Mawuli Afenyo
University of Manitoba, Asper Business School, Department of Supply Chain Management
mawuli.afenyo@umanitoba.ca

Adolf K.Y. Ng[1]
University of Manitoba, Asper Business School, Department of Supply Chain Management. St. John's College
adolf.ng@umanitoba.ca

Changmin Jiang
University of Manitoba, Asper Business School, Department of Supply Chain Management
changmin.jiang@umanitoba.ca

A Method for Assessing the Socio-Economic Impacts of Oil Spills in Arctic Area[2]

Abstract

This paper develops the Socio-Economic Model for the Arctic (SEMA), a probabilistic graphical model based on Bayes' theory, in assessing the socio-economic impacts of oil spills in the Arctic area. It is illustrated through a case study and scenario-based analysis. The results of the latter using SEMA is that the size of vessel and the oil type spilled during shipping in the Arctic are the most critical factors contributing to the impact of oil spill. Further, to a small extent, the response methods used, and the season of operation can also be determinants. The contribution of the latter would increase when more ice melts and ice-breakers are deployed. SEMA however faces challenges related to limited and non-existent of data in some cases. To overcome this shortcoming, a participatory modeling approach has been proposed which will involve collecting data from all stakeholders in Arctic shipping especially the indigenous communities to be used as inputs. Despite the limitations of SEMA at the moment, we believe

[1] Corresponding author.
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that the model is valuable for contingency planning for oil spill, allocation of resources, and decisions to insure ships going through the Arctic region.

Keywords: *Arctic Shipping, Bayesian Network, Oil Spill, Socio-Economic Model for the Arctic (SEMA)*

1. Introduction

The consequences associated with climate change in the transportation industry are often described in a negative way. Some accompanying implications of climate change include, but are not limited to, floods, hurricanes, and poor weather conditions (Ng et al., 2018b). These often require huge investments to address. However, climate change impacts may not necessary be negative. The rapid rate of ice melt due to climate change has accelerated the activities of shipping and resource exploration in the Arctic area (Ng et al., 2018a; Østreng et al., 2013; Stephenson et al., 2013). In this case, previous research showed that the Northern Sea Route (NSR) already accounted for about 5% of shipping worldwide (Liu and Kronbak, 2010; Zhu et al., 2018; Østreng et al., 2013).

The use of Arctic routes usually implies a reduction of shipping distance and thus cost. For example, traveling from the Port of Rotterdam to Yokohama would normally take 21,170 Km through the Suez Canal. Compared to 13,950 km via NSR (Frédéric, 2011). The potential benefits of Arctic shipping do not only apply to cargo movement. In recent years, there is an increase in cruise activities in the Arctic area. Cruise shipping companies have projected an increase in fleet in addition to the current high number of vessels available for Arctic voyages (Anon, 2018). Big cruise companies, such as Ponant, show that there is already booking ongoing for the 2020 Northwest Passage (NWP) voyage. Even LINDBLAD has already conducted a cruise voyage through the NWP, while there are plans advanced to do so for the NSR as well. Furthermore, both HURTIGRUTEN and SILVERSEA have increased their shipping destinations in the Arctic (Anon, 2018). All these motivate Arctic countries, notably Russia, to invest heavily into Arctic navigation facilities (e.g., icebreakers) (Plisetskiy,2016; Brigham,2017). The opportunity is not only being explored by the Arctic countries but also non-Arctic countries. For example, China has as a key strategic component of the Belt and Road Initiative, namely the Polar Silk Road (PSR) (Schach and Madlener, 2018). PSR has at its core the use of Arctic routes for the delivery of goods and services. In line with this, China has an observer status on the Arctic Council. Even though issues related to sovereignty remains a major hurdle, there is optimism about the gains from shipping in the Arctic. These perspectives have therefore sparked a debate to that effect. However, this heightens the possibility of increase oil spill (OS) from routine operations of these ships through the Arctic.

Hence, without any doubt, there is an urgent need for investments and research with the aim to enable transportation and global supply chains withstand the impact of climate change.

Rather than considering them in isolation, it should be part of a regional system that incoporates the potential impact areas around it (Chen et al., 2018). Any such investments require careful consideration of the socio-economic impacts in highly sensitive areas like the Arctic. On the other hand, for an Arctic country like Canada, the opening up of the Arctic also means that the indigeneous communities would be impacted, as some live along the Arctic shorelines. According to Satistics Canada (2016), there are approximately 36,000 people in Nunavut, while there are 57 recognised 'rights holders' in the province of Manitoba (Government of Manitoba's 'Manitoba Land Initiative' website, last accessed in 2018). Potential consequences emanating from Arctic shipping, such as OS, can have devastating socio-economic impacts on the culture, livelihood, and social make-up of the northern communities. In this context, literature suggests that trust can erode among community members, as was the case of the *Exxon Valdez* oil spill, while families become separated (Ritchie, 2012).

Of course, one should not forget that oil behaves differently in open and ice-covered waters. Review of literature shows that, most processes that occur after an oil spill are slowed in ice-covered waters compared to those in open waters (Afenyo et al., 2016a). Oil spill may emanate from accidents or routine leaks from ships as well as blowouts from oil and gas exploration. The focus however for this paper is shipping. The most likely scenario for an oil spill in the Arctic currently is a cruise ship releasing marine oil. This is so because the accidental leaks from tankers are scarce, that is not to say they may not occur. Furthermore, depending on the type of oil leaked, the impact could be different (Afenyo et al., 2016b). Indeed, it is well-documented that the impact of light oil for example is lower than that of heavy oil.

The impact of oil spills is environmental, social, and economic in nature. For example, an oil spill in the Arctic marine environment is likely to affect the reproductive cycle of species (Celik et al., 2009; Afenyo et al., 2016b). In some cases, since the food on which these species feed on is lacking, they die. Some species of fish are sources of food for the "right's holders". Thus, this means that their source of food and finance is affected. It is also likely to affect families which depend on the fishes and other Arctic-related activities for their financial support. Relationships among family members become strained mainly because of the stress, trauma and depression during the aftermath of the OS. This occurrence is well documented in the case of the *Exxon Valdez* OS. Finally, divorce rate among the members of the communities rose and thrust was broken. Families leave the towns and many more are left excessive drinking or indulging themselves in social vices (Ritchie, 2012).

