set of assumed distances between these two vessels when one of them experiences an incident requiring external assistance. These assumed distances are 5 nm, 10 nm, and 20 nm. As there currently is, to the best of the authors' knowledge, no operational guidance on how far apart buddy vessels would operate to instill an impression on passengers that they are venturing out in the Arctic waters as a sole vessel, these numbers appear plausible. Furthermore, five vessel speeds are assumed as tabulated in Table 1, corresponding to the first quartile (Q1) value of historically observed vessel speeds in different POLARIS RIO categories, as reported in Stoddard et al. (2025). POLARIS is the Polar Operational Limit Assessment Risk Indexing System, a widely used risk assessment tool used to evaluate the operational limitations of ships in polar waters by calculating risk levels based on ice conditions and the vessel's ice class. RIO (Risk Index Outcome) values are numerical scores calculated within the POLARIS framework, indicating the relative risk of operating in given ice conditions (Stoddard et al., 2016). Lower RIO values correspond to more severe ice conditions, whereas values higher values indicate less severe or ice-free conditions. The Q1-value is taken in the analysis as a conservative estimate of the attainable speed in ice, similarly as in the more elaborate METR-VT approach for response to independently operating cruise vessels in the next section.

Table 1. POLARIS RIO values and first quartile (Q1) values of observed vessel speeds, based on Stoddard et al. (2025)

RIO value	Interpretation	Q1 vessel speed
RIO > 30	Ice free operations	12.1 kn
$0 \leq$ RIO ≤ 30	Normal ice operations	6.9 kn
$-10 \leq$ RIO ≤ 0	Elevated risk operations	3.0 kn
$-20 \leq$ RIO ≤ -10	High risk operations	1.7 kn
RIO < -20	Extreme risk operations	0.8 kn

Determining METR-VT for scenarios of independently operating cruise vessels

The response time to incidents of independently operating cruise vessels for the scenarios listed in the above section on the test conditions, is determined following a methodology depicted in Figure 2. The process consists of three high-level phases: i) the vessel data preparation stage, where AIS data is processed to attain vessel trajectories, ii) the construction of a transportation network for determining the fastest route of a given vessel to a specified location in sea ice conditions representative of a given time period, and iii) the calculation of the maximum expected vessel transit time (METR-VT). The first two phases are preparatory steps common to all scenarios, whereas the third phase takes a specific incident location and time period of the combinations listed in the section above introducing the test conditions.

