



**ARCTIC DOMAIN**  
**AWARENESS CENTER**  
A DEPARTMENT OF HOMELAND SECURITY CENTER OF EXCELLENCE

***Arctic Domain Awareness Center (ADAC)***

***A DHS Science and Technology Office of University Programs,***

***Center for Maritime Research***

**Current State of Science for Arctic Maritime Search and Rescue**

**A Literature Synthesis in support of**

**Arctic-Related Incidents of National Significance as/of 14 June 2016**

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## Preamble

Search and Rescue (SAR) situations are conceptualized as a series of sequential (discrete) and emergent (transitional) elements [1]. Sequential elements consist of a) predisposition to incident (e.g., inclement weather, equipment malfunction(s), human factors including purposeful and/or malicious intent, b) convergence of contingency failures and/or inability to self- correct and c) communication of incident [2]. Emergent elements are an area where more research is needed but these are conceptualized to consist of spatiotemporally convergent events for which the locus of control lies outside any given human actor [3]. SAR operations similarly can be conceptualized into different components and phases. Components consist of technologies, personnel, plans and thresholds [4, 5]. Phases consist of awareness, authorization, operations (including one and two sided search patterns with and without coordination) and reporting [4, 5, 6].

The current literature on SAR for maritime operations, including the Arctic region, is limited primarily to both linear and non- linear dynamics of both object drift and optimal sweep (search) patterns as well as the utility of robotics and other technologies to assist human operators in executing on-the- ground operations (OTGOs). Our analysis concludes that current thinking in SAR operations would benefit from taking a systems approach, that is, considering more diverse components and elements including a) situational awareness and context as enhanced by local and place based knowledge (LPBK), b) data fusion beyond command and control, that is, the utility of hand- held decision support for OTGOs and c) trade-offs and consequences in restricted and/or limited capacity SAR settings such as those which occur in the Arctic domain. Using the vast legacy of SAR operations “lessons learned” as well as a body of knowledge we anticipate being able to extend the science of SAR to include systems approaches. Compounding SAR, even in the Arctic, is the advent of publically accessible information, smartphone technology, rapidly growing broadband networks, and the explosion of open content on microblogs and social media platforms presents analysts with a myriad of new challenges. Due to the “fire-hose” of information available, analysts are finding it increasingly difficult to obtain validated and timely information that effectively facilitates informed decisions without the increased expenditure of resources.

The following challenges have been identified as significantly prohibitive to the analytical process across the full spectrum of mission sets:

- Existing data is not easily leveraged to model trends and risk in order to increase the effectiveness of information driven operations;
- There is a gap in the capability to synergize collection, aggregation and operational processes with analysis;
- Mobile real time data inputs from local responders are underutilized;
- Analysis can be resource intensive in an increasingly resource weakened field

Two systems emerge to provide superior features for SAR operations both at the Command and Control and OTGOs levels. The first is SAROPS which is written as a series of extensions to ESRI's ArcGIS 10.4 (COTS, not part of the SAROPS distribution). SAROPS makes requests to and receives from an Environmental Data Server (EDS) real-time gridded environmental products. SAROPS also allows manual inputs of winds and currents input via a 'sketch' tool using objective analysis techniques. SAROPS uses the latest drift algorithms to project the drift of the survivors and craft. Search Rescue Unit (SRU) allocation is automated in SAROPS by maximizing Probability of Success (POS). Each SRU gets a recommended search pattern that accounts for the relative motion between the SRU and the drifting particles. This is done by using the Probability of Detection as function Lateral Range to update the probability of detection for each particle.

The second is the Field Information Support Tool (FIST). FIST provides innovative whole-of-government C4I solutions which integrate data, sensor feeds, analytical processes, intelligence, operations and support. Our solutions provide the capability to collect, analyze, visualize and share geo-referenced information using mobile devices and an internet portal with advanced features. These solutions empower every stakeholder with current information, incisive analysis and shared situational awareness in support of effective, timely decision-making. The system was designed to operate across a broad mission space to enable and accelerate information-driven operations. A mission-agnostic architecture supports intelligence and operations tasks through rapid and efficient knowledge creation and the implementation of a continuous information cycle to drive operations with actionable information. The FIST system is easily implemented, simple to use and versatile; no downrange contractor support or expensive deployed infrastructure are required. The system enables powerful analysis and reporting including: geospatial, temporal, link and social cultural dynamics; an automated analysis module brings analytical power to staffs that may not have dedicated analysts available. These solutions are ideal for interagency coordination and for collaboration with partner and ally nation organizations.

The following is a literature review and synopsis organized by focus area. Each synopsis provides a brief explanation and/or abstract of the article. A full text database of all available articles can be accessed here:

<https://drive.google.com/folderview?id=0ByPVpFZAFRuRQ1pnb3NhbJJFLWs&usp=sharing>

## **Search Theory, Modeling, and Statistics**

### *1. (Frost and Stone 2001) "Review of Search Theory: Advances and Applications to Search and Rescue Decision Support"*

Fundamental limitations inherent in manual search planning methods have severely limited the application of advances in several areas that could improve the efficiency and effectiveness of the U.S. Coast Guard's search and rescue mission. These areas include advances in search theory, environmental data products, knowledge of detection profiles for various sensors, and knowledge of leeway behavior. The U.S. Coast Guard's computerized search planning aids have not kept up with advances in these areas or with technology in general. This report reviews the history and recent advances of search theory and its application to a variety of search problems. It then reviews the history of the U.S. Coast Guard's search planning methods, showing where search theory was initially applied, albeit in a necessarily very limited way, and where later modifications departed from the theoretical basis of the original methodology. Several computerized search planning decision support tools are analyzed and compared, as are the differences between an analytic approach and a simulation approach. The results are summarized in a matrix. The U.S. Coast Guard needs a new search planning decision support tool for search and rescue and other missions. This tool should use the simulation approach due to its power and flexibility as compared to analytic techniques.

### *2. (Haley 2012) Search Theory and Applications*

Book, originally published in 1980, funded by NATO: mathematical basis of search theory... from the "Brief Overview":

#### Elements of a Search Problem

There are three basic elements which are present in an optimal search problem, one being Probability Distribution for Target's Location and Motion.

Information about the target's location at some initial time (e.g., his last reported position) and his subsequent motion are quantified in terms of probability distributions. The probability distribution for initial location and subsequent motion are combined to produce a probability map for the target's location at any subsequent time.

### *(Guitouni et al. 2008) "Application of Search Theory for Large Volume Surveillance Planning"*

DRDC Valcartier has initiated, through a PRECARN partnership project, the development of an advanced simulation test bed called CanCoastWatch. The main focus of this test bed is to study net-enabled concepts such as distributed information fusion algorithms and architectures, dynamic resources and networks configuration management, and self-synchronizing units and agents. The test bed allows the evaluation of a range of control strategies from independent platform search, through various levels of platform collaboration, up to a centralized control of

search platforms. In this paper, we present the integration of a planning tool based on search theory concept: SARPlan. In particular, we discuss the original idea of combining fusion results to build a containment probability distribution according to the search theory approach. This paper presents the results and discusses future development.

### 3. *(Brevik et al. 2011) "Wind-induced drift of objects at sea: The leeway field method"*

A method for conducting leeway field experiments to establish the drift properties of small objects (0.1–25 m) is described. The objective is to define a standardized and unambiguous procedure for condensing the drift properties down to a set of coefficients that may be incorporated into existing stochastic trajectory forecast models for drifting objects of concern to search and rescue operations and other activities involving vessels lost at sea such as containers with hazardous material. An operational definition of the slip or wind and wave-induced motion of a drifting object relative to the ambient current is proposed. This definition taken together with a strict adherence to a 10 m wind speed allows us to refer unambiguously to the leeway of a drifting object. We recommend that all objects if possible be studied using what we term the direct method, where the object's leeway is studied directly using an attached current meter. We establish a minimum set of parameters that should be estimated for a drifting object for it to be included in the operational forecast models used for prediction of search areas for drifting objects. We divide drifting objects into four categories, depending on their size. For the smaller objects (less than 0.5 m), an indirect method of measuring the object's motion relative to the ambient current must be used. For larger objects, direct measurement of the motion through the near- surface water masses is strongly recommended. Larger objects are categorized according to the ability to attach current meters and wind monitoring systems to them. The leeway field method proposed here is illustrated with results from field work where three objects were studied in their distress configuration; a 1:3.3 sized model of a 40-foot Shipping container, a World War II mine and a 220 l (55-gallon) oil drum.

