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Infrastructure Investments for Improving Arctic Emergency Response across Multiple Man-Made Hazards

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Abstract

The Arctic has been experiencing significant changes to its climate, thus allowing the emergence of new tourism and industrial activities. Underdeveloped emergency response capabilities in the region raise concerns regarding managing man-made hazards; i.e., oil spill and mass rescue incidents. We propose a mathematical optimization model that considers new infrastructure investments within a limited budget to optimally allocate shared response resources across these different emergency response events. Our case study focuses on response in Arctic Alaska and helps answer policy questions that could aid decision-makers in the region.

Keywords
Arctic, infrastructure investments, emergency response, man-made hazard, network optimization

1. Introduction

The Arctic has been experiencing substantial changes over the past several decades. As the air temperature increases, sea ice thickness faces a rapid decrease [1]. Maritime-based tourism and industrial activities have been increasing due to long-lasting ice-free seasons. This trend poses potential risks, as unless proper measures are taken, fundamental ecological and socio-economic systems in the Arctic will be at a high risk [2]. For example, the *Crystal Serenity* sailed for 32 days through the Northwest Passage with over 1600 people in 2016 and 2017 [3]. Due to the remote nature of the region, mass rescue operations of cruise ships could result in evacuations where the evacuated passengers outnumber the population of the Arctic community they are moved to. Further, there is interest in expanding oil and gas exploration activities in the region, including Russia and China recently investing in the region [4].

However, preparedness for emergency response events (ERE) in the Arctic is a major concern [5]. In general, Arctic ERE, including oil spill (OS) events, which require cleaning up and/or remedying the impacts of the spill, and mass rescue (MR) events, which require evacuation of ships with a large number of passengers, are likely to happen in the future and need to be effectively responded to. This is further complicated by unique challenges in the Arctic including limited infrastructure, long distances between the Arctic villages, and the unpredictable and harsh weather conditions [6]. Fjortfort and Berg [7] discuss the importance of preparedness to sustain safer maritime and offshore operations in the Arctic Ocean. Afenyo et al. [8] review risk assessments techniques for oil spills in the Arctic. Further, Wright et al. [9] discuss the risks associated with oil spill incidents and potential measures to mitigate such risks.

Garrett et al. [10] develop an optimization model for an Arctic ERE which allocates response resources in order to complete the response tasks required after oil spill incidents. Camur et al. [11] then introduce the first integer programming (IP) model for a large-scale maritime evacuation that could take place in the Arctic. The model contains two-phase transportation operations where evacuees are moved off of the cruise ship in distress via rescue ships to the local Arctic communities and then out of the Arctic via available aircraft. Das et al. [5] optimize the location of oil spill response stations to maximize spill coverage in the Canadian Arctic. These previous works do not consider planning for multiple types of Arctic EREs, which is the main contribution of our work.

In this paper, we contribute to the literature through designing a novel IP model, which integrates OS and MR events along with infrastructure decisions thereby introducing a planning approach to understand the tradeoffs between planning for OS and MR events in the Arctic. At a high level, our optimization model contains both infrastructure planning and resource allocation decisions. At a lower level, we evaluate how these decisions perform with respect to success of OS and MR events and examine the tradeoffs between focusing on one or the other of these events.

2. Problem Definition

Our goal is to make effective investment and resource allocation decisions under restricted budgets to handle multiple EREs that could take place in the Arctic. We note that investment decisions impact available infrastructure by either increasing capacity (e.g., increasing the size of a hangar) or introducing a new capability (e.g., lengthening a runway to allow a larger type of plane to land), similar to Garret et al. [10]. For example, a C130 aircraft could be used both as a way to deliver OS resources to a community or to pick up stranded evacuees, should the local runway be sufficient to have it land. As for the allocation decisions, we equip Arctic communities (e.g., Point Hope, Nome) to respond to EREs by taking purchasing, maintenance, and transportation costs of resources into consideration.

For the OS incidents, our model, inspired by [10], aims to minimize the total weighted completion time of each task which are required to respond an OS incident. If a task cannot be completed by its deadline, the model takes the follow-up task into consideration in order to complete it by the end of the response time periods. If neither task can be completed due to the lack of resources, the model penalizes the uncompleted tasks.

For the MR incidents, we focus on large-scale maritime incidents where the goal is to take evacuees off of a cruise ship and transport them to the communities located around shore. They then are brought to Anchorage since evacuees are tourists visiting the Arctic and cannot stay in the communities for a long time without straining local systems. Note that we do not consider any relief commodity allocation during MR event since the Camur et al. [11] found that the true bottleneck is the transportation decisions during an Arctic MR event.