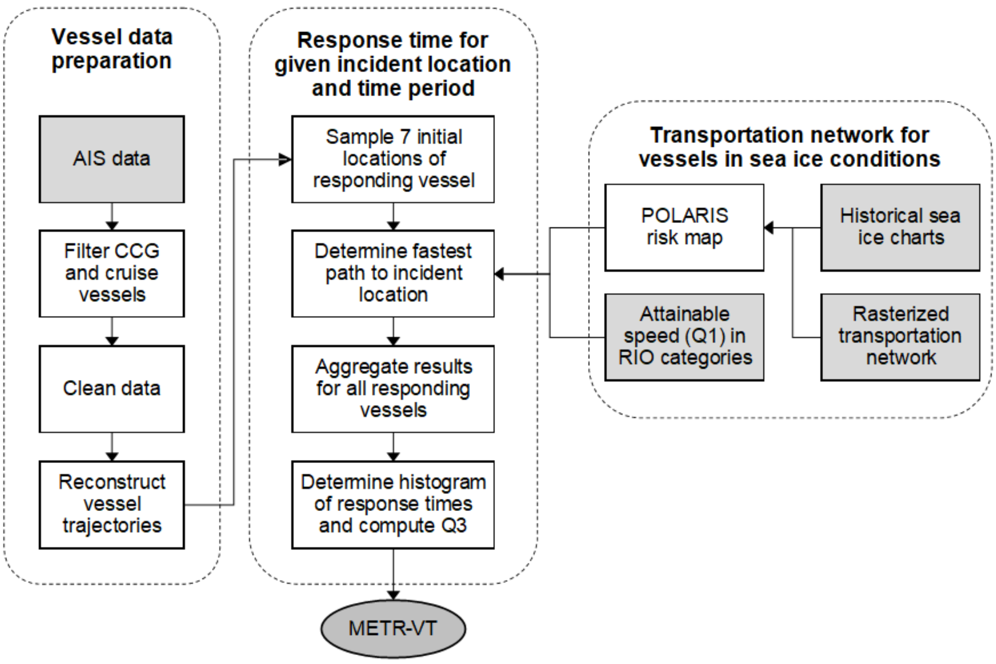

Figure 2. Overview of the method for determining METR-VT

First, the AIS data from Spire (2024) is filtered, so that only CCG vessels and other cruise vessels are retained as possible responding vessels. Then, the data is cleaned to remove outliers and erroneous data fields, using a similar approach as in Stoddard et al. (2025). Subsequently, a vessel trajectory is reconstructed using the ‘points to path’ tool of the QGIS software (QGIS, 2025).

Second, the transportation network is constructed for determining the fastest route of a responding cruise or CCG vessel to an incident location. The transportation graph is composed of nodes and arcs with a consistent spacing between nodes of ca. 12 km, with each node connected to its eight closest neighbors, excluding nodes in area of less than 30 m water depth. The resultant graph is explained in further detail by Stoddard et al. (Stoddard et al., 2024). All nodes of this network are matched with historical sea ice chart information from USNIC (2025), for the period from 1991 to 2020, and the POLARIS RIO value is computed for aggregate 2-week periods as described in Stoddard et al. (2024). For the present analysis, the median value of these RIO values is retained, which is taken as a representative plausible sea ice condition across the Canadian Arctic. This POLARIS risk map is then used together with earlier computed attainable vessel speeds from Stoddard et al. (2025), again using Q1-values as in the previous section and Table 1, to determine the attainable speed in different locations on the transportation graph network in the given time period.

Finally, for each of the scenarios listed in the section introducing the test conditions, the METR-VT is calculated. Starting from a given vessel trajectory of a CCG or cruise vessel operating in the Arctic in the given time period, seven points are sampled, representing the possible staring locations when a response operation would begin. This number is selected to reduce computational time (since the subsequent fastest path calculation is computationally expensive), with resulting METR values having been found to be robust to the randomness of this sampling (Mostaghimi, 2024). The fasted path calculation uses Dijkstra’s algorithm as implemented in QGIS (2025), similarly as in Siljander et al. (2015) and explained in further detail in Stoddard et al. (2024). This algorithm is applied to each sampled point of each responding vessel, and the travel time to the incident location is determined, using the time to traverse an arc as cost distance in the transportation graph, using results of the second phase of the method, as explained above. Then, the resulting response times for all sampled points for all CCG and cruise vessel trajectories are collected, and a histogram of these times is made. Finally, the METR-VT value for the specified scenario is determined as the third quartile (Q3) value of these response times. This Q3-value is selected as a conservative estimate, similarly to in the response time analysis for the buddy system as explained in the previous section.

RESULTS

Scenarios of cruise vessels in buddy system

Table 2 shows the results of the scenario analyses for the cruise vessels operating in a buddy system, using the data, information, and assumptions elaborated in the method section. It is seen that the response time ranges from 0.4 h (25 min) to 6.3 h (6 h 15 min) in case the vessels operate within 5 nm of one another, depending on the severity of the ice conditions at the time the incident occurs. When this distance is increased, the range of response times increases to between 0.8 h (50 min) and 12.5 h (6 h 30 min) for 10 nm distance, and to between 1.7 h (1 h 40min) and 25 h for 20 nm distance.

Table 2. Response times for cruise vessels in buddy system for different distance and ice condition scenarios, for interpretation of RIO values see Table 1

ID	Distance	RIO > 30	0 ≤ RIO ≤ 30	-10 ≤ RIO ≤ 0	-20 ≤ RIO ≤ -10	RIO < -20
B1	5 nm	0.4 h	0.7 h	1.7 h	2.9 h	6.3 h
B2	10 nm	0.8 h	1.4 h	3.3 h	5.9 h	12.5 h
B3	20 nm	1.7 h	2.9 h	6.7 h	11.8 h	25.0 h

Scenarios of independently operating cruise vessels

In this section, abridged results are shown of selected aspects of the method explained in the last subsection of the method section. Figure 3 shows an example of a trajectory of a vessel operating in the Canadian Arctic, as reconstructed based on AIS data. It also shows seven random initial positions from where a response to an incident location could start from.