### 4. *(Russell and Quigley 2006) "Modelling the reliability of search and rescue operations within the UK Through Bayesian Belief Networks"*

This paper uses a Bayesian Belief Networks (BBN) methodology to assess the reliability of Search and Rescue (SAR) operations within the UK Coastguard (Maritime Rescue) coordination centers. This is an extension of earlier work, which investigated the rationale of the government's decision to close a number of coordination centers. The previous study made use of secondary data sources and employed a binary logistic regression methodology to support the analysis. This study focused on the collection of primary data through a structured elicitation process, which resulted in the construction of a BBN. The main findings of the study are that approaches such as logistic regression are complementary to BBN's. The former provided a more objective assessment of associations between variables but was restricted in the level of detail that could be explicitly expressed within the model due to lack of available data. The latter method provided a much more detailed model but the validity of the numeric assessments was more questionable. Each method can be used to inform and defend the development of the

other. The paper describes in detail the elicitation process employed to construct the BBN and reflects on the potential for bias.

5. *(Norrington et al. 2008) "Modelling the reliability of search and rescue operations with Bayesian Belief Networks"*

This paper uses a Bayesian Belief Networks (BBN) methodology to model the reliability of Search and Rescue (SAR) operations within UK Coastguard (Maritime Rescue) coordination centers. This is an extension of earlier work, which investigated the rationale of the government's decision to close a number of coordination centers. The previous study made use of secondary data sources and employed a binary logistic regression methodology to support the analysis. This study focused on the collection of primary data through a structured elicitation process, which resulted in the construction of a BBN. The main findings of the study are that statistical analysis of secondary data can be used to complement BBNs. The former provided a more objective assessment of associations between variables, but was restricted in the level of detail that could be explicitly expressed within the model due to a lack of available data. The latter method provided a much more detailed model, but the validity of the numeric assessments was more questionable. Each method can be used to inform and defend the development of the other. The paper describes in detail the elicitation process employed to construct the BBN and reflects on the potential for bias.

6. *(Ni, Qiu, and Su 2010) "On predicting boat drift for search and rescue"*

A theoretical model for predicting boat drift for search and rescue missions is presented in this work. The drift model is based on the law of physics which govern the motion of a floating body in a given wind and surface current field. In terms of the empirical aerodynamics force coefficients of the boat or any other drifting object, external wind field, and current field, the drift velocity of the boat being searched for can be obtained. The uncertainty of the characteristics of the boat's drift is evaluated by interval analysis of the uncertainties of the characteristics of the drifting boat and external forcing fields. The search area expansion and the source of uncertainty is systematically evaluated. The current statistical model-based operational definitions of leeway drift, leeway rate, leeway angle, divergence angle, leeway divergence, downwind component of leeway, and crosswind component of leeway are clarified in light of the presented theoretical model. The divergence angle and leeway divergence are evaluated through the interval analysis of the uncertainty of the parameters involved.

7. *(Azofra et al. 2007) "Optimum placement of sea rescue resources"*

In countries with autonomous regional governments, the positioning of the national sea rescue resources is often a permanent source of friction between the national and regional authorities. This friction usually resurges after any heavily publicized accident. However, the process of planning sea rescue resources and their distribution in the various locations should be carried out according to scientific criteria. The aim of the present work is to build a tool which allows sea rescue resources to be assigned objectively. To this end, we formalize a general

methodology based on gravitational models which allows us to define individual and zonal distribution models. Also, a practical application of the zonal model is performed, assigning 'sea rescue boats' to a segment of the coast where there are three ports.

8. *(Pestov and Pilat 2012) "A Net-Enabled Approach to Modelling Joint Interagency Systems."*

This report discusses a new network-based modelling framework that we have developed for representation and analysis of joint interagency systems. Agents in such systems differ by the roles they play in the system, by the environmental domains in which they operate, and also by other case-specific attributes. The agent heterogeneity gives rise to an Operational network, which represents a step-by-step execution of a response action to a particular incident. The network measures of the Operational network serve as performance indicators for the entire system. The utility of the presented modelling framework is illustrated using an example of the Canadian Arctic Search and Rescue system. Under our approach, the system is viewed and modelled as a set of inter-linked dynamical networks with embedded heterogeneous agents. Each agent is encoded as a multidimensional string of data, which represents agent attributes. The resulting dynamical network model, SARnet, provides visualization and computational capabilities for system analysis and exploration. The visualization capabilities of the model are used to examine the architectural make-up of the system and to explore its multidimensional agents. The computational capabilities are applied to analyze the Operational network of a real incident in the Arctic. The presented modelling framework is applicable to a variety of joint interagency systems. SARnet is a prototype dynamical network model that implements the presented modelling framework, creating a virtual laboratory in which different aspects of system performance can be efficiently evaluated.

9. *(Washburn 1980) "On a search for a moving target"*

We consider the problem of searching for a target that moves in discrete time and space according to some Markovian process. At each time, a searcher attempts to detect the target. If the searcher's action at each time is such as to maximize his chances of immediate detection, we call his strategy "myopic." We provide a computationally useful necessary condition for optimality, and use it to provide an example wherein the myopic strategy is not optimal.

10. *(Richardson and Discenza 1980) "The United States Coast Guard Computer-Assisted Search Planning system (CASP)"*

This paper provides an overview of the Computer-Assisted Search Planning (CASP) system developed for the United States Coast Guard. The CASP information processing methodology is based upon Monte Carlo simulation to obtain an initial probability distribution for target location and to update this distribution to account for drift due to currents and winds. A multiple scenario approach is employed to generate the initial probability distribution. Bayesian updating is used to reflect negative information obtained from unsuccessful search. The principal output of the CASP system is a sequence of probability "maps" which display the current target location

probability distributions throughout the time period of interest. CASP also provides guidance for allocating search effort based upon optimal search theory.

*11. J. R. Frost (Soza & Co.) L. P. Stone (Metron, Inc.) 2001 Report No. CG-D-15-01  
"REVIEW OF SEARCH THEORY: ADVANCES AND APPLICATIONS TO SEARCH AND RESCUE  
DECISION SUPPORT"*

Fundamental limitations inherent in manual search planning methods have severely limited the application of advances in several areas that could improve the efficiency and effectiveness of the U.S. Coast Guard's search and rescue mission. These areas include advances in search theory, environmental data products, knowledge of detection profiles for various sensors, and knowledge of leeway behavior. The U.S. Coast Guard's computerized search planning aids have not kept up with advances in these areas or with technology in general. This report reviews the history and recent advances of search theory and its application to a variety of search problems. It then reviews the history of the U.S. Coast Guard's search planning methods, showing where search theory was initially applied, albeit in a necessarily very limited way, and where later modifications departed from the theoretical basis of the original methodology. Several computerized search planning decision support tools are analyzed and compared, as are the differences between an analytic approach and a simulation approach. The results are summarized in a matrix. The U.S. Coast Guard needs a new search planning decision support tool for search and rescue and other missions. This tool should use the simulation approach due to its power and flexibility as compared to analytic techniques.