We have a multi-objective optimization problem where the objective components are different metrics for OS and MR response. We implement the weighted sum approach to analyze the trade-off between the different components.

3. Model Overview

In this section, we first introduce Tables 1, 2, and 3 which illustrate set, variable, and parameter definitions, respectively. We then introduce our innovative IP, discussing the objective function together with the related constraints.

Set	Definition
O	Infrastructure design options
O^{CB}	Capability design options where $O^{CB} \subset O$
O^{CP}	Capacity design options where $O^{CP} \subset O$
E^o	Oil spill incidents
E^m	Mass rescue events
I	Resources
I^A	Air resources where $I^A \subset I$

Set	Definition
I^S	Sea resources where $I^S \subset I$
I^C	Combination of sea and air resources
J	Response sites
J'	Locations where $J' = J \cup$ "Cruise ship (CS)"
S	Response time periods (in six-hour time buckets)
L	Tasks where $\mathrm{L}_1 \subset L$ represents initial tasks
P	Task pairs

Table 1: Definition of sets

Objective Function

$$\min w^1_{E^o}\Big(\sum_{l\in L}\sum_{e\in E^o} w^2_{el}\tau_{le} + \sum_{(l_1,l_2)\in P}\sum_{e\in E^o}|S|(1-\pi_{l_1e}-\pi_{l_2e})\Big) + w^1_{E^m}\sum_{s\in S}\sum_{e\in E^m}\big(w^2_{e\text{``CS"}}T_{\text{``CS"}se} + w^2_{e\text{``Vil."}}T_{\text{``Vil"}se}\big)$$

The objective aims to minimize the weighted pieces of the penalties incurred due to delays or failures in responding to OS incidents and the number of evacuees remaining on a stranded ship and in Arctic communities across the set of potential MR events. Note that we incorporate a user-defined weight vector w^2_{en} where n corresponds to OS tasks and MR tasks including transporting evacuees off of the ship (i.e., "CS"") and from the Arctic villages (i.e., "Vil").

Infrastructure Planning Decisions

$$\sum_{i\in I} z_{io}\Omega_{ij} \le c_{oj}(\lambda_{oj}+\Lambda_{oj}) \quad o\in O^{CP}, j\in J \tag{1}$$

$$\sum_{i\in I} z_{io}\Omega_{ij} \le c_{oj}\beta_{oj} \quad o\in O^{CB}, j\in J \tag{2}$$

Variable	Definition
π_{l_1e}	whether initial task $l_1 \in L$ is completed for OS incident $e \in E^o$
π_{l_2e}	whether follow-up task $l_2 \in L$ where $(l_1,l_2) \in P$ is completed for OS incident $e \in E^o$
τ_{le}	completion time of task $l \in L$ for OS incident $e \in E^o$
δ_{ijles}	whether resource $i \in I$ is transported from response site $j \in J$ for task $l \in L$ for OS incident $e \in E^o$ in $s \in S$
χ_{ijle}	amount of resource $i \in I$ is transported from response site $j \in J$ for task $l \in L$ for OS incident $e \in E^o$
X_{ijse}	whether resource $i \in I^C$ is located in location $j \in J'$ in $s \in S$ to be used in MR event $e \in E^m$
Z_{ijse}	whether resource $i \in I^C$ stays in location $j \in J'$ in $s \in S$ during MR event $e \in E^m$
Y_{ijkse}	whether resource $i \in I^C$ departs from location $j \in J'$ to reach location $k \in J'$ in $s \in S$ during MR $e \in E^m$
T_{jse}	number of evacuees who stay in location $j \in J'$ in response time period $s \in S$ in MR event $e \in E^m$
f_{ijkse}	number of evacuees carried by resource $i \in I^C$ from location $j \in J'$ to $k \in J'$ in $s \in S$ in MR event $e \in E^m$
Ω_{ij}	amount of resource $i \in I$ in response site $j \in J$
ϕ_{ij}	amount of resource $i \in I$ purchased in response site $j \in J$
σ_{ijk}	amount of resource $i \in I$ transported from response site $j \in J$ to response site $k \in J$
β_{oj}	whether infrastructure capability option $o \in O^{CB}$ already exists or is constructed in response site $j \in J$
Λ_{oj}	amount of infrastructure capacity option $o \in O^{CP}$ constructed in response site $j \in J$
κ_j	whether any infrastructural development is taken place in response site $j \in J$