Generally, there is a lack of understanding about the impact of oil spills in the Arctic. For example, Northern Gateway Hearings (JRP, 2013) in Canada illustrates limited knowledge on the subject matter among the Canadian population. Even more revealing is the outcome of a report by the Royal Society of Canada which states the lack of understanding of the behavior of oil and, above all, the unreadiness of even Arctic countries like Canada for a potential oil spill in the region (Lee et al., 2015). The social and economic impact of oil spills are less discussed compared to the environmental implications and therefore tools to assess the socio-economic impact comprehensively are lacking. One of the consequences of such scarcity of knowledge is that OS problems have often been approached reactively, with *Exxon Valdez* OS being an illustrative example. The Oil Pollution Act (OPA) (1990) was only enacted after the *Exxon Valdez* OS. A more proactive approach is therefore required, thus planning and possessing the ability to predict the impact of OS in the Arctic before they happen is extremely important.

Nevertheless, it is difficult to study OS mainly because of the rare nature of its occurrence in the Arctic, but more difficult is to quantify its socio-economic impact. Despite the existence of some tools for compensating the affected communities and individuals (e.g. Natural Resource Damage Assessment (NRDA)) they are more useful where the incident has already occurred. The NRDA depend extensively on the knowledge of bio-database of the particular area. In the case of Arctic areas, such data is either completely unavailable or very limited. In some cases, there are regulations and compensation schemes which offer a one-time payment to victims (Etkins, 2015), but the question is what is the formula for such compensation? The answer there is no scientific basis for the distribution of money and materials for the affected populace. In fact, in some cases such programs become an avenue for corruption and those in charge enrich themselves. Due to the lack of reliable data, and the right legal framework for Arctic OS, it becomes increasingly difficult to conduct impact assessment for a relatively unexplored terrain like the Arctic. Furthermore, shipping activities in the Arctic have yet reached a significant level to convince (most) industrial stakeholders to take the risk to invest massively in infrastructure (Afenyo et al., 2015; Lee et al., 2015). This presents challenges for governments for planning purposes and insurance companies that cover vessels going to the Arctic. Finally, there is a misconception among many people that the Arctic is an isolated, uninhabited place that can be dealt with easily. The often-wrong assumption is that there are no economic implications and so no environmental and social consequences when an OS should occur in the Arctic. This assumption is flawed since there are a lot of "rights holders" in the northern communities (Liu and Kronbak, 2009; Zhang et al., 2016a; Zhu et al., 2018). Therefore, any assessment that does not consider transportation in a comprehensive way is to say the least, limited in scope and subsequently its output.

Understanding such, the paper strives to develop a model to estimate the socio-economic impacts that an OS is likely to cause in the Arctic area due to shipping. For the purpose of this paper, 'socio-economic impact' is understood as the social, biophysical, economic and legal impacts of an OS. This paper seeks to achieve three objectives: 1) to identify and understand the effects of shipping in the Arctic and the accompanying benefits, risks as well as the uncertainties, 2) to understand the socio-economic impact of OS from Arctic shipping, and 3) to present a methodology for evaluating the socio-economic impacts of OS from shipping. Named by the authors as the Socio-Economic Model for the Arctic (SEMA), it bears the goal of estimating the social, economic, and biophysical impacts of oil spills from shipping in dollar terms (monetary value). We strongly believe that SEMA will be useful for decision-making on planning, response to oil spills and compensating affected parties of an oil spill incident. Moreover, insurance companies would benefit from such a model in that they will have an effective tool to do a first-step evaluation of the potential risks and subsequently the monetary value of the consequences of an OS in the Arctic from shipping. Finally, in terms of regulation, SEMA presents a platform for making scientific decisions on the regulatory regimes to adopt, improve and update. To the best of our knowledge, this is a pioneer work being done in ice-covered waters.

The rest of the paper will evolve as follows. In Section 2, a literature review of relevant works is presented while Section 3 presents SEMA, as well as the model. The illustration of SEMA is also presented in this section. Sections 4 and 5 consist of the discussion and conclusion, respectively.

2. Literature Review

Consequences from OS during maritime accidents are well documented in literature. From the *Exxon Valdez OS* to the *Prestige OS* (Afenyo et al., 2018a; Melia et al., 2016; Fuglestvedt et al., 2014), these accidents can be divided broadly into five distinct groups. These include grounding, collision, fire, explosion and structural failure. Furthermore, in the context of adaptation to climate change (Ng et al., 2018a; Xiao et al., 2015; Wang and Zhang, 2018), it is important that researchers take note of historical accidents over the years and plan accordingly (Kum and Sahin, 2015). This includes the causes of accidents and what the accompanying consequences are (Afenyo et al., 2016a). The ability of ports and other facilities involved in shipping to adapt to climate change gives investors an opportunity to contribute to port economics, management, and planning, in terms of profits and subsequently expansion and jobs (Wang and Zhang, 2018).

Table 1 summarizes the major studies that assess the economic, social, and environmental impacts of OS. Although they exist individually, none has put it together and applied it to shipping in the Arctic. Table 1 offers further credence to this statement. It is a difficult task evaluating the effects in the three categories together comprehensively. Even more challenging is performing same in a less explored terrain like the Arctic. Furthermore, the social impacts have not been quantified. The economic models presented face certain challenges, such as the restriction to regression analysis and models that do not incorporate inputs from stakeholders. In fact, for the acceptability of the models, it is important that stakeholders and 'right holders' are involved right from the start – to the point where the model is implemented, and the output is satisfactory.

Table 1 – Social, environmental, and economic impacts of oil spills (OS) related studies

Author(s)	Category	Details
Ritchie (2012)	Social Impact	Investigated the effect of stress, trauma and social capital on the local population and economy after the *Exxon Valdez* OS.
Yamada (2009)	Economic impact	Estimated the cost of an OS using regression analysis.
Etkins (1999;2000;2015)	Economic impact	Estimated the cost of OS using models developed by authors.
Liu and Wirtz (2009)	Economic and environmental impact	Used an integrated model made of OS Contingency and Response (OSCAR) tool and cost functions to estimate cost of an oil spill.
Cheong (2011)	Social Impact	Conducted a qualitative social assessment of the Heibei-Spirit OS incident.
Shahriari and Frost (2008)	Economic impact	Presented a regression-based model for the cleanup of OS.
Negro et al. (2009)	Economic impact	Estimated economic implication of the impact of *Prestige OS* on fisheries
Ng and Song (2010)	Economic impact	Presented a model for assessing the impact of pollutants from routine shipping operations.