*12. T. M. Kratzke, L. D. Stone and J. R. Frost, "Search and Rescue Optimal Planning System," Information Fusion (FUSION), 2010 13th Conference on, Edinburgh, 2010, pp. 1-8. doi: 10.1109/ICIF.2010.5712114*

In 1974 the U.S. Coast Guard put into operation its first computerized search and rescue planning system CASP (Computer- Assisted Search Planning) which used a Bayesian approach implemented by a particle filter to produce probability distributions for the location of the search object. These distributions were used for planning search effort. In 2003, the Coast Guard started development of a new decision support system for managing search efforts called Search and Rescue Optimal Planning System (SAROPS). SAROPS has been operational since January, 2007 and is currently the only search planning tool that the Coast Guard uses for maritime searches. SAROPS represents a major advance in search planning technology. This paper reviews the technology behind the tool.

*13. (Sjölin, S. G. 1985) "Visco-elastic buckling analysis of floating ice sheets"*

The purpose of this article is to critically analyze the yield stresses of ice flows; or otherwise, when the ice flows disassemble. The idea is that Arctic infrastructure is being overdesigned to protect against flowing ice which may not be cost-efficient. The authors suggest that their most significant deduction is the prediction theory of viscoelastic buckling of ice by reason of creep deformations.

In view of this, viscoelastic creep buckling is proven to have significantly lower loading than loads predicted by elastic buckling. The methodology adopted by the authors is described in detail, such that any improvement can be easily reapplied to derive more quantitative results. This work uses an analytic approach by using engineering assumptions to simplify and idealize a physical problem; the approach gives physical insight into general viscoelastic buckling problems. The authors include examples depicting characteristic buckling length and time to failure. An example of interest illustrates that the buckling of ice may even occur after crushing begins. The authors make clear that refinement is necessary before this technique is used to quantitatively predict loads on structures.

### **Search Technology and Robotic Assistance**

#### *14. (Breivik et al. 2013) "Advances in search and rescue at sea"*

A topical collection on "Advances in Search and Rescue at Sea" has appeared in recent issues of Ocean Dynamics following the latest in a series of workshops on "Technologies for Search and Rescue and other Emergency Marine Operations" (2004, 2006, 2008, and 2011), hosted by IFREMER in Brest, France. Here, we give a brief overview of the history of search and rescue at sea before we summarize the main results of the papers that have appeared in the topical collection.

#### *15. (Davidson et al. 2009) "Applications of GODAE ocean current forecasts to search and rescue and ship routing"*

As GODAE ocean forecast systems progress, their contributions toward improving the safety and efficiency of operations at sea will increase. In this article, we review present uses of GODAE ocean forecast systems for various safety applications at sea, including search and rescue drift calculations, iceberg drift calculations, ice cover prediction, and safety of offshore operations. Additionally, we review how various countries presently use safety and decision support tools that incorporate ocean current forecasts.

#### *16. (Yang, Polycarpou, and Minai 2007) "Multi-UAV Cooperative Search Using an Opportunistic Learning Method"*

The control of networked multivehicle systems designed to perform complex coordinated tasks is currently an important and challenging field of research. This paper addresses a cooperative search problem where a team of uninhabited aerial vehicles (UAVs) seeks to find targets of interest in an uncertain environment. We present a practical framework for online planning and control of a group of UAVs for cooperative search based on two interdependent tasks: (i) incrementally updating "cognitive maps" used as the representation of the environment through new sensor readings; (ii) continuously planning the path for each vehicle based on the information obtained through the search. We formulate the cooperative search problem and develop a decentralized strategy based on an opportunistic cooperative learning method, where

the emergent coordination among vehicles is enabled by letting each vehicle consider other vehicles' actions in its path planning procedure. By using the developed strategy, physically feasible paths for the vehicles to follow are generated, where constraints on aerial vehicles, including physical maneuverability's, are considered and the dynamic nature of the environment is taken into account. We also present some mathematical analysis of the developed search strategy. Our analysis shows that this strategy guarantees a complete search of the environment and is robust to a partial loss of UAVs. A lower bound on the search time for any strategy and a relaxed upper bound for the proposed strategy are given. Simulation results are used to illustrate the effectiveness of the proposed strategy.

17. (Curry et al. 2004) "*Applications of Aerosondes in the Arctic*"

The U.S. Arctic remains one of the most difficult places on Earth for year-round scientific observations and research. Logistical support is very expensive, and scientists frequently face dangerous, cold sea-ice dynamics, aircraft icing—even polar bears. While satellites can obtain data in remote regions, their application to many arctic environmental problems is hampered by persistent cloudiness and the complexity of the underlying snow/ice surface.

One of the major recommendations of the 1997 report, "Logistics Recommendations for an Improved U.S. Arctic Research Capability" ([www.arcus.org/logistics/index.html](http://www.arcus.org/logistics/index.html)), was to increase use of robotic aircraft to meet the growing need for environmental observing in the region. Unmanned aerial vehicles (UAVs) excel in "dull, dirty, dangerous" missions.

**Decision Support and Operational Frameworks**

18. (Glomseth 2012) "*Ambulance helicopter contribution to air based search and rescue in North Norway during 2000-2010.*"

Background: Search and rescue (SAR) operations constitute a small but important proportion of the Norwegian ambulance helicopter services' workload. There is no common database for all SAR helicopter operations, because several different resources contribute to the operations, and there is no common definition of SAR in use among different services.

Methods: We performed a manual search through the mission databases for the three dedicated SAR and helicopter emergency medical service (HEMS) bases in our area, and the Joint Rescue Coordination Centre (North) database, for helicopter-supported SAR operations in the potential operation area of the Tromsø HEMS base during the years 2000-2010. We defined SAR operations as all missions above sea inside 10 nM from the coast line, all missions with rescue hoist or static rope, missions with an initial search phase, and all avalanches.

Results: There were 769 requests for helicopter support in 639 different search and rescue operations, and 600 helicopter missions were completed. The number of operations increased over the study period, from 46 operations in 2000 to 77 operations in 2010. The Tromsø HEMS contributed with the highest number of missions and the service also experienced the largest increase over the years, from 10 % of the missions in 2000 to 50 % in 2010. Simple terrain

operations or sea operations dominated in the different sub- regions of the study area, but avalanches accounted for as many as 12 % of the missions. Static rope or rescue hoist was used in 141 out of the 639 operations.

Conclusions: We have been able to describe all helicopter supported SAR operations in our area by combining available databases and employing common SAR definition. The local HEMS service experienced the greatest increase in SAR operations, and further studies are suggested to understand the causes for the increase. We suggest that increased availability is one potential explanation.

*19. (Abi-Zeid and Frost 2005) "SARPlan: A decision support system for Canadian Search and Rescue Operations"*

We present SARPlan, a geographic decision support system designed to assist the Canadian Forces in the optimal planning of search missions for missing aircraft. Its primary purpose is to ensure that the available search resources are deployed in a way that will maximize the mission's probability of success. The optimization modules are based on search theory, on gradient search methods and on constraint satisfaction programming. We include results that demonstrate that SARPlan improves the performance when compared to the current manual method. This improvement translates to an increase in the chances of finding lost aircraft and survivors, resulting in more saved lives. Another benefit of using SARPlan is a potential decrease in the operations costs. In 2001, SARPlan was the winner of three prestigious excellence awards in the information technology domain.

*20. (Breivik and Allen 2008) "An operational search and rescue model for the Norwegian Sea and the North Sea"*

A new operational, ensemble-based search and rescue model for the Norwegian Sea and the North Sea is presented. The stochastic trajectory model computes the net motion of a range of search and rescue objects. A new, robust formulation for the relation between the wind and the motion of the drifting object (termed the leeway of the object) is employed. Empirically derived coefficients for 63 categories of search objects compiled by the US Coast Guard are ingested to estimate the leeway of the drifting objects. A Monte Carlo technique is employed to generate an ensemble that accounts for the uncertainties in forcing fields (wind and current), leeway drift properties, and the initial position of the search object. The ensemble yields an estimate of the time evolving probability density function of the location of the search object, and its envelope defines the search area. Forcing fields from the operational oceanic and atmospheric forecast system of The Norwegian Meteorological Institute are used as input to the trajectory model. This allows for the first time high-resolution wind and current fields to be used to forecast search areas up to 60 h into the future. A limited set of field exercises show good agreement between model trajectories, search areas, and observed trajectories for life rafts and other search objects. Comparison with older methods shows that search areas expand much more slowly using the new ensemble method with high resolution forcing fields and the new leeway

formulation. It is found that going to higher-order stochastic trajectory models will not significantly improve the forecast skill and the rate of expansion of search areas.