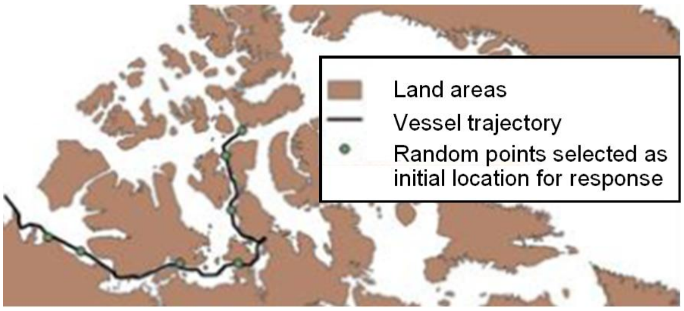

Figure 3. Example vessel trajectory and selection of random points from where a response to a cruise vessel incident location is initiated, based on Mostaghimi (2024)

Figure 4 shows an example of a result of the calculation of the fastest trajectory of a responding vessel to an incident location in Zone 13 of Figure 1. It also illustrates the RIO values determined based on the POLARIS method, using the median statistical aggregate of USNIC ice chart data for the period mid-July. In this example, the travel time from the start to the end location amounts to 76 h, i.e. about 3 days.

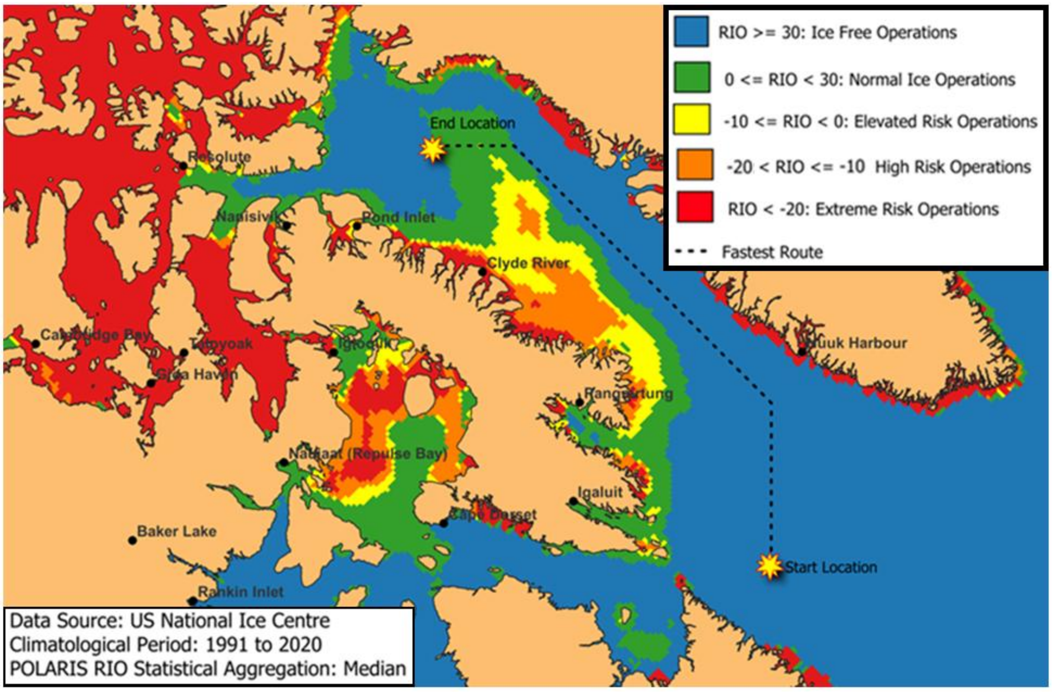

Figure 4. Example of a fastest route calculation accounting for attainable safe speeds in ice conditions, interpreted through POLARIS RIO values, adapted from Stoddard et al. (2024)

Table 3 shows the final results of the calculation of METR-VT values for the scenarios of cruise vessels operating independently in the Canadian Arctic, as introduced in the method section. It shows that for Zone 13, where ice conditions are comparatively milder during the summer months than in the other considered zones, and where there is more intense shipping activity, the response time varies from 3 to 4 days over different time periods. In contrast, in Zone 7 the response time is estimated to be 7 days in mid-July, reducing to 4 days in mid-September when ice conditions improve and shipping activity intensifies. Zone 12 shows a similar pattern with 8 days response time to mid-July, which reduces to 3 days in mid-September. It is noted that for several zones and time periods, these exceed the minimum of 5 days as required by the Polar Code.