Table 2: Definition of variables

Constraints (1)-(2) imply that the size of resources for an infrastructure design option at a response site cannot exceed the capacity designated for that option. A capacity infrastructure includes its initial capacity and the increased capacity via investments. Meanwhile, a capability infrastructure option is determined by a binary decision variable stating if it is readily available, either pre-existing or to be constructed.

$$\sum_{o\in O^{CB}}\sum_{j\in J} b_{oj}(1-\alpha_{oj})\beta_{oj} + \sum_{o\in O^{CP}}\sum_{j\in J} b_{oj}\Lambda_{oj} \leq B \tag{3}$$

Constraint (3) ensures that the investments on the infrastructure design options do not exceed the total budget. The binary parameter α_{oj} indicates the existence of a capability option. If $\alpha_{oj}=1$, β_{oj} is unrestricted by (3), allowing the model to use the infrastructure. If $\alpha_{oj}=0$, the model evaluates the feasibility of constructing this option by (3).

Inventory Decisions

$$\Omega_{ij} + \sum_{k\in J}\sigma_{ijk} = \psi_{ij} + \phi_{ij} + \sum_{k\in J}\sigma_{ikj} \quad i\in I, j\in J \tag{4}$$

$$\sum_{i\in I}\sum_{j\in J}(a^1_{ij}\phi_{ij} + \sum_{k\in J} a^2_{ijk}\sigma_{ijk} + a^3_{ij}\Omega_{ij}) \leq A \tag{5}$$

In Constraint (4), we ensure that the total of resource $i \in I$ at a response site $j \in J$ and what is sent elsewhere from the site is equal to the initial inventory, purchases, and transport from other areas. Constraint (5) ensures that total purchasing, transportation, and maintenance cost incurred across all response sites stay within the allocated budget.

Oil Spill Response Decisions

$$\chi_{ijle} \leq r_{ile}\sum_{s\in S}\delta_{ijles} \quad i\in I, j\in J, l\in L, e\in E^o \tag{6}$$

$$\sum_{e\in E^o}\sum_{l\in L}\chi_{ijle} \leq \Omega_{ij} \quad i\in I, j\in J \tag{7}$$

Constraint (6) states that a resource $i \in I$ cannot be deployed from a response site $j \in J$ for task $l \in L$ in incident $e \in E^o$ without a preceding transportation decision. Further, Constraint (7) limits the total resources transported for all tasks to the available inventory at site $j \in J$.

$$\sum_{i\in I}\sum_{l\in L}\delta_{ijles} \leq u_j \quad j\in J, \in E^o, s\in S \tag{8}$$

$$\sum_{s\in S}(m_{ije}+s-1)\delta_{ijles} \leq \tau_{le} \quad i\in I, j\in J, l\in L, e\in E^o \tag{9}$$

Constraint (8) limits the total mobilization decisions across resources/tasks at each site per time period of the response to an incident. Constraint (9) helps to determine a task's completion time.

$$\tau_{l_1e} \leq d_{l_1e}\pi_{l_1e} \quad l_1\in L_1, e\in E^o \tag{10}$$

$$\tau_{l_2e} \geq (d_{l_1e}+1)\pi_{l_2e} \quad (l_1,l_2)\in P, e\in E^o \tag{11}$$

Constraint (10) ensures that deadlines are met for initial tasks. If an initial task misses its deadline, Constraint (11) checks if the follow-up task can be done within the response time.

$$\pi_{l_1e} + \pi_{l_2e} \leq 1 \quad (l_1,l_2)\in P, e\in E^o \tag{12}$$

We also make sure that at most one task in each pair is completed through Constraints (12).