21. (Haagensen et al. 2004) *"Long-range rescue helicopter missions in the Arctic"*

Background: Search and rescue helicopters from the Royal Norwegian Air Force conduct ambulance and search and rescue missions in the Barents Sea. The team on-board includes an anesthesiologist and a paramedic. Operations in this area are challenging due to long distances, severe weather conditions, and arctic winter darkness.

Methods: One-hundred, forty-seven ambulances and 29 search and rescue missions in the Barents Sea during 1994–1999 were studied retrospectively with special emphasis on operative conditions and medical results.

Results and Discussion: Thirty-five percent of the missions were carried out in darkness. The median time from the alarm to first patient contact was 3.3 hours and the median duration of the missions was 7.3 hours. Forty-eight percent of the missions involved ships of foreign origin. Half the patients had acute illnesses, dominated by gastrointestinal and heart diseases. Most of the injuries resulted from industrial accidents with open and closed fractures, amputations, and soft tissue damage. Ninety percent of the patients were hospitalized; 7.5% probably would not have survived without early medical treatment and rapid transportation to a hospital.

Conclusion: Using a heavy search and rescue helicopter in the Barents Sea was the right decision in terms of medical gain and operative risk.

22. (Breivik, Øyvind, et al. 2016) *"Advances in search and rescue at sea."*

Primarily an overview paper into the current state of search and rescue technology used in search theory and trajectory models.

Understanding and theories of ocean drift and currents have advanced considerably since first investigated during WWII in response to downed aircraft and ships. The advances in this field have led directly to the development of search and rescue theory. From the development of CASP (Computer Assisted Search Planning) which uses Monte Carlo statistical trajectories in order to better identify search locations. These scenarios combined with the use of self-locating buoys on the IRIDUM network have greatly added in the ability to find objects at sea. These developments have led to Search and Rescue Optimal Planning System (SAROPS) used by the USCG, and deployed in 2007, which incorporates wind, environmental, and meteorological data

into the system. All of these systems came into play during the AF 447 crash in 2009, by tracking the debris field the models could hind-cast to sufficient accuracy the impact point and crash location. While this article does not specifically refer to the arctic, as an overview paper it provides many references to current research in the dynamics of rescue theory. While data is limited the same approach may be possible with ice flow and movement, to develop early warning for ice, and models to project locations if an emergency occurs.

23. (Kurowski, Martin, and Bernhard P. Lampe 2014) *"AGaPaS: A new approach for search-and-rescue-operations at sea."*

AGaPaS is an automated search and rescue system developed by the Germans primarily for a person over board scenario. The system relies on the use of GPS tracking of crew/personal, once a person is recognized as no longer on board; the system automatically deploys via free fall, and is self-righting. The system has a catamaran hull, self-righting roof structure, separate drive motors allowing for increased agility, and cameras both IR and visible light to guide the craft during the final 10 m of a rescue where GPS is no longer accurate. Once the craft is over the victim; a hydraulic operated net recovers the them from the water. In addition to the automated system there is a remote control override that that can be initiated from a ship; it was noted in trials that while the remote generally has better results in the final 10 m of the rescue, it takes considerable practice to achieve this level of accuracy. The paper goes into the matrix based control system with great detail, and notes that the guidance system is unreliable in the final several meters due to the inaccuracy of GPS. Testing indicated that the system is reliable in relatively heavy seas.

### **Policy and Governance**

24. (Council 2011) *"Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic"*

The objective of this Agreement is to strengthen aeronautical and maritime search and rescue cooperation and coordination in the Arctic.

25. (Kao, Pearre, and Firestone 2012) *"Adoption of the arctic search and rescue agreement: A shift of the arctic regime toward a hard law basis?"*

This paper examines the Arctic Search and Rescue Agreement—the first legally-binding instrument negotiated and adopted under the auspices of the Arctic Council—and analyzes its implications for the current Arctic regime. Led by the Arctic Council, the Arctic regime was established in a soft law format. However, the soft law nature and restricted mandates of the Arctic Council have limited its capacity to respond to new issues emerging from climate change, particularly those related to the exploitation of oil and gas reserves, commercial shipping through the region, effects on wildlife, and impacts on indigenous peoples' homelands and culture. The adoption of the Agreement represents a new approach for the Arctic States to

respond to these new challenges. At the same time, it does not imply that a legally-binding instrument is necessarily preferable for every issue, and importantly, the new Arctic Agreement does not establish new institutional relationships, suggesting satisfaction among the Arctic States with the existing arrangements. Thus, although the Arctic regime is undoubtedly changing, this change should not be treated today as a shift from soft to hard law. What is more certain is that the Arctic Council will continue to function as a cooperative forum where the Arctic States can address these challenges, and its importance will only increase in coming years.

26. (Stewart and Draper 2008) *"The sinking of the MS Explorer: implications for cruise tourism in Arctic Canada."*

Built in 1969, and affectionately known as "the little red ship," the *MS Explorer* was the first vessel specifically designed for transport of passengers in the polar regions (Fig. 1). Under the name *Lindblad Explorer*, she took passengers to Antarctica in the 1969–70 austral summer (Spletstoesser, 2000), and in 1984 she was the first ship to take visitors through the Northwest Passage in the Canadian Arctic. These achievements earned the *Explorer* an esteemed reputation in the niche polar travel sector. Ironically, however, the *Explorer* was also the first cruise ship to sink in polar waters, off the coast of the Antarctic Peninsula, in November 2007 (see Fig. 2). This incident is a sad tribute to the veteran polar cruise ship and a concern for all who support responsible tourism in Antarctica and who care about the conservation of the Antarctic environment.

A major incident involving a cruise vessel, such as this, came as little surprise; it was an accident some observers had predicted was waiting to happen (Stewart and Draper, 2006). This prediction was premised on the facts that the number of cruise vessels operating in both the Arctic and Antarctic had been increasing and that, since 2000, large cruise liners that were not ice-strengthened had entered the Antarctic cruise market.

What came as a surprise was that the first sinking was of a veteran ice-strengthened vessel designed and purposely outfitted for polar travel. Even more surprising was that, at the time of the incident, the cruise ship was operating in seemingly benign ice and calm weather conditions. This essay provides an overview of polar cruise tourism trends, highlighting the important role played by the ill-fated *Explorer* and describing briefly what happened to her in Antarctica, and comments on the implications of the incident for cruise tourism in light of climate warming in the Arctic.

27. (Kao, Pearre, Firestone 2011) *"Adoption of the Arctic Search and Rescue Agreement: A shift of the arctic regime toward a hard law basis?"*

Due to threats in the Arctic, an Arctic regime was institutionalized in the late 1980s and early 1990s. The Arctic regime is a group consisting of all the eight Arctic States brought together to discuss the protection of the Arctic environment, ultimately resulting in implementation of the Arctic Council. The Arctic Council is a "soft law" regime making it susceptible to limitations and weaknesses. However, on May 12 2011, the Arctic Council signed the Arctic SAR Agreement (Search and Rescue.) This is a legally-binding tool that will help to strengthen SAR cooperation

in the Arctic. This agreement addresses concerns with restriction of SAR regions by stating that, “the delamination of search and rescue regions is not related to and shall not prejudice the delamination of any boundary between States or their sovereignty, sovereign rights or jurisdiction” [2 Article 3(2)]. This will ideally lead to joint SAR operations between the Arctic States and put safety over political agendas. This will become considerably more crucial in the future when disputes between maritime boundaries and land masses become a rising issue. The Arctic SAR Agreement is the first legally-binding agreement and is the first step to a “hard law” basis regime. However, it is still too early to tell if the current “soft law” regime will be replaced in the upcoming future.