Table 3. METR-VT for cruise vessels in independent navigation, for interpretation of zones see Figure 1

ID	Zone	mid-July (k = 1)	mid-August (k = 2)	mid-September (k = 3)
$I_{1,k}$	13	3 days	3 days	4 days
$I_{2,k}$	7	7 days	4 days	4 days
$I_{3,k}$	12	8 days	5 days	3 days

DISCUSSION

A comparison of the results presented in the previous sections indicates that the implementation of a buddy system would significantly reduce the response time, as could be expected. Table 4 compares the response times of a buddy system with those of independently operating cruise vessels for a selected subset of plausible scenarios. It shows the ratio of the response time in case of independent navigation to that of a buddy system, giving an estimate of how much faster on-scene assistance would arrive for a cruise vessel experiencing an incident. It is seen that for the selected cases, the response time would be reduced by a factor between 22 and 116, depending on the zone, time period, and assumed ice conditions in the vicinity of the cruise vessel in distress.

Table 4. METR-VT for cruise vessels in independent navigation, for interpretation of zones see Figure 1, for interpreting RIO values see Table 1

Buddy system			Time period		
Distance	Ice conditions	Zone	mid-July	mid-August	mid-September
10 nm	RIO > 30	13	87	87	116
10 nm	0 ≤ RIO ≤ 30	7	116	66	66
10 nm	-10 ≤ RIO ≤ 0	12	58	36	22

Notwithstanding the clear improvements in response time of a buddy system and the related safety benefits implementing such an operational approach would offer, several uncertainties and areas for future work remain. First, the analysis as presented rests on assumptions highlighted in the method section, which may not all be equally realistic. For instance, the application of historic AIS data from 2018 and 2019 does not account for likely increases in vessel activity in the Canadian Arctic, which would likely reduce the response time to independently navigating vessels. Hence, using more years of shipping data, and/or developing and using a maritime traffic simulation model to estimate future shipping patterns, and using that as a basis for estimating future response time, could be useful future work to mitigate this uncertainty. Similarly, relying on statistically averaged historic ice conditions from 1991 to 2020 does not account for future projected reduction of Arctic sea ice, as found e.g. by Barnhart et al. (2016), and the possible response time implications this has. Hence, relying instead on models of sea ice under projected climate change scenarios, and understanding response times for those scenarios, could be an area of future work to mitigate this uncertainty. Another arguable assumption is the restriction of a response solely by maritime resources (CCG and other cruise vessels). Were aeronautical assets, in particular SAR helicopters operated by the Royal Canadian Air Force considered, the external assistance would be significantly faster as well, going by results reported by Fernandes (2024). Hence, developing and applying aeronautical SAR response models and applying this to understand rescue times by aeronautical assets compared to a buddy system, would be a fruitful area of future work to mitigate this uncertainty. Furthermore, the analysis as presented makes no distinction between large cruise vessels and smaller expedition cruises, which would benefit from scrutiny in future work. Finally, a key limitation of the work as presented is that only the transit time is considered. However, there may be significant differences in the effectiveness of operational on-scene emergency support between CCG vessels, large cruise vessels, and expedition cruise vessels. Developing and applying approaches to understand these differences in on-scene response effectiveness is an important area for future research. For instance, performing tabletop, simulation, or real-life exercises to understand the effectiveness of SAR activities by vessels without a dedicated SAR mandate could be pursued in future research. Similarly, developing qualitative and/or quantitative models to estimate the effectiveness (e.g. in terms of probability of survival or time-based metrics) of a buddy vessel under different accident scenarios would be a useful area of future work.