Parameter	Definition
A	total budget for the resource planning (i.e., transportation, purchasing, and maintenance)
B	total budget for the infrastructural developments
α_{oj}	whether infrastructure capability option $o \in O^{CB}$ is available in response site $j \in J$
λ_{oj}	the amount of infrastructure capacity option $o \in O^{CP}$ available in response site $j \in J$
b_{oj}	expansion cost of infrastructure design option $o \in O$ in response site $j \in J$
c_{oj}	total available capacity of infrastructure capacity option $o \in O^{CP}$ in response site $j \in J$
ψ_{ij}	the initial amount of resource $i \in I$ in inventory in response site $j \in J$
z_{io}	the size of resource $i \in I$ for infrastructure design option $o \in O$
a^1_{ij}	the purchasing cost of resource $i \in I$ in response site $j \in J$
a^2_{ijk}	the transportation cost of resource $i \in I$ from response site $j \in J$ to response site $k \in J$
a^3_{ij}	the maintenance cost of resource $i \in I$ in response site $j \in J$
m_{ije}	response time period taken to transport resource $i \in I$ from response site $j \in J$ for OS incident $e \in E^o$
Π_{ijk}	response time period taken to transport resource $i \in I$ from location $j \in J'$ to location $k \in J'$
d_{le}	deadline of task $l \in L$ required for OS incident $e \in E^o$
r_{ile}	the amount of resource $i \in I$ required to complete task $l \in L$ for OS incident $e \in E^o$
ν_e	the number of evacuees on the cruise ship in MR event $e \in E^m$
u_j	the upper bound on the number of mobilization decisions that can be performed in a site $j \in J$
Φ_i	passenger capacity of resource $i \in I^C$
ϑ_j	hosting capacity of response site $j \in J$ with respect to number of evacuees
w^1_E	weight assigned to emergency response events OS and MR

Table 3: Definition of parameters

$$\sum_{j\in J} \chi_{ijle} \geq r_{il_1e}\pi_{l_1e} \quad i \in I, l_1 \in L_1, e \in E^o \tag{13}$$

$$\sum_{j\in J} \chi_{ijle} \geq r_{il_2e}\pi_{l_2e} \quad i \in I, (l_1,l_2) \in P, e \in E^o \tag{14}$$

Constraints (13) and (14) ensure that the required resources for completing either an initial task l_1 or a follow-up task l_2 in pairs $(l_1,l_2) \in P$ for each OS incident $e \in E^o$ are transported.

Mass Rescue Response Decisions

$$\sum_{i'\in I'_i} X_{i'j(s=1)e} \leq \Omega_{ij} \quad i \in I^C, j \in J, e \in E^m \tag{15}$$

$$\sum_{j\in J'} X_{i'jse} \leq 1 \quad i' \in I'_i : i \in I^C, s \in S, e \in E^m \tag{16}$$

Constraints (15) make sure that air and sea resources starting in a MR event do not exceed the current inventory in any response site. For certain types of high-value assets, such as aircraft, our modeling approach limits the number of them purchased and creates variables for each potential purchase in order to track how they are used in MR events. Constraint (16) implies air and sea resource cannot be in multiple locations within the same response time period.

$$X_{i'jse} = Z_{i'jse} + \sum_{k\in J'} Y_{i'jkse} \quad i' \in I'_i : i \in I^C, j \in J, s \in S, e \in E^m \tag{17}$$

Constraint (17) ensures that in a response time period, every air and sea resource either remains in its current location or travels to another location.

$$X_{i'jse} = Z_{i'j(s-1)e} + \sum_{k\in J' : s-\Pi_{i'kj}\geq 1} Y_{i'kj(s-\Pi_{ikj})e} \quad i' \in I'_i : i \in I^C, j \in J', s \in S \setminus \{1\}, e \in E^m \tag{18}$$

Constraint (18) implies that for an air/sea resource to be at location j in response time period s, the model requires either a stay decision at $s-1$ or a transportation decision from location k at $s-\Pi_{ikj}$.

$$f_{ijkse} \leq \Phi_i Y_{ijkse} \quad i \in I^C, j \in J', k \in J', s \in S, e \in E^m \tag{19}$$

$$T_{(j=\mathrm{CS})(s=1)e} = \nu_e \quad e \in E^m \tag{20}$$

The number of evacuees transported by resource i cannot exceed its passenger capacity as enforced by Constraint (19). Constraint (20) initializes the number of evacuees to be rescued from the cruise ship in MR event $e \in E^m$.

$$T_{jse} + \sum_{i\in I^C}\sum_{k\in J'} f_{ijkse} \leq \vartheta_j \quad j \in J', s \in S, e \in E^m \tag{21}$$

Constraint (21) makes sure that the hosting capacity of a response site is not violated at any response time period. We also restrict the usage of rotary wing air resources only to operate between the cruise ship and the response sites.

$$T_{jse} + \sum_{i \in I^C} \sum_{k \in J'} f_{ijkse} = T_{j(s-1)e} + \sum_{i \in I^C} \sum_{k \in J'} f_{ikj(s-\Pi_{ikj})e} \quad j \in J', s \in S \setminus \{1\}, e \in E^m \tag{22}$$

Constraint (22) balances the number of evacuees staying and arriving at location j at time s, with the RHS representing those transported from other locations and the LHS including those staying and departing from j.