28. *(Rose, Campagna, McNulty 2014) "Improving Safety in the U.S. Arctic by Heath C. Roscoe"*

One side effect of the continual melting of the arctic is that previously inaccessible economic activities in oil exploration, shipping, mining, and tourism are quickly becoming viable. This will result in an increased risk in the need to respond to emergency situations and a discussion of arctic sovereignty becomes a debated topic. The US would like to be posed to be able to respond to whatever disaster may befall its shore. To address these stressors, the Arctic Council, an international body of Arctic nations, penned an Arctic SAR agreement that was signed by the U.S. Secretary of State in May 2011. The agreement is the first legally binding instrument to accelerate cooperation between arctic nations. The primary US federal agency responsible for operational safety in the Arctic is the Department of Homeland Security (DHS) with the Coast Guard as its operational arm. The nearest Coast Guard air station to the Arctic is in Kodiak but there are members in Juneau and response crews in Anchorage. In the event of a rescue operation, current response times from Kodiak to the North Slope community of Barrow are a 4-hour fixed-wing, 10-hour rotary wing voyage, or at least 3 days once embarked to reach the Arctic Ocean by Coast Guard cutters, who routinely patrol the Bearing Sea. Currently, mass rescue operations would currently be nearly impossible.

Quick response is essential in the arctic due to the extreme climatic conditions present. Strategically positioning Search and Rescue (SAR) infrastructure in key locations in the U.S. Arctic would decrease response times by significantly reducing transit distances which is why Barrow was identified as an ideal location. Despite its advantages as a key location for SAR support assets, Barrow’s central North Slope position creates significant logistical challenges due to a limited road network and port access. No roads link Barrow to the rest of Alaska, which prevents ground shipment of supplies, and the lack of a deep-water port requires extensive use of small landing craft and fuel barges to deliver supplies to the mainland. Given weather impacts, Barrow’s primary line of communication is by aviation from either Anchorage or Fairbanks. Furthermore, the U.S. needs additional icebreakers as we only have the fewest out of all arctic nations at two. Constructing additional icebreakers would allow: continued Antarctic presence (scientific research and McMurdo resupply), arctic presence (enforcement of vessel routing regimes, compliance with safety, security, and environmental laws/treaties, freedom of

navigation, response to vessels in distress, SAR, protecting against potential pollution), Arctic Research/Thule Air Force Base resupply/Flex—support to the NSF, resupply of Thule, and an option to flex to any location in case a crisis or emergency arises. If the U.S. wants to continue to play a role in developing the arctic, additional resources such as icebreakers, response guidelines, response equipment, and proper training will need to have funding appropriated by members of congress.

29. (Mileski, J. P., & Honeycutt, J. 2013). "Flexibility in maritime assets and pooling strategies: A viable response to disaster"

This journal discusses viable responses to marine time disasters and the concept of marine time asset pooling. This article was written because the authors believed that disaster implementation usually focused on solutions and resources regarding to land. The authors highlight a conceptual model on how to prepare for a disaster. The first dimension of the model is identifying the nature of the disaster, is it a natural or manmade/terrorist disaster? Preparation for both of these natures is very different from one another, and depending on the marine location, some vessels may be more equipped to handle one over the other. The second nature is the nature of the responder, is the entity government or privately owned? The government usually excels in coordination but lacks in speed of response due to relying on supplemental assets to be activated, where private owners usually excel at speed and response time but lack in organization and management. The final dimension is the nature of the recipient. Is the recipient an individual citizen or an enterprise such as the government? Individuals may have immediate needs such as food, water and medical care whereas an enterprise may be looking at repairs to infrastructure to mitigate any further losses. The article identifies flexibility in a disaster plan as being a key factor and suggest the use of a concept called marine time asset pooling. This concept is where all available assets are brought together from various owners and managed under a designated supervisor for optimal application.

30. (Ghoram, L. C. 2015) "Cooperation among Stakeholders for a Preventative and Responsive Maritime Disaster System: The Mitigation of an Arctic Wicked Problem"

The purpose of this article is to communicate flaws regarding international cooperation for disaster response. The authors make clear that as the Arctic waters open, maritime traffic will increase; presenting disaster opportunities, challenges, and triggered disputes between competing countries or organizations. One author adds that developing plans and techniques to best manage these Arctic risks require action and cooperation locally, nationally, and internationally. One review by the authors suggests there is a relative lack of good ship charts, communication systems, and other navigational aids for mariners. Furthermore, emergency response is critically limited by the lack of infrastructure, travel distance, weather, and harsh operating conditions. The article continues by explaining the different political frameworks for each Arctic nation; or otherwise contingencies and international cooperation. The authors show

that the variety of policies makes disaster response difficult to accomplish with the involvement of multiple countries. The authors have recognized, in various articles, conflicting and competing values in the management and organization of nations. Currently, there is no central authority for enforcement of policy or cooperation in the Arctic. However, one author suggests that cooperation in a maritime disaster is important because one party may not have full knowledge and resources to resolve the situation. To begin the implementation of a disaster plan, the authors advise firstly designating a response manager. The article concludes its four-part plan by explaining that a uniform safety procedure is imperative across multiple levels to prevent future disasters.

### **Incidence Reports**

31. *(Alaska Department of Environmental Conservation 2009) "M/V Monarch Sinking Situation Report"*

When making a delivery to the Granite Point Platform, the M/V Monarch was pinned to the platform by sea ice and began to sink. The seven-member crew was able to evacuate to the platform and were then transferred from the platform to shore by helicopter.

32. *(Alaska Department of Environmental Conservation 2006) "T/V Seabulk Pride Grounding Situation Report"*

The tanker was moored at the KPL dock transferring cargo and was struck by an ice flow. The mooring lines parted causing the vessel to drift northward and go aground approximately 200 yards north of the KPL dock.

33. *(Alaska Department of Environmental Conservation 2012) "T/V Renda Nome Fuel Delivery"*

As of 12:00 PM on January 3, 2012, the T/V *Renda* is in Dutch Harbor completing U.S. Coast Guard (USCG) inspections and loading gasoline cargo. The current estimated schedule has the T/V *Renda* leaving Dutch Harbor around midnight on January 4, 2012 and meeting the CGC *Healy* at the ice edge at approximately noon on January 5, 2012. With help from CGC *Healy*, the T/V *Renda* will pass through approximately 280 miles of sea ice and arrive at Nome on January 8, 2012.

34. *(Liberian Bureau of Maritime Affairs 2009) "Report of Investigation in the Matter of Sinking of Passenger Vessel EXPLORER (O.N. 8495) 23 November 2007 in the Bransfield Strait near the South Shetland Islands"*

On 23 November, 2007, at about 1530 local time, the Liberian registered passenger vessel EXPLORER sank in a position 25 miles southeast of Penguin Island in the Bransfield Strait near the South Shetland Islands, in about 1300 meters of water. All 54 crew and 100 passengers abandoned the ship without loss of life or major injury. All of the passengers and crew were rescued by the Norwegian registered vessel NORDNORGE.

## Logistical

### 31. (Bercha, F. G. 2004) "Arctic Offshore Escape, Evacuation, and Rescue."

Looks at EER (Escape Evacuation and Rescue) on off shore arctic drilling platforms, and advances the need for Performance based standards. There is a need to have evacuation systems set to a performance standard, (i.e. a 98% reliable, life boats down for maintenance 1 week out of the year) rather than a "how to standard". As of publication (2004), the trend is to move to a performance based standard. This standard than needs to be set on escape and evacuation technology to achieve and optimize the following; design, performance, reliability, and availability. For example, life boats in the arctic need to be designed to be ice buoyant, rising out of ice when frozen rather than crushed. Generally, full scale evaluations and practice of EER systems are very limited too due to risk and cost. Concludes that current systems often have design flaws such as, designed only for open water with no considerations taken for ice, thus limiting the technological response. The paper argues for the need to conduct trials outside of computer simulations.