Source: Compiled by authors

Qualitative evaluation of social and economic impacts is perhaps not as challenging as doing the same in quantitative terms. Also, Arctic related regulations, such as the Polar Code, is biased towards environmental impact as opposed to social and economic impacts. For regions like northern Canada, simply focusing on the environmental impact is not adequate. Going some steps further and address the social and economic impact of an OS is of paramount importance. This is because their very way of life would be affected by the OS.

3. Materials and Methods

The proposed model in this paper is described in the context of the Natural Resource Damage Assessment (NRDA). Figure 2 shows the general steps taken during the NRDA. Also, it shows potentially where the proposed model could be useful, even though it could be used as a stand-alone tool to achieve the capabilities described earlier.

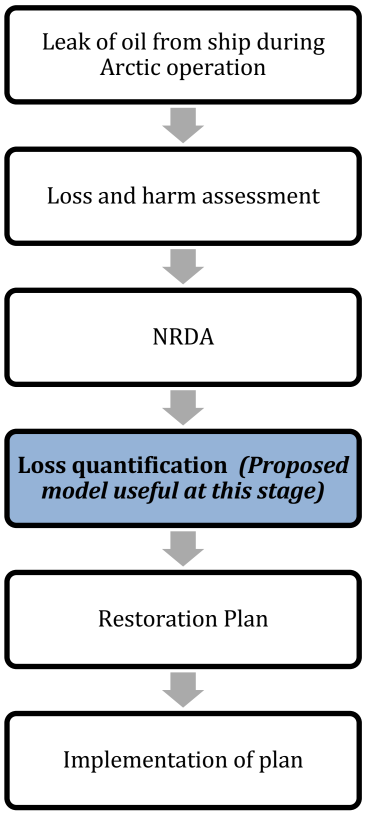

Figure 1 – The location of the proposed model in the NRDA process

Source: Authors

The assumption used in building Figure 2 is that after the loss and harm assessment, the injuries and losses were not taken care of so the NRDA has to proceed. Furthermore, the scenario assumes that there has been an OS from a shipping accident in the Arctic. The level of harm and loss is then ascertained by the trustees and if the losses and injuries have not been addressed, an NRDA is then conducted to determine the economic, social, and environmental losses to affected parties. This requires a robust, scientific tool that accounts for as many factors as possible. This is the stage where the proposed model would be useful. Once the quantity of loss is determined, a restoration plan is put in place and subsequently implemented.

The proposed tool is a Bayesian-based model that operates on probabilities. In this study, an extension of the classical Bayesian model is used – referred as Influenced Diagrams (ID). The use of the theory in different disciplines is well documented. Table 2 shows a snapshot of relevant works done using the theory. Focus in the Table 2 is shipping and OS.

Table 2 – Bayesian theory related studies for oil spill (OS) and shipping

Study	Details
Montewka et al. (2013)	Used influence diagram to predict the cost of OS in the Gulf of Finland. The focus of the study is on the cost related to clean up.
Lehikoinen et al. (2013)	Presented an influence diagram model to determine the efficiency of oil combating vessels in Finland.
Lecklin et al.(2011)	Used a Bayesian based model for predicting the biological impact of spilled oil in the Gulf of Finland.
Musella et al. (2016)	Authors applied Bayesian Network to resource mapping

Source: Compiled by authors

Despite the notable applications of BN to many problems, missing in the literature is its application to estimate the social, economic, and biophysical impacts together in monetary terms. To our best knowledge, no such studies have been conducted in open water environment. Such has not been attempted in ice-covered waters precisely to Arctic shipping. This may be due to the challenges involved.

3.1. Bayesian Network

The Bayesian Network (BN) is a graph-based model that is implemented using the Baye's theorem (Islam et al., 2017; Kjaerulff and Madsen, 2008; Landuyt et al., 2013; Aktaş et al., 2007). The extension of the BN referend to as the ID is made up of six components. These include independent and dependent nodes, decision nodes and the utility nodes, edges, and the Conditional Probability Table (CPT). Each node is connected by the edges (links). The nodes could take both continuous and discrete inputs. To operationalize the BN, CPT is used to establish the relationships between the nodes. They rely on probability values (Islam et al., 2017; Kjaerulff and Madsen, 2008; Montewka et al., 2013).

The Baye's equation is described by Equation 1

$$P(D|C) = \frac{P(C|D)}{P(C)} P(D) \tag{1}$$

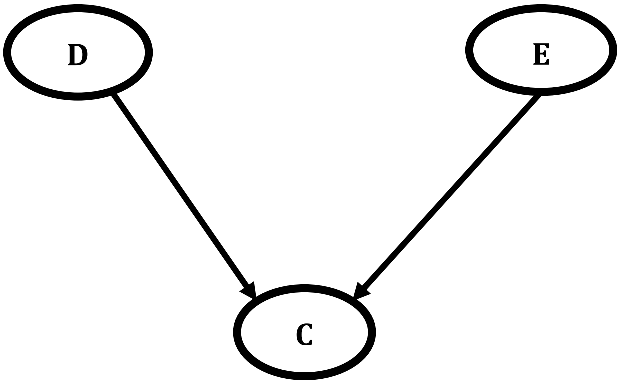

Figure 2 – A simple structure of Bayesian Network
Source: Authors

$P(D|C)$ represents the posterior probability, $P(C|D)$ is the likelihood of the occurrence of the event and $P(D)$ is the prior probability and $P(C)$ is the normalization factor. The details and rules of construction of the BN can be inferred from Pearl (2000). Here it is important to note that, since BN is a Directed Acyclic Graph (DAG), it is not possible to have a feedback loop.

To predict the probabilities of a series of variables for example y which is part of the DAG = (U, V), where U represents the node and V the edge/link, the relation used is Equation 2 for the joint probability for $Y_1 \ldots\ldots\ldots.Y_n$

$$\mathrm{P}\,(Y_1 \ldots\ldots\ldots.Y_n) = \prod_i^n \left(Y_i \middle| Y_{pa}\right) \tag{2}$$

where Y_{pa} are the parent variables.

The use of BN creates the possibility to combine expert knowledge, stakeholders' input, and information from literature and other relevant sources (e.g., websites). One key use of BN is for predicting events and for carrying out diagnosis analysis. The latter would help determine critical factors contributing to a particular effect, such as socio-economic impacts.