Apart from methodological improvements and work to better understand emergency response in Arctic marine conditions and limit analysis uncertainties, there is also a range of other issues which would benefit from further analysis in support of a decision whether to implement a buddy system. For instance, there are questions for cruise operators concerning the economic implications of planning cruises in a buddy system, considering for instance capacity limitations for tourism and passenger volumes, for which research as done by Lasserre & Têtu (2015) could be useful. Similarly, given the importance of including Inuit as rights holders in issues related to maritime shipping activities in the Canadian Arctic (Goerlandt & Pelot, 2020) and the socio-cultural impacts of Arctic tourism to Northern communities (Stephen, 2018; Stewart et al., 2007), future work addressing the socio-cultural implications of increased cruise tourism on Arctic communities with and without a buddy system would be worth pursuing. There would also be marine policy questions concerning whether a buddy system would need to be mandated through regulatory action at the national or international level, or whether this is best left to voluntary schemes for the cruise tourism sector. Case study analysis of shipping industry schemes to alleviate Inuit concerns related to shipping for indicate that voluntary schemes can be an important tool to support area-based management (Wang & Aporta, 2024), which suggests that having a voluntary buddy system could be used to test the feasibility of this approach. A thorough policy analysis of the different implications of implementing a buddy system in the Canadian Arctic, and in other jurisdictions, is an important area of future work.

Should a buddy system be recommended or mandated, further work to improve emergency management training for ship crews to engage in responses to other vessels under a buddy system would be recommended. As reported by Chaure & Gudmestad (2020), there is significant room for improvement in training for evacuation and survival in harsh environments under the current provisions of the Polar Code. As a response to another vessel in harsh Arctic conditions is likely even more taxing, developing specific training modules would likely be important.

Finally, research to understand stakeholder and rights holder views on this issue of implementing a buddy system should be pursued, given the ambiguities involved in risk management of Arctic shipping (Goerlandt & Pelot, 2020) and the importance of Inuit rights and the shift to polycentric governance in shipping governance in Canada (Wang, 2023).

CONCLUSIONS

This article investigated how much faster can a cruise vessel in distress in the Canadian Arctic can be expected to receive external assistance in a buddy system compared to a baseline system where cruise vessels operate independently. Through a scenario-based comparison, relying on AIS and ice chart data, the POLARIS method, and a fastest path algorithm, it is found that response times with maritime assets can be significantly reduced. Depending on assumptions of how a buddy system would be practically implemented, response times could be reduced approximately by a factor 20 to 100, depending on the area and time of year in which an incident would occur.

Despite the promising findings and the safety benefits of implementing a buddy system for cruise vessels operating in the Canadian Arctic, several methodological improvements can be considered as future research to further confirm the findings. More importantly, other questions concerning the economic feasibility and socio-cultural concerns related to possible intensification of tourism in small Arctic communities, would also need consideration. Furthermore, understanding Inuit and broader stakeholder views on the relative merits of implementing a buddy system is of key importance. Questions on whether such a system would best be a voluntary industry practice or whether to mandate this through a policy intervention would also need to be answered.

ACKNOWLEDGMENTS

This work was performed as part of the project 'Nunavut Search and Rescue (NSAR): Supporting Inuit Health and Well-being, Food Security, Economic Development, and Community Resilience by Strengthening Nunavut's Whole-of-society SAR capabilities'. This project has received funding through the Canada-Inuit Nunangat-United Kingdom Arctic Research Programme (CINUK), under grant number ANCP 311241. The contributions by the first author were furthermore supported by the Canada Research Chairs Program, through the Natural Sciences and Engineering Research Council (NSERC), under grant CRC-2023-00059. This financial support is gratefully acknowledged.

REFERENCES

Albrigtsen, A., Gudmestad, O. T., & Barabadi, A. (2015). Marine activities in the Arctic: The need for implementation of a "buddy system." *2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 1056–1061. https://doi.org/10.1109/IEEM.2015.7385810

Ash, J. (2023). Flying against the clock – risk management and resilience in Arctic search and rescue and casualty evacuation flights. *Safety in Extreme Environments*, *5*(2), 79–89. https://doi.org/10.1007/s42797-023-00071-x

Barnhart, K. R., Miller, C. R., Overeem, I., & Kay, J. E. (2016). Mapping the future expansion of Arctic open water. *Nature Climate Change*, *6*(3), 280–285. https://doi.org/10.1038/nclimate2848

Boileau, R., Mak, L., & Lever, D. (2010). Avoiding the next Titanic. *Journal of Ocean Technology*, *5*(4), 1–12.