4. Computational Experiments

In this section, we discuss the computational experiments. Our experiments were conducted using the Java API and CPLEX version 22.1.1 on a computer equipped with an Intel Core i7-8550U CPU at 1.80 GHz and 8.0 GB of RAM. In total, we consider six OS events and four MR events. The response sites are selected within six communities (i.e., Anchorage, Nome, Kotzebue, Point Hope, Wainwright, and Utqiagvik). The evacuees hosting capacities are set to equivalent to 10% of the population of the community.

We present the locations of the response sites along with the OS and MR events in Figure 1. Note that four different transportation assets (two types of vessels and two types of aircraft) were considered for both OS and MR events. However, more distinct resources are required for OS events. We refer the reader to [10] and [11] for more details regarding the datasets that we built off of. Overall, we set up three scenarios using different weights for the OS and MR events in the objective function. The goal is to understand how infrastructure and inventory decisions change as the importance of OS and MR events varies.

	Obj. Weights (OS:MR)		
	1:1	**100:1**	**1:100**
Runtime	50.5	248.4	94.2
Opt. Gap	1%	1%	1%
Last evac. departure	6	11	6
Evac. time to Anc.	13	16	12
# of failed OS task pairs	23	18	22

Table 4: The summary of computational experiments

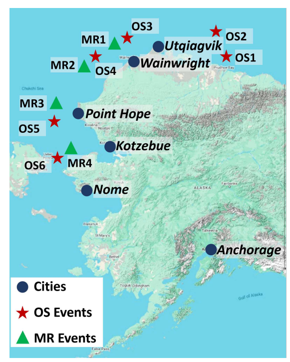

Figure 1: Selected OS and MR events in the region

During our experiments, we set a time limit of 1,800 seconds and an optimality gap limit of 1%. The summary of computational experiments is presented in Table 4. We show the total run time, the optimality gap, the last time period when an evacuee leaves the cruise ship among all three scenarios, the last time period when an evacuee enters Anchorage the three MR events, and the number of OS task pairs that failed to be completed within the given time limit across the OS events.

To begin with, all scenarios were solved with a 1% optimality gap in under five minutes. This is because the number of OS and MR events was chosen to be relatively small to obtain preliminary results. Further, the number of response sites is limited by the relatively small number of Arctic communities. Since the model imposes a high penalty for leaving evacuees stranded on the cruise ship, which is logical given the utmost importance of human life, we observe that the outcomes for both the equal-weighted objective value and the weight biased towards MR events yield similar results. This indicates that further increasing the weights of the objective component related to the MREs is not expected to alter the modeling decisions drastically.

However, when the significance of OS events is increased, the model requires nearly three times as long to achieve the final result compared to other experiments. Our insight is that because OS events demand a range of resources, including dispersant materials and skimmer systems, it challenges the model to make better infrastructure investment and inventory management decisions. Even though the importance of MR events is increased in the third experiment, the number of failed task pairs decreases by one. While fewer tasks fail, the completion times increase since we aim to minimize the weighted completion times.

Note that in the first and third experiments, it takes six time periods to evacuate all evacuees from the cruise ships, and twelve to thirteen time periods until all evacuees are transported to Anchorage via available aircraft, where there are enough resources to accommodate them. However, when weighing OS response heavily, we reduce the number of failed task pairs at the expense of delaying the rescue of evacuees. As the time taken to rescue all evacuees from the cruise ships increases from six to eleven time periods, the time to transport all evacuees from the cruise ship to Anchorage increases to sixteen time periods (see Table 4).

Upon examining the failure rates in responses to both MR and OS events, it becomes apparent that certain response sites are more critical than others. For MR events, incident location ‘MR4’ consistently experiences the most delays during evacuation. This outcome is anticipated due to the clustering of other MR locations around Wainwright and Point Hope. On the other hand, incident locations 'OS1' and 'OS2' carry the highest rate of uncompleted OS task pairs. This can be explained due to the presence of a single response site (i.e., Utqiagvik), which is the only location that can be reached in a timely manner for those incident locations.