3.2. Methodology for developing the model

To develop the model, we follow a few steps, as illustrated in Figure 3. The first step involves the definition of the problem. To do so, literature, stakeholders as well as "rights holders" are consulted to define the problem more appropriately. For the sake of this study, the identified problem is the leak of oil from shipping activities within the Arctic region. Following this exercise, a brainstorming event takes place to identify the potential variables contributing to the identified problem. To do this, contributory factors are defined in a simplest possible way in order to make the modeling exercise easier. The outcome is a mental picture of the model and its accompanying variables.

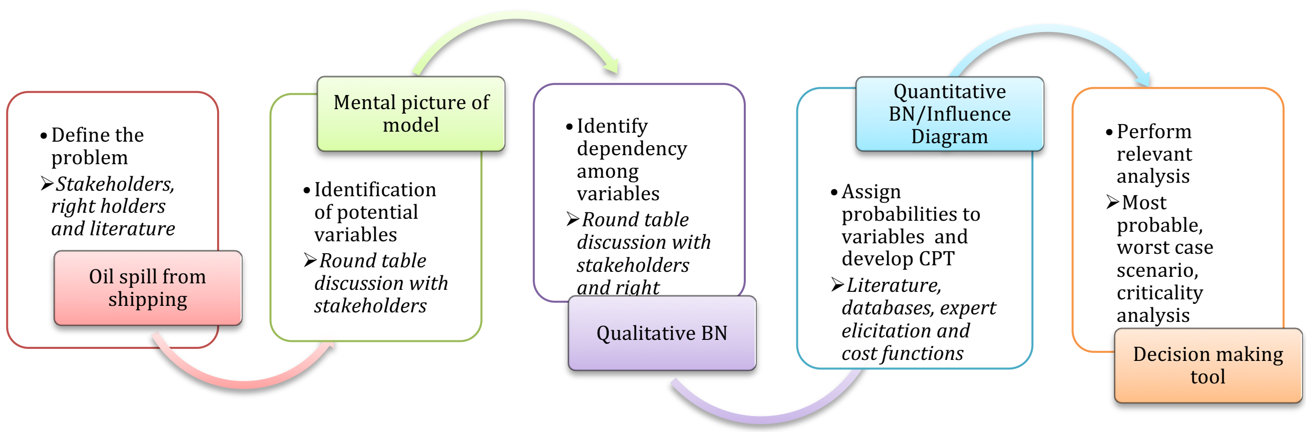

Figure 3 – A simple structure of Bayesian Network
Source: Authors

Once the variables have been identified, the next step requires linking each variable to the ultimate goal of the exercise which is the socio-economic impacts of the problem identified. The variables that are dependent on each other are linked with arrows and those that are not are left to stand alone. Variables occurring in multiple positions are reduced to one. The outcome is a qualitative model that captures the problem in a BN form. BN at this stage is further upgraded by introducing decision nodes and utility nodes. The final node (socio-economic impact) is replaced with a utility node since we want our output in monetary terms. The decision nodes are the recovery methods that may be used during/after an OS in the Arctic.

Following this step is the assigning of the probabilities and the introduction of cost functions for the cost related variables. In this study, the probabilities used are mostly from relevant literature and websites. It should be noted that, the values have not be copied directly from these sources but have been modified to illustrate the operationalization of the model. To improve this model, it is important to conduct a survey to elicit probabilities for variables that are subjective. This is very important for obtaining good results for specific Arctic communities. The current model is global in nature and can be modified for a local area. Also, CPT are obtained in a similar way utilizing equations and probabilities with guidance from literature and discussions with stakeholders. However, this can be improved with an extensive survey to elicit the probabilities.

Once the quantitative model is developed, analysis can be conducted. This includes the most probable scenario analysis, the worst-case scenario analysis, and the criticality analysis. These analyses enable us to predict the socio-economic impacts of the OS under different scenarios. Moreover, it is possible to assign a potential amount to a scenario and identify the critical factors contributing to that scenario. In this way, such factors can be managed to reduce the impact. It will therefore inform the allocation of resource by government and other planning agencies.

3.3. The model

The model is made of six types of nodes as described earlier. Figure 4 is the qualitative model. It was developed using GeNie 2.0 (GeNie, 2018).The logic behind it is that when there is an OS from a shipping accident such as grounding, collision, fire and explosion or leak from (routine) shipping activities, it finds its way into the Arctic marine environment.