Chaure, M. R., & Gudmestad, O. T. (2020). Effectiveness of the Polar Code training of cruise liner crew for evacuation in the Arctic and Antarctic. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *14*(4), 923–928. https://doi.org/10.12716/1001.14.04.17

Cucinelli, J., Goerlandt, F., & Pelot, R. (2023). Exploring risk governance deficits of maritime Search and Rescue in Canada. *Marine Policy*, *149*, 105511. https://doi.org/10.1016/j.marpol.2023.105511

Dawson, J., Carter, N. A., Weber, M., Orawiec, A., Stewart, E. J., & Holloway, J. E. (2021). *Tourism vessels and Low Impact Shipping Corridors in Arctic Canada* (p. 58). University of Ottawa. 10.20381/d3dd-yk49

Dawson, J., Copland, L., Cook, A., Holloway, J., & Kochtitzky, W. (2021). *Analysis of ice navigational risks by level of ice strengthening among vessels in the Canadian Arctic (1990-2019)* (p. 86). University of Ottawa.

Eliopoulou, E., Papanikolaou, A., & Voulgarellis, M. (2016). Statistical analysis of ship accidents and review of safety level. *Safety Science*, *85*, 282–292. https://doi.org/10.1016/j.ssci.2016.02.001

Fernandes, I. de A. (2024). *Estimating Maximum Expected Time of Rescue: Focusing on helicopter rescue to marine incidents in the Canadian Arctic* [Master of Applied Science]. Dalhousie University.

Ford, J., & Clark, D. (2019). Preparing for the impacts of climate change along Canada's Arctic coast: The importance of search and rescue. *Marine Policy*, *108*, 103662. https://doi.org/10.1016/j.marpol.2019.103662

Fu, S., Goerlandt, F., & Xi, Y. (2021). Arctic shipping risk management: A bibliometric analysis and a systematic review of risk influencing factors of navigational accidents. *Safety Science*, *139*, 105254. https://doi.org/10.1016/j.ssci.2021.105254

Goerlandt, F., & Pelot, R. (2020). An Exploratory Application of the International Risk Governance Council's Risk Governance Framework to Shipping Risks in the Canadian Arctic. In A. Chircop, F. Goerlandt, C. Aporta, & R. Pelot (Eds.), *Governance of Arctic Shipping: Rethinking Risk, Human Impacts and Regulation* (pp. 15–41). Springer International Publishing. https://doi.org/10.1007/978-3-030-44975-9_2

Government of Canada. (2024). Shipping Safety Control Zones Order. In *Justice Laws Website*. https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._356/FullText.html

IMO. (2017). *International Code for Ships Operating in Polar Waters (Polar Code)*. International Maritime Organization.

Kennedy, A., Gallagher, J., & Aylward, K. (2021). *Evaluating exposure time until recovery by location* (Technical Report No. OCRE-TR-2013-036; p. 55). National Research Council Canada.

Kikkert, P., Pedersen, C. A., & Lackenbauer, P. W. (2023). Mitigating the tyranny of time and distance: Community-based organizations and marine mass rescue operations in Inuit Nunangat. In K. Bartenstein & A. Chircop (Eds.), *Shipping in Inuit Nunangat* (Vol. 101, pp. 182–210). Brill, Nijhoff. https://doi.org/10.1163/9789004508576_010

Lasserre, F., & Têtu, P.-L. (2015). The cruise tourism industry in the Canadian Arctic: Analysis of activities and perceptions of cruise ship operators. *Polar Record*, *51*(1), 24–38. Cambridge Core. https://doi.org/10.1017/S0032247413000508

Loot, J. A. (2020). Seafarers and Arctic Cruise Shipping: Protecting Those Who Work While Others Explore and Sightsee. In A. Chircop, F. Goerlandt, C. Aporta, & R. Pelot (Eds.), *Governance of Arctic Shipping: Rethinking Risk, Human Impacts and Regulation* (pp. 171–190). Springer International Publishing. https://doi.org/10.1007/978-3-030-44975-9_9

Lu, L., Kujala, P., & Goerlandt, F. (2021). A method for assessing ship operability in dynamic ice for independent navigation and escort operations. *Ocean Engineering*, *225*, 108830. https://doi.org/10.1016/j.oceaneng.2021.108830