### 32. (Dahle, L. G. 1985) "Evacuation in the Arctic put to the test"

Volunteers test the current safety measures of being distressed in an Arctic environment. The exercise takes place in North-Western part of Svalbard with no satellite surveillance, transpiring under the cooperation of various Norwegian research institutions headed by the University of Stavanger. The purpose of this research project is to anticipate the length of survival time if a cruise shipwrecked in the Arctic ice. Norwegian Coast Guard vessel KV Svalbard served as the base of operations and contingent medical station for the week-long research mission. Ove Tobias Gudmestad, a multi-disciplined engineering professor at the University of Stavanger, is responsible for the scientific part of the voyage. He and the volunteers are left in a cold, wet lifeboat and life raft in the ice. Professor Gudmestad considers himself a study subject that best represents the target group of the research expedition, that is, mature passengers. One research fellow explains that "having a group with a broad academic range and such a level of expertise work so closely together on search and rescue and survival in the Arctic is unique." Medical personnel interviewed all participants afterwards and the results will be applied in further research that will make everyday life safer for more than just cruise passengers and ship crews.

### 33. (IAMSAR, I. 2007) "International aeronautical and maritime search and rescue manual"

The International Aeronautical and Maritime Search and Rescue Manual for Mobile Facilities is an essential document to coordinate rescue operations between search and rescue (SAR) operations and civil vessels/aircraft to provide assistance to those who are in distress at sea. The SAR's responsibility within this coordination effort is to define who has what primary responsibility for resolving distress situations. In the event of a ship response, the responding

parties are required to make and maintain contact with the ship, identifying its position, speed, identity and bearing. There is long list of recommended items that are helpful in SAR response efforts which include: lifeboats and jackets, lamps, supplies and survival equipment, for instance. If a plane responds to a SAR request, many of the same processes and procedures should be implemented. The first response is to evaluate the call for urgency and relay it to appropriate parties, ensuring that the relayed message indicates who and where are the distressed parties. Planes often have a much greater search capability than response capability. This gives planes a unique role to find persons in distress, designate an area of interest, a description of the event, the number of persons on board/in the water and the amount/types of survival equipment. Additionally, planes can provide on-scene weather and progress of the rescue effort. This is accomplished by dropping materials, which are clearly labelled, to the correct location. Further assistance can be provided by helicopter, assuming there is an adequate response vessel that is nearby. This can allow the rescue sling to be used, allowing rapid evacuation in rapidly eroding conditions. These rescue efforts can be accomplished with a rescue blanket, net, sling, litter, or seat. When developing a SAR response policy, it is important to consider the risk to SAR personnel, the distribution of the survivors, the weather conditions, time of day and the equipment available. While it is important to rescue as many people in distress as possible, it is essential to ensure that the rescue group does not, itself need rescuing. Safety briefings are essential and proper understanding of how and where to use equipment allows to minimize future risk. The guidance document goes into further details, explaining specific techniques and methodologies for rescue, how to address a dead body, how to properly address the media. I did not view these topics to be as essential as the search and response guidelines, so they were given a lower priority.

### **Medical**

34. (Hoyme, Helmut. Meyer-Rochow, Victor. 2009) *“Reasons and frequency of visits to the ship’s doctor by passengers and crew members of cruise ships in polar waters”*

The most frequent patrons of cruise vacations are the elderly population. Arctic cruise lines should expect the same trend, due in part to the access this population has to time and money. Most frequent medical concerns upon arctic ships include respiratory complaints including bronchitis, general complaints ranging from sleep and psychological distress, and motion sickness. The health concerns among patrons that could be in relation to the arctic conditions seemed to include orthopedic complaints due in part to the bitter cold nature of the arctic wind. Back pain, hip pain, and rheumatism aches were all reported. Expeditions to shore may increase the orthopedic concerns, as rocks and ice blocks caused several falls. The natural dry condition of the arctic air was the common cause of several nose bleeds during the voyage and patrons must be weary of over exertion while on hikes in the uneven and unfamiliar terrain. Doctors on the cruise ship must have the ability to treat a variety of ailments ranging from minor to life threatening due to the remote nature of the arctic waters. In arctic expeditions, it is

recommended the doctor have knowledge in chiropractic care for the orthopedic complaints. Doctors should ensure an ample supply of antibiotics and Antihistaminic medication for the voyage.

35. (Bercha, Frank G., Chris J. Brooks, and Fred Leafloor 2003) "*Human Performance in Arctic Offshore Escape, Evacuation, and Rescue.*"

As part of a comprehensive escape, evacuation, and rescue (EER) research program sponsored by the Transportation Development Centre of Transport Canada, the co-authors have investigated human performance under extreme conditions involving physical and mental stress. Part of the work focused on personnel performance in emergency evacuation situations causing extreme mental stress from offshore accident conditions, with Arctic environmental conditions also adding extreme physical stress.

Because only limited and anecdotal data on human performance under such extreme conditions are available, and dedicated experiments would clearly be unacceptable, analysis of human performance under life-threatening conditions has been approached through the development of a computer model based on data from the literature giving unit error rates and times of performance, and on discussions with experts. The paper presents the background, methodology, computer program description, and gives examples of several different Arctic EER scenarios analyzed and selected comparative non-Arctic scenario results.

### **Environmental**

36. (Dalsøren, S. B. 2013) "*Environmental impacts of shipping in 2030 with a particular focus on the Arctic region*"

As the sea ice in the Arctic region continues to deplete, there will be an increase in ship traffic. Unless restrictive measures are placed on shipping regulations, an increase in emissions is expected. Emissions are changed due a concentration difference of short-lived pollutants such as NO<sub>x</sub>, SO<sub>x</sub>, CO, NMVOCs, BC and OC. In this study, researchers compared the High and Low scenarios for 2030 models to investigate the potential changes in pollution levels due to the increase in Arctic traffic.

Emissions in the Arctic will see a primary increase during the Spring and Summer months where there is less ice coverage.

Increases in emissions will not only negatively impact the health of those exposed, but speed up the melting process of the Arctic. As the melting increases, the production of methane that is trapped within the ice will also increase. According to the study, NO<sub>2</sub> changes will be directly found on the shipping paths with an increase from 10% to 60% in Coastal Regions and as much as a 200% increase in the pristine regions of the Arctic. In surface ozone production there is a projected 10%+ increase in the Arctic Oceans. Sulfate levels could increase upwards of 50% in the Arctic Region in the months of operation. If these rates increase as projected, the Arctic may be a candidate as an Emission Control area, especially related to the extreme increase of NO<sub>x</sub>.

37. (Service, F. N. n.d.) "Space weather is a hidden risk to Arctic cruises, and it could be a significant one"

As the decades pass, Arctic summer ice has been quickly receding which has opened up the Arctic to a vast increase in maritime activity, including the willing advancement of large passenger cruises. In August 2016, the 1,000-person cruise ship Crystal Serenity will depart Seward, Alaska on a thirty-two-day expedition across the Northwest Passage, ultimately docking in New York City, New York. This article advocates that the Serenity will be the first cruise ship to endeavor the Northwest Passage, if successful. The obvious obstacles include ice, rocks and uncharted bathymetry, however this article briefly discusses the drawback of "space weather". The authors refer to space weather as large eruptions of radiation and plasma from the sun's surface. These eruptions may cause geomagnetic storms on Earth which may affect or possibly disable electrical grids, radio communications, GPS and other satellite services. Little is known about the duration of these charges or the forecasting of the events. Communication and situational awareness are necessities to the support of emergency responders, the authors insist; however, the threat of space weather may be a menacing detachment from them.