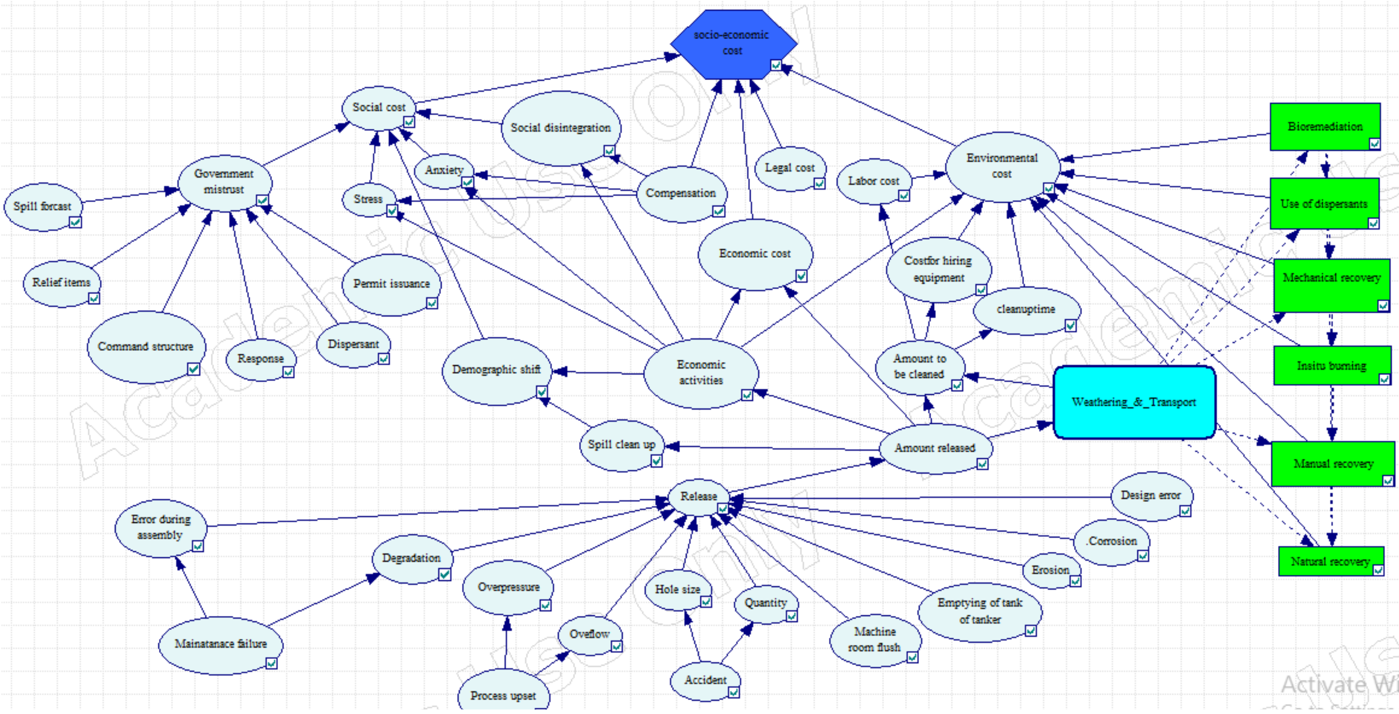

Figure 4 – The qualitative influence diagram

Source: Authors

Furthermore, there may be other causes of such a leak, and these may include maintenance failure, process upset, corrosion, design failure, and erosion. The leaked oil undergoes weathering and transport processes, such as evaporation, spreading, emulsification, dispersion, encapsulation, and sedimentation. The OS results in social, environmental, and economic impacts. The social cost can be captured in terms of anxiety, stress, social dis-integration, and government's mistrust. Also, there is a legal cost from the fees paid to the attorney and other fees related to such. The environmental cost is captured by the labor cost for cleaning, equipment cost and compensation for environmental pollution among others.

The decision nodes in the model are the various recovery methods to be employed for dealing with the oil. They include bioremediation, dispersant use, mechanical recovery, insitu-burning, and manual recovery. These together with the aforementioned contribute to the final impact (i.e., socio-economic impacts in monetary terms).

3.3.1 The sub-model

The sub-model depicts the transformation of the oil into tar balls and mouse, as well as breaking it down for degradation. The phenomena are collectively referred to as weathering and transport processes. They are mostly affected by the environmental and oceanographic factors.

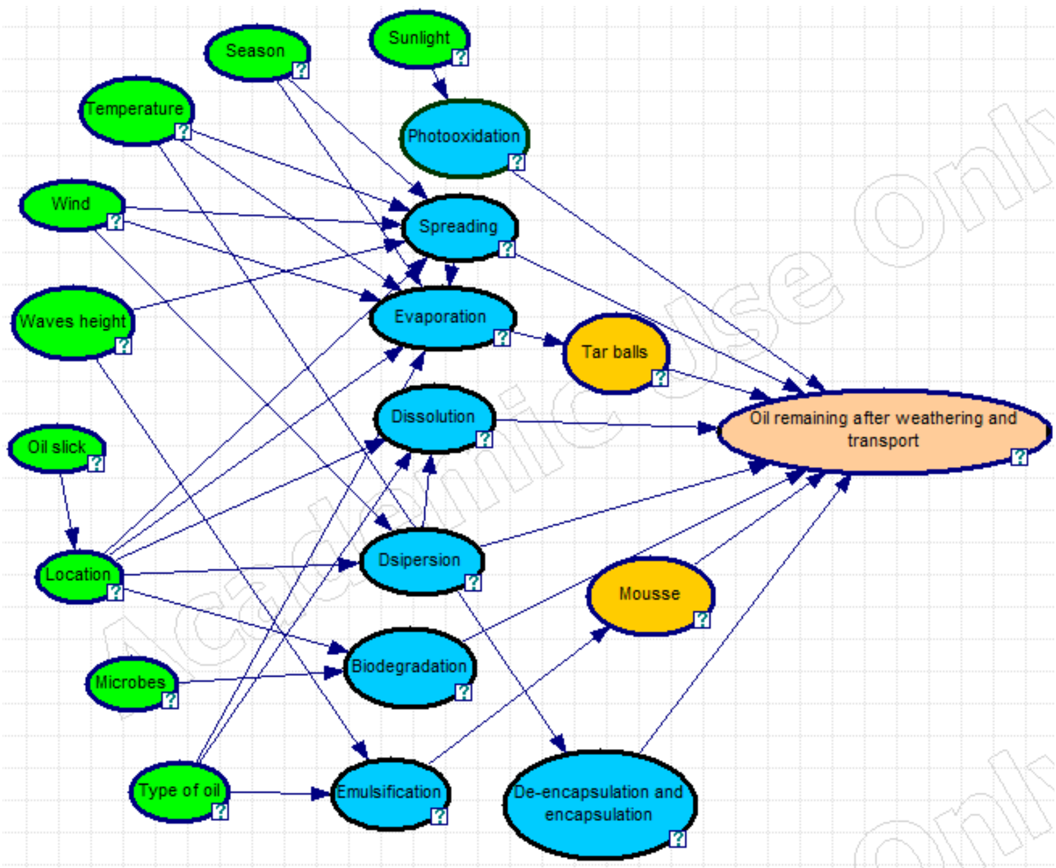

Figure 5 – The sub-model depicting weathering and transport processes

Source: Authors

For example, wind speed and oil type affect the process of emulsion while evaporation is affected by wind, temperature, and the season of occurrence of the OS. This is not exhaustive, but an attempt has been made to cover as many processes as possible. The location of the OS in the sub-model refers to whether it occurred under ice, in water, between ice or in snow.[3]

3.3.2 Independent and dependent variables

The independent and dependent variables take discreet probability values in the model presented. Some are shown in Table 3.

Table 3 – Some independent and dependent variables

Variable	**Data Source**
Type of oil	Toxicological data base, literature,
Location	Expert elicitation, literature
Wave height	Statistical observation from environmental and oceanographic data base, government and international meteorological data base
Microbes	Expert elicitation, literature
Oil slick	Expert elicitation, literature
Wind	Statistical data observation from Environmental organizations, government and international meteorological data base
Temperature	Statistical data observation from environmental organizations, government and international meteorological data base
Season	Statistical data observation from environmental organizations, government and international meteorological data base
Sunlight	Statistical data observation from environmental organizations, government and international meteorological data base
Type of vessel	Statistical data observation from maritime data
Accident	Statistical data observation from maritime accident data
Erosion	Statistical observation from maritime data, expert elicitation and stakeholder engagement
Corrosion	Statistical observation from maritime data, expert elicitation and stakeholder engagement; Offshore Reliability Handbook (OREDA)
Design error	Statistical observation from maritime data, expert elicitation and stakeholder engagement; OREDA

[3] For details about how weathering and transport processes interact and the science behind, see Afenyo et al. (2016a) and Lee et al. (2015).