Lu, L., Kujala, P., & Kuikka, S. (2022). On risk management of shipping system in ice-covered waters: Review, analysis and toolbox based on an eight-year polar project. *Ocean Engineering*, *266*, 113078. https://doi.org/10.1016/j.oceaneng.2022.113078

Manley, B., Elliot, S., & Jacobs, S. (2017). Expedition Cruising in the Canadian Arctic: Visitor Motives and the Influence of Education Programming on Knowledge, Attitudes, and Behaviours. *Resources*, *6*(3). https://doi.org/10.3390/resources6030023

Montewka, J., Goerlandt, F., Kujala, P., & Lensu, M. (2015). Towards probabilistic models for the prediction of a ship performance in dynamic ice. *Cold Regions Science and Technology*, *112*, 14–28.

Mostaghimi, K. (2024). *Estimating Maximum Expected Time of Rescue: Focusing on transit time to incidents in the Canadian Arctic by marine resources* [Master of Applied Science]. Dalhousie University.

QGIS. (2025). *QGIS Software* [Computer software]. https://qgis.org

Qi, X., Li, Z., Zhao, C., Zhang, Q., & Zhou, Y. (2024). Environmental impacts of Arctic shipping activities: A review. *Ocean & Coastal Management*, *247*, 106936. https://doi.org/10.1016/j.ocecoaman.2023.106936

Siljander, M., Venäläinen, E., Goerlandt, F., & Pellikka, P. (2015). GIS-based cost distance modelling to support strategic maritime search and rescue planning: A feasibility study. *Applied Geography*, *57*, 54–70. https://doi.org/10.1016/j.apgeog.2014.12.013

Spire. (2024). *Maritime AIS Data for vessel tracking* [Dataset]. https://spire.com/maritime

Stephen, K. (2018). Societal Impacts of a Rapidly Changing Arctic. *Current Climate Change Reports*, *4*(3), 223–237. https://doi.org/10.1007/s40641-018-0106-1

Stewart, E. J., Howell, S. E. L., Draper, D., Yackel, J., & Tivy, A. (2007). Sea Ice in Canada's Arctic: Implications for Cruise Tourism. *Arctic*, *60*(4), 370–380. JSTOR.

Stoddard, M. A., Etienne, L., Fournier, M., Pelot, R., & Beveridge, L. (2016). Making sense of Arctic maritime traffic using the Polar Operational Limits Assessment Risk Indexing System (POLARIS). *IOP Conference Series: Earth and Environmental Science*, *34*(1), 012034. https://doi.org/10.1088/1755-1315/34/1/012034

Stoddard, M. A., Pelot, R., Etienne, L., & Goerlandt, F. (2025). Determining ship speeds in ice using the Polar Operational Limitation Assessment Risk Indexing System (POLARIS). *Ocean Engineering*, *submitted*.

Stoddard, M. A., Pelot, R., Goerlandt, F., & Etienne, L. (2024). Making Sense of Marine-Based Search and Rescue Response Time Using Network Analysis. In A. Chircop, F. Goerlandt, R. Pelot, & C. Aporta (Eds.), *Area-Based Management of Shipping: Canadian and Comparative Perspectives* (pp. 287–313). Springer Nature

Switzerland. https://doi.org/10.1007/978-3-031-60053-1_12
USNIC. (2025). *Arctic ice charts* [Dataset]. https://usicecenter.gov/Products/ArcticCharts
Wang, W. (2023). UNDRIP rights to guide the governance of the Northern Low-impact Shipping Corridors initiative. *Marine Policy*, *155*, 105737. https://doi.org/10.1016/j.marpol.2023.105737
Wang, W., & Aporta, C. (2024). Area-Based Management for Arctic Shipping Governance: An Exploratory Study. In A. Chircop, F. Goerlandt, R. Pelot, & C. Aporta (Eds.), *Area-Based Management of Shipping: Canadian and Comparative Perspectives* (pp. 209–226). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-60053-1_9
Wang, X., Liu, Y., Key, J. R., & Dworak, R. (2022). A New Perspective on Four Decades of Changes in Arctic Sea Ice from Satellite Observations. *Remote Sensing*, *14*(8). https://doi.org/10.3390/rs14081846