### General

38. (Stewart, E. J., and J. Dawson 2011) "A matter of good Fortune? The grounding of the Clipper Adventurer in the Northwest Passage, Arctic Canada."

In the late summer of 2010, the Clipper Adventurer cruise ship ran aground in a hazardous region of Arctic Canada known as the Coronation Sills; a cluster of vertical underwater cliffs. It took two days for the Canadian Coast Guard (CCG) to dispatch an icebreaker and evacuate the passengers and crew, all of whom stood safe and unharmed. In some ways, the Clipper Adventurer was "lucky" due to their relative proximity with the icebreaker and the quick response of the CCG. Onboard the icebreaker were researchers of the University of New Brunswick's Ocean Mapping Group. With the help of high-resolution multi-beam sonar, "the approach adopted by the [researchers] minimized risk associated with the evacuation" and maneuverability of the icebreaker itself. "It was a matter of good fortune" for the disabled cruise ship that the icebreaker had been carrying the appropriate equipment, personnel, and operational expertise necessary to support a rescue of such fragility. Under alternative circumstances, the outcomes may have been different. "Increased attention is clearly needed" to smooth the cruise sector's intensive governance structure and reduce human risk.

39. (CBC News 2016) "Arctic Rescue fears loom as massive cruise ship prepares to sail Northwest Passage"

The Crystal Serenity cruise ship is scheduled to set sail on August 16th to begin its month long journey through the Northwest Passage. With the warming temperatures and diminishing Arctic

ice, the Northwest Passage has opened up enough for shipping to take place. Major cruise lines are getting ready to jump on board, and Crystal Cruises and their ship the Serenity are taking that step this summer. With 1000 passengers and 600 crew, safety is of the upmost key. Most of this trip is largely out of reach of Canada's search and rescue (SAR) helicopters. In 2010 it took two days for the coast guard and icebreakers to reach a smaller cruise ship that had struck an uncharted rock shelf while traveling through the Passage. The United States and Canadian coast guards are preparing for a disaster of this magnitude over the next several weeks by running through worst case scenario exercises in the Arctic. "As a coast guardsman, I don't want a repeat of the Titanic.... We need to make sure we think this through and get it done correctly," Vice-Commandant Charles D. Michel of the U.S. Coast Guard said. [1] Crystal Cruises has commissioned its own icebreaker ship to accompany the cruise the entire time. Countless efforts are being made to assure the cruise is a success. The success of voyage such as this will most likely lead to cruises through the Passage to become a normality, and is why a set plan needs to be in place if and when a future ship is in need of aid and support.

40. *(Addy, Trego, Pancotti, Savage 2016) "ARCTIC ZEPHYR Multinational Arctic Search and Rescue Operations AFTER ACTION REPORT"*

The proceedings and After Action Report of a TTX (Tabletop Exercise) designed to practice the S&R response. The scenario involved a 1001 passenger cruise ship with a crew of 550 having an explosion that disabled the ship resulting in an evacuated to lifeboats, and an airplane with 250 people on board that crash landed. The results of the exercise found that international coordination during an event is likely to be difficult and data sharing is challenging as nations have separate tracking systems and software, not necessarily compatible. While international law has protocols for cooperation in a S&R there is need to look specifically at the Arctic setting.

Due to the nature of the Arctic, logistics and communication is will be challenges during a S&R operation. It is recommended that; exercises continue as each of the Arctic Council members holds chairmanship, a sub- group focuses on logistics alone, industry (aeronautical and maritime) need to be incorporated into the S&R plans. The findings of this exercise indicate that many improvements can be made in area of Arctic S&R, the exercise found gaps and the continuation of exercises will improve the capabilities and response of all players. This exercise found that the greatest improvements can be made in communication and data sharing amongst nations.

41. *(USCG Dept. Commander for Operations, Policy and Capabilities 2016) "Memo for the Emergency Prevention, Preparedness, and Response; Working Group of the Arctic Council"*

Memo addressing the observations and issues as well as the proposed solutions to these problems based on the results of the 2015 Arctic Zephyr TTX, a tabletop exercise designed to better understand the issues with arctic S&R. The exercise was conducted in accordance with the Arctic Council's Arctic S&R agreement, chaired by the United States during 2015. The

recommendations of this exercise include a call for better coordination during S&R, better data sharing amongst arctic nations, developing networks dedicated to S&R. Additionally there is a need for continued exercises to address potential problems and changes, ideally an exercises should be conducted on an annual basis. Additionally, there is a need to have increased involvement from the industry to enhance the S&R capabilities.

42. *(Zoë Schlanger 2012) "Scientists Plan to Freeze a Ship into the Arctic Icepack"*

Since 2012, a team of experts from several countries have been planning a 13-month expedition in the Arctic to freeze a ship into an Arctic ice block. The \$65 million-dollar trip, accommodating the ship dubbed as the Multidisciplinary Observatory for the Study of Arctic Climate (MOSAIC), will study the impact of clouds on ice. The MOSAIC will hold 90 crew members, including researchers in the fields of oceanography, physics, biogeochemistry, and sea ice science. Germany's Alfred Wegener Institute has already dedicated an icebreaker with a medicine team and culinary staff. Additionally, the U.S. Department of Energy plans to supply the equipment necessary to draw the team's wide variety of measurements. Initially, the researchers will locate an area in the Arctic during summer months and let the winter ice freeze around them. The team and their ship will then float with the icepack over the next year gathering data from above, within, and below the ice block. The core objective is to assemble data associated with the effect of clouds on the ice; whether cloud cover will block the sun's heat or act as a blanket and trap heat. "Clouds are one of the huge uncertainties [the researchers] have," says Matthew Shupe, an atmospheric scientist from the University of Colorado.

43. *(Fridtjof Nansen Institute, Norway) "The Arctic Council and the Search and Rescue Agreement: The Case of Norway"*

The melting of Arctic sea ice and the warming temperatures in the North have resulted in the effort to use the Arctic for shipping regularly. These shipping routes can reduce shipping times between Asia and Europe by 40%. However, increased activity in the Arctic brings up concerns of socio-economic consequences. The warmer temperatures do not necessarily correlate with nicer conditions. As stated in the Arctic marine shipping assessment, "harsh conditions and lack of infrastructure in much of the Arctic create a higher vulnerability to emergencies than in more temperate climates," [2, pg. 13] meaning that the Arctic climate will most likely become less mild and more active. This will make the Arctic Council (AC) and the Search and Rescue agreement that much more important in the future. In regards to Norway, this agreement has few practical consequences, seeing as they had already been an active player in the Arctic. The Bearing Sea has a much longer ice free period than the rest of the North, and incidentally Norway is at the lead of search and rescue in the Arctic. Since they are a central player, Norway will mostly likely lead arrangements of search and rescue in the future when pertaining to the Arctic. It is still too early to tell if and how much the SAR agreement will benefit SAR efforts.

Nonetheless, it is a representation of the willingness of the Arctic States and the AC to come together to ensure that with the increasing use of the Arctic Sea that safety is of the utmost importance.

44. (Geography Department, Laval University, Québec QC, Canada 2013) *“The cruise tourism industry in the Canadian Arctic: analysis of activities and perceptions of cruise ship operators”*

The melting of sea ice in the Arctic in the summer has sparked interest in using the Northwest Passage for tourism and exploration activities. However, although it seems like the shipping industry is increasing in the Arctic, the tourism industry as discussed in this article does not seem to be progressing in the same manner. Many of the operators surveyed communicated their lack of interest in expanding their business in the Canadian cruise market. Only three out of nearly 51 operators intended to enter the market. This lack of interest and enthusiasm mainly stems from the need for ice-strengthened vessels to cope with much of the sea ice that remains. Unlike Southern Greenland, Iceland, or southern Alaska, ice is still predominant in Canadian waters. From the data collected in the article, most markets peaked between 2008 to 2010, but have been fairly steady up until present. An advisor of Beluga Expedition and Adventure’s summarized the market by saying this, “It is not really a grow(ing)-market, but more (of) a steady one.”