Process upset	Statistical data observation from maritime data, expert elicitation and stakeholder engagement; OREDA
Maintenance failure	Statistical data observation from maritime data, expert elicitation and stakeholder engagement; OREDA
Spill forecast	Numerical and other OS modelling tools, expert elicitation and stakeholders' engagement, metrological data
Command structure	Expert elicitation and stakeholders' engagement
Response	Expert elicitation and stakeholders' engagement
Permit issuance	Expert elicitation and stakeholders' engagement
Dispersant use	Expert elicitation and stakeholders' engagement
Machine room flush	Expert elicitation and stakeholders' engagement
Emptying tank of tankers	Expert elicitation and stakeholders' engagement

Source: Authors

For illustrative purpose, the probabilities used for some of the variables are shown in Tables 4a and 4b.

Table 4a – Probability values for the variable "Type of accident"

Type of accident	Probability
Grounding	0.4
Collision	0.4
Fire	0.1
Explosion	0.05
Structural failure	0.05

Table 4b – Probability values for the variable "Wind"

Wind speed	Probability
High	0.63
Medium	0.31
Low	0.06

The current model is global in nature. Thus, it would change if being applied to a regional or local setting. The factors may differ, and the input data would also differ.

3.3.2 Utility node

The utility nodes are modeled using cost functions and, in some cases, like the cost of compensation, the regulations applying to a particular jurisdiction may be considered, such as OPA 1990. However, in this study, a one-time amount has been assumed for compensation.

The cost functions proposed by Ng and Song (2010) is adopted for this paper. The relations shown in Equations 3, and 4 are used in estimating $E_{P,}$ and $C_{P,}$

$$E_p = \sum_s \int_m^n V_n \times g(Q_p) \times (1 - f(t_n)) \times \left(\frac{1}{1+r_n}\right)^{t_s - m} dt_n \quad (3)$$

$$C_p \text{ is } \sum(\alpha_p, \beta_p \times Q_P) \quad (4)$$

Where α, β and Q are positive. The subscript p referes to the oil, $E_p(\$)$ is the economic damage, $C_p(\$)$, is the cost related to the cleanup/removal of pollutants. There are other minor costs not captured in this text. $f(t)$ in Equation 3 stands for the recovery function, n and s are the damaged entities, t is the time (years), α is the research cost and β is the unit cost of response, Q_P is the quantity of discharged oil. The social cost is calculated considering how much is spent per head in treating anxiety, trauma and stress during a particular period.

3.3.3 Decision nodes

These nodes are represented by the recovery methods for OS. In the model, they include bioremediation, use of dispersants, mechanical recovery, manual recovery, *in situ* burning, and natural recovery. In this case, it is noted that certain methods are not accepted within some jurisdictions (e.g., *in situ* burning, use of dispersants) due to the environmental implications that such methods might generate. For example, the gas (mostly greenhouse gas) leaked during the process of burning the oil can be highly dangerous. Furthermore, the compositions of the dispersants are dangerous to the marine environment. All the possible methods of recovery have been included, making it possible to choose from this suit during simulation. In response exercises, sometimes more than one method may be needed to take care of the oil.

3.3.4 Conditional Probability Table

CPT has the function of linking the various variables quantitatively. The approach adopted in this study is similar to that used by Montewka et al. (2013). However, a combination of cost function, discrete probabilities has been employed to develop the various CPTs. In cases where it is a challenge obtaining values for the CPT, informed approximations are used. This is guided by knowledge from literature and interaction with stakeholders. Table 5 is the CPT for the process of photo-oxidation. It is observed that when the sunlight intensity is high, the rate of photo-oxidation is high too. Similar tables exist for the other variables.

Table 5 – Sample CPT for photo-oxidation

Sunlight	***Low***	***Medium***	***High***
High rate of photo-oxidation	0.1	0.2	0.7
Low rate of photo-oxidation	0.9	0.8	0.3

Source: Authors

3.3.5 Model Validation

The validation of the model is two-folded. First, it has to be accepted by stakeholders as a true representation of the problem. Second, it needs to be compared to major existing models. The first one is qualitative in nature, while the second one is mainly to have an idea of the order of magnitude of the output. Since no two models (and therefore predictions) are the same, it is not expected that the comparison would yield the same result. In this study, the output of the model is compared to the work by Ng and Song (2010). The current model is probabilistic in nature and so addresses uncertainty to some extent. That is not the case for the others.

3.3.6 Analysis of case and potential scenarios

Two types of analysis are conducted in this study. The first one is a case involving a scenario of the *MS Explorer*. The famous incident occurred in November 2007. The vessel was navigating in relatively low ice conditions. In this scenario it is assumed that 5,000 barrels of Marine Gas Oil (MGO) was leaked. Furthermore, an amount of $10M was invested in the compensation of the affected parties. The area affected is assumed to be inhabited by approximately 900 people. The main livelihood of the inhabitants is fishing, and the period of projection is five years. The price of the affected fish species is $400 per ton. Another assumption is that *in situ* burning is deployed as the recovery method. Using the stated model, the result of the simulation resulted in approximately $101,300,000 in terms of socio-economic impact damages.

In the second case, a series of potential scenarios are simulated. Table 6 illustrates different type of scenarios to be simulated. It is noted that these have be chosen purely for illustration purposes. Table 7 gives details of the scenarios in Table 6. As can be inferred from Table 6, the main variables are the season, type of oil, recovery method, and the size of ship. Different combinations have been presented, some with recovery methods and the others without it.