It is crucial to emphasize the criticality of shared infrastructure and resources between MR and OS events. We observe a competition for these limited resources, particularly by the competition for vessels (i.e., offshore and nearshore vessels). Despite solely one pair of OS tasks requiring the use of the same type of MR vessels, this pair experiences the highest failure rate. This is because of the model's inherent prioritization of evacuation which results in leaving barely enough vessels available for OS tasks requiring those.

Furthermore, it becomes evident that purchasing decisions are heavily influenced by the weighting of the objective function. A bias towards MR objectives results in increased resource acquisitions in Point Hope, Nome, and Wainwright. Conversely, an OS-biased objective function tends to favor resource purchasing and transportation in Wainwright, Utqiagvik, and Kotzebue. In fact, vessels become the most frequently purchased resources in this scenario with the objective of enhancing the success rate of OS tasks.

Another important observation is that the infrastructure investments show a tendency towards Wainwright in all scenarios, which is followed by Kotzebue and Utqiagvik in the case of OS-biased objective, and by Point Hope and Nome in the case of MR-biased objective. The common infrastructure needed in Wainwright are typically boat launch, harbor, refueling facilities, gravel pad, and conex containers.

Analyzing asset purchases and movements reveals the critical importance of Wainwright, Point Hope, and Nome. It is important for policy makers to ensure the sufficient acquisition of resources, and infrastructure investment in these locations, given their significant roles in both MR and OS events. Such proactive measures are essential to minimize human and environmental costs in the Arctic. However, this presents potential logistical challenges due to the relatively low populations of Wainwright and Point Hope.

5. Conclusions

This paper has introduced a multi-objective optimization problem that helps plan investments into Arctic ERE, specifically focusing on OS [10] and MR events [11]. The model is capable of identifying important locations for investment, as well as understanding the potential impacts of OS and MR events. There are several future research directions. First, a review of our analysis should be done by Arctic domain experts to understand the impact of such investments on the communities. Second, advanced solution techniques should be investigated to solve the problem at scale, with an eye towards advanced Arctic ERE across the entire region.

References

[1] H. Sumata, L. de Steur, D.V. Divine, M.A. Granskog, and S. Gerland. Regime shift in Arctic Ocean sea ice thickness. *Nature*, 615(7952):443–449, 2023.

[2] D.A. Streletskiy, S. Clemens, J.-P. Lanckman, and N.I. Shiklomanov. The costs of Arctic infrastructure damages due to permafrost degradation. *Environmental Research Letters*, 18(1):015006, 2023.

[3] P.T. Maher. Tourism futures in the Arctic. In *The Interconnected Arctic—UArctic Congress 2016*, pages 213–220. Springer International Publishing, 2017.

[4] A. Krivorotov. The Quest for the Ultimate Resources: Oil, Gas, and Coal. In *Global Arctic: An Introduction to the Multifaceted Dynamics of the Arctic*, pages 257–278. Springer, 2022.

[5] T. Das, F. Goerlandt, and R. Pelot. A mixed integer programming approach to improve oil spill response resource allocation in the Canadian Arctic. *Multimodal Transportation*, 3(1):100110, 2024.

[6] K. Schwaeble, T. Birkland, M. Lowe, M. Grabowski, D. Jimenez, T.C. Sharkey, and W.A. Wallace. Emergency Response, Infrastructure, and Governance in Arctic Alaska. *More than'Nature': Research on Infrastructure and Settlements in the North*, 3:283, 2022.

[7] K. Fjørtoft and T.E. Berg. Handling the Preparedness Challenges for Maritime and Offshore Operations in Arctic Waters. In *Arctic Marine Sustainability*, pages 187–212. Springer, 2020.

[8] M. Afenyo, F. Khan, and A.K.Y. Ng. Assessing the risk of potential oil spills in the Arctic due to shipping. In *Maritime Transport and Regional Sustainability*, pages 179–193. Elsevier, 2020.

[9] S. K Wright, S. Allan, S.M. Wilkin, and M. Ziccardi. Oil Spills in the Arctic. In *Arctic One Health: Challenges for Northern Animals and People*, pages 159–192. Springer, 2022.

[10] R.A. Garrett, T.C. Sharkey, M. Grabowski, and W.A. Wallace. Dynamic resource allocation to support oil spill response planning for energy exploration in the Arctic. *European Journal of Operational Research*, 257(1):272–286, 2017.

[11] M.C. Camur, T.C. Sharkey, C. Dorsey, M.R. Grabowski, and W.A. Wallace. Optimizing the response for Arctic mass rescue events. *Transportation Research Part E: Logistics and Transportation Review*, 152:102368, 2021.