Table 6 – Matrix of potential scenario to be simulated

Scenario	Season	Type of oil	Recovery method	Type of ship
1	Summer	Light	None	Small
2	Winter	Light	None	Small
3	Summer	Light	None	Large
4	Winter	Light	None	Large
5	Summer	Light	*In situ* burning	small
6	Winter	Light	*In situ* burning	Small
7	Summer	Light	*In situ* burning	Large

8	Winter	Light	*In situ* burning	Large
9	Summer	Heavy	None	small
10	Winter	Heavy	None	Small
11	Summer	Heavy	None	Large
12	Winter	Heavy	None	Large
13	Summer	Heavy	*In situ* burning	Small
14	Winter	Heavy	*In situ* burning	Small
15	Summer	Heavy	*In situ* burning	Large
16	Winter	Heavy	*In situ* burning	Large

Source: Authors

Table 7 – A detailed description of the scenarios in Table 6

Scenario	Details
1	In this scenario, it is assumed that cruise ship categorized as small grounded and leaked light crude. Furthermore, no recovery method was implemented. The accident occurred in summer. The implication of this scenario is that, the oil is allowed to undergo natural weathering and transport processes. Since the leaked oil is light and scenario occurred in the summer, it is anticipated that the weathering and transport processes would proceed faster.
2	In this scenario, the conditions remain similar to that of scenario 1, but the assumption here is that, the incident occurred in winter. The fact that the scenario occurred in winter means that there is the presence of ice and the weathering and transport processes are slowed compared to the former scenario.
3	In this scenario, the conditions remain similar to that of scenario 1, but the vessel is large implying the quantity of oil leaked is high. The behavior of oil will be same as scenario 1, only that the impact on flora and fauna and subsequently the populace is likely to be higher.
4	In this scenario, the conditions are similar to scenario 2 but the vessel involved is large, implying a large quantity of leaked oil. The impact in this case is also likely to be higher considering the fact that the processes would proceed slowly and take a longer time to get rid of the oil.
5	This is the first scenario where a recovery method is introduced. Furthermore, this scenario is assumed to have occurred in summer. So, in the model, the decision node for *in situ* burning is activated. Together with dispersant use, *in situ* burning is often described as environmentally unfriendly. The burning produces greenhouse gases which pollutes the environment and subsequently cause global warming.
6	The conditions for scenario 6 are analogous to 5, the only addition being the season of occurrence, i.e., winter.

7	In this scenario, the conditions are analogous to that of 5. However, the size of vessel involved is large. The implication for this is that the impact is large since the estimated quantity of oil leaked is high as well.
8	The conditions are same as previous scenario but the season under consideration is winter. It means that the weathering and transport processes would be slow, so will the response process. This means that oil is likely to persist in the marine environment longer than the previous scenario.
9	This is the first-time heavy oil is introduced into the scenarios. Here the accident is assumed to have occurred in the summer and involves a small vessel. The type of oil implies that the weathering processes would be slow compared to the light oil. This is because processes like evaporation would have fewer light components exiting from the surface compared to when it involved light oil. Also, there is no recovery method used in this scenario.
10	Compared to the previous scenario, i.e., 9, the characteristics are similar, the only difference being the season of occurrence. In this scenario, it is assumed OS occurred in summer. The impact would be more because the weathering and transport processes would be further slower.
11	The characteristics of this scenario is similar to scenario 9, but the vessel involved here is a large one. This implies a large quantity of leaked oil, hence a higher impact.
12	This scenario is analogous to 11, the only difference being the season of occurrence. The season of occurrence is winter.
13	In this scenario, *in situ* burning is introduced again with the combination of the leak of heavy oil. It is assumed to have occurred in summer and the type of vessel involved in the grounding accident is a small one.
14	This scenario is similar to scenario 13. However, the season of occurrence is assumed to be winter. The processes are slower and so the impact is projected to be more than that of the previous.
15	In this scenario, the characteristics are analogous to that of scenario 13, but the vessel involved is large, meaning a high quantity of oil is leaked into the marine environment.
16	In this scenario, the season of occurrence is winter and the quantity of oil leaked is also large.

Source: Authors

4. Results and Discussion

In the analysis of the case simulated, the predicted socio-economic impact of the leaked oil is approximately $101,300,000. A comparison to the output from the model developed by Ng and Song (2010) a similar order of magnitude with a 7% difference. This is however small. . Furthermore, the 16-scenario analysis shows that the type of vessel, type of oil, and the season of occurrence have huge influence on the socio-economic impacts of an OS in the marine environment, and subsequently the people. Also, of significance is the type of recovery method deployed. It is noted that different combinations could have been presented and further investigation carried out on the impact of other recovery methods and other oil types on the socio-economic impacts. The current model gives us that flexibility to be able to do this. It is important to note that the scenarios presented are hypothetical and mainly for illustrative purposes. For example, most countries do not allow shipping during the winter seasons. This is likely to change with the rapid change of ice-melt. In addition, there is a huge investment of icebreakers so, it is a possibility.

It can be inferred from the output in Figure 5 that heavy oil spilled in the winter and applying *in situ* burning pose significant negative socio-economic impacts on the area under investigation. This may be due to the fact that heavy oil takes a while to degrade also the other weathering and transport processes are slowed down significantly.

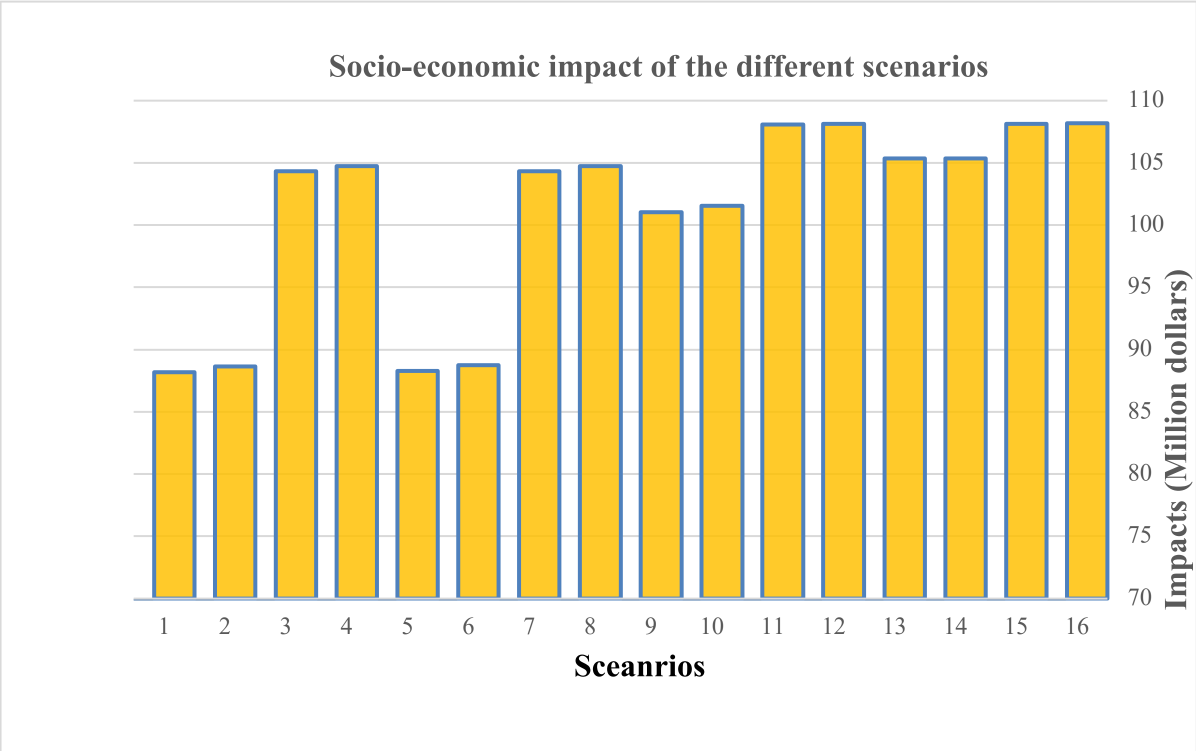

Figure 5 – Output of scenario simulation

This implies that the amount of oil that would persist in the marine environment is likely to be high and so the impact. It may even result in health problems. The longer the oil persist in the environment, the higher would be the likelihood that the fishes would die, which in turn would affect community livelihood. Furthermore, the burning of oil releases greenhouse gas into the atmosphere. These factors may attract higher legal and labor costs when dealing with the oil leaked.

The scenario with a small vessel releasing light oil in the summer produced the least impact. This scenario did not have any recovery methods, meaning that the oil is allowed to undergo natural attenuation. While it may be true that the biodegradation of the oil by bacteria may take a while, natural dispersion and other oceanographic factors that may speed up the breaking down of the oil may be slow. This output should be look at in the context of time. In the long run, this may be the best option. But in the short run where immediate results are needed, it may not help deal with the oil.

Also, the trend shows that the impact in the winter is generally slightly higher compared to same in summer. It may look quite similar for some scenarios mainly because a higher weight was not assigned to the seasonal impact in SEMA. The slightly higher impact may however be because response during the winter is hampered by harsh conditions. These problems include lack of light and extremely low temperatures. Also, the effect of the environmental and oceanographic factors on the oil are reduced. The insignificant variation in SEMA shows that the season may not be a major factor in determining the impact at the moment as most Arctic countries only allow navigation in the summer. Thus, it is difficult for us to know what the main difference would be between summer and winter. Even though we know there will be some difference, we do not know by how much. However, this is likely to change when more activities are experienced in the Arctic.

For policy implication, we argue that it is important to enact regulations to prevent vessels from going to the Arctic at some parts of the year. This would lower the risk of potential OS and subsequently the associated socio-economic impacts that come with it. Also, the government and other environmental agencies would need to do proper planning and develop contingency plans to respond to such spills should they occur. The northern communities must be involved in every stage of policies regarding shipping in the Arctic. Most of them know where the fauna and flora they depend on are and so can help direct Arctic shipping routes.

Furthermore, a scheme could be developed to make Arctic-going ships paying some forms of deposits/premiums before embarking on voyages to this area. In this way should an OS happen, this fund could be used immediately for response. Such schemes can only be enforced if the right holders, government, and other Arctic shipping players are all engaged at all levels of policy development. For example, the Nunavut acts and agreements are a good example of how policy can help shape the discussion on shipping in the Arctic. To the northern communities, ice is part of their lives and virtually everything they do throughout the year involves ice. In this case, we argue that it is appropriate to have first responders trained from the community rather than waiting on the Coast Guard or other relevant governmental organizations to respond during OS. Also, government needs to invest heavily in the equipment for response to these communities. Their very existence depends on a clean environment devoid of oil pollution. Finally, the social implications in the form of trauma, stress, anxiety, social system distortion are all implications of an OS. A proactive approach would be very helpful rather than a reactive one. Dedicated centers need to be established for such emergency considering how remote some of these places are. Regional and global collaboration is very important in order to address the consequences of OS.

For future work, it is pivotal to customize the current model to a local scale and receive inputs from the local population. A survey-based approach can be adopted which would involve insurers, scientists, engineers, right holders, and relevant government organizations. This will further validate and improve the accuracy, acceptability, and the validity of the model proposed in this study.

5. Conclusion

This paper presents a Bayesian-based model referred to as SEMA for estimating the socio-economic impacts of oil spills (OS) from shipping in the Arctic. The model combines a probabilistic-based theory and cost functions to fulfil this. To illustrate the model, a case study and a scenario-based analysis have been performed. In this study, we illustrate that the model has the capability to analyse different scenarios including worst case scenarios and most likely scenarios. Furthermore, it can be used for contingency and response planning. The model is valuable for a terrain like the Arctic where no significant OS incident has been recorded. Also, the flexibility of the model and its core characteristics means that it combines expert knowledge and inputs from stakeholders. Thus, we argue that SEMA will be very useful in shaping Arctic shipping policy especially with regards to OS. In this case, it is noted that SEMA can be updated and adjusted to fit more specific situations, once new information becomes available.

Governments, rights holders and insurance companies can all benefit from the outputs of the model. It captures comprehensively the social, biophysical and economic impact of a potential OS in the Arctic. The study shows that the type of ship, type of oil, season, and the recovery method deployed can affect the socio-economic impacts of the OS. However major challenges remain which includes finding experts on OS from shipping in the Arctic for elicitation. Furthermore, obtaining inputs from indigenous people comes with substantial challenges in terms of regulation and accessibility. Indeed, database for some input variables are confidential for certain jurisdictions. This will hinder conducting an extensive study for such areas. Nonetheless, a customised model for an Arctic community would be helpful. Even though climate change is sometimes perceived as negative, the introduction and implementation of appropriate approaches to develop Arctic shipping is a way to add silver linings to it. Northern communities would benefit from cheaper supplies and increased number of tourists. On the other hand, some are worried about the potential impact of OS in their community. The model therefore presents an important tool for projecting what to expect and plan accordingly. Both Arctic and non-Arctic countries need to present a united front in addressing the potential problems of OS in the Arctic. Even as the economic prospects are promising, we should be ready to address its accompanying socio-economic impacts. For a rather isolated terrain like the Arctic, there is a lot of uncertainty in terms of information. There is always the opportunity for new discoveries and so will require frequent updates.

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