This being said, the Arctic is still most likely going to see an increase in activity. The increase doesn’t appear as though it will have the rapid growth that have been projected by the media. This will allow for more time and research to be put into Arctic travel and SAR response before the Arctic becomes a chief player in the shipping and cruise markets.

45. (Roarty, Hugh J. 2013.) *“Expanding Maritime Domain Awareness Capabilities in the Arctic: High Frequency Radar Vessel- tracking”*

A study conducted with partners of the U.S. Department of Homeland Security has tested the ability of their SeaSonde® for a dual purpose of ocean current observation as well as Search and Rescue Operations by the ship tracking capability. The University of Alaska Fairbanks deployed two High Resolution SeaSondes during the summer months in the Chukchi Sea. Notable issues were found during the testing in the arctic including the needed shelter, power and communications, weather conditions, and the presence of ice. Ice creates a separate Doppler echo which scientists have not been able to separate completely from the Doppler echoes of the passing ships. There was also noted challenges with the radio frequency interference from aurora sources. The SeaSonde may help during the entire Vessel tracking process which includes three steps; detection, association, and tracking. Once data is received by the SeaSonde it was able to be transferred by satellite from Barrow, Alaska to the research headquarters in New Brunswick, New Jersey every five minutes. It was concluded that even with the challenges in the Arctic waters, the maximum detection range was 82 km with a maximum detection rate of 88

percent. This sensor will help in the surveillance and search and rescue operations over large areas. It was noted also that this sensor will be a valuable asset to the U.S. Coast Guard.

46. (M. Lewandowski. et al. 2010.) *“Maritime Mass Rescue Interventions; Availability and Associated Technology”*

With help from the Coast Guard, The Research and Development Center has focused on shortcomings in mass rescue operations since 2006. The original Study focused on the most likely mass rescue incident scenarios including complete evacuation of a ship as well as the event of a capsized, displacing passengers. Rescue gaps were discovered during the processes including the inability to provide timely response to ships in inaccessible or remote locations. It has been recommended that ships traveling in remote locations have systems of rescue equipment on board which allows them to perform ‘self-rescue’. An important aspect of ‘self-rescue’ is life support, indicated in short term (up to 12 hours), medium term (24-48 hours), and long term (more than 48 hours). Arctic expedition to remote locations are recommended to provide the necessary support for the latter two time frames. The life support vessels that would be deployed from the ship in the case of an emergency would have means of food, water and medical supplies as well as protection from the water and weather until further rescue measures can be deployed from the Coast Guard or other means. Although many rescue vessels are mentioned in this report, none have been explicitly tested for use in Arctic Mass Rescue.

47. (Emergency Preparedness Roundtables n.d.) *“National Roundtable on Arctic Emergency Preparedness: Report of Proceedings”*

This is a report that goes over the outcomes of the regional roundtables held in each of Canada’s three territories in the fall of 2013 with regard to Canada’s preparedness in the Arctic. The themes of the discussions are as follows: the flexibility of northern communities need to be recognized, the local needs and abilities for emergency management should be stressed instead of concentrating on visitors to the region, the frequency of emergencies is increasing, the ability to respond to these incidents has not matched the increase in the incidents, and each territory has their own approach to emergency management. It is believed that the Northern residents are often overlooked in these situations and it had come to the attention of this forum to focus the discussion on them. Although you can never be one hundred percent prepared, the council turned the discussion towards how to increase the North’s preparedness if an incident were to arise. The outcome of this roundtable was to reinstate the Joint Emergency Preparedness Program to full capacity. This program helps train and encourage skill development throughout communities with regards to emergency response.

48. Mileski, J. P., Wang, G., & Beacham, L. L. (2014). Understanding the causes of recent cruise ship mishaps and disasters. *Research in Transportation Business & Management*, 13, 65-70.

The authors evaluate the causation of 580 cruise ship mishap incidences occurring between 1987 and 2013, using a two stage measurement design. The data assessed came from crusejunkie.com, and attempts were made to verify all data although it may not be a comprehensive set. Analysis divided the incidences into 7 categories; human error by the crew, ship design, lack of maintenance, unknown, and combinations of the above. Results indicated that 61% of the incidences were the result of maintenance, 26% human error, and several percent in each of the remaining categories. Several factors within the cruise industry contribute to these findings, first the fast turnaround results in deferred or improper maintenance, as well as a tired crew. Additionally, the international nature of the crew and passengers can lead to communication problems. The paper suggests several solutions such as introducing remove and replace components to help maintenance, and enhanced crew training. They point out that a well-trained crew is and flexible resources are necessary in a disaster situation.

49. (Texas A&M University at Galveston n.d.) "Will the United States Be Able to Respond to an Arctic Disaster?"

Between March and September of 2012, 4.57 million square miles of arctic sea ice melted. Under this melted ice, USGS estimates 13% of the world's undiscovered oil and 30% undiscovered gas is located. Issues arctic nations are facing include national sovereignty, commercial shipping, oil and gas exploration, endangered species and military operations as well as an increase in Arctic traffic and activity. In 2013, Mileski and Honeycutt published the Arctic Disaster Response Framework which is dependent on three dimensions of response; nature of disaster, nature of responder, and nature of recipient. The nature of disaster includes the dimension of casualties and ecological impact such as in the case of an oil spill. The responder will usually be the US Coast Guard which has the ability to deploy cutters, aircrafts and boats from the headquarters in Kodiak. Assisting responders may include the Army, having cold weather training and an aviation presence, Air Force, having a Polar System of high frequency military satellite communications about 65° N and aviation presence, and the Marine corps who are trained in arctic operations but have no operations out of Alaska. The Navy does not have ice hardened vessels or training in arctic operations. The US has two ice breakers, one heavy and one medium. It is estimated that with the increase in Arctic traffic there will need to be a minimum of six heavy and four medium ice breakers.

50. (Hunter, C. 2013) "National Search and Rescue Literature Review: Annotated Bibliography - Report 1"

The purpose of this report was to conduct a literature review and develop an annotated bibliography of existing analytical techniques, models, and methods that have been applied to the delivery of search and rescue. The document contains an annotated bibliography and review of Canadian and foreign search and rescue studies related to resource allocation and basing models, response posture, strategic policy, tactics and procedures, and search and rescue techniques associated with multiple areas of search and rescue. The authors explain their primary focus to be

aeronautical search and rescue, however maritime and humanitarian search and rescue categories were also considered. The objectives of this project were to find literature and create an annotated bibliography, and to summarize two papers discussing resource allocation and basing models. The first reviewed paper developed a methodology to analyze if the current and future locations of bases are adequately located to ensure the shortest response times. The second paper proposed two models that would be used to determine the best location for mobile search and rescue resources.

### **Additional Readings**

51. (Harrald, J., & Jefferson, T. 2007) "Shared situational awareness in emergency management mitigation and response"

Abstract: The US is replacing its historical federalist concept of emergency management where primary responsibility resides with state and local governments and their emergency management and first responder resources for coordinating emergency response and recovery, supported by the resources federal government (coordinated by FEMA) with a homeland security national response system where response to events is controlled by DHS using a military command and control model. This model assumes that those controlling and coordinating the response and recovery would attain and maintain an accurate, shared common operating picture and situational awareness. The objective of this paper is to discuss why the transfer of this concept from its safety and combat origins to the complex, heterogeneous emergency management structure of the United States would be exceedingly difficult, and that short term strategies based on the assumption that shared situational awareness would be easily achieved are doomed to failure.

52. (Harrald, J. R., & Jefferson, T. I. 2007) "Supporting Critical Multi-Organization Collaboration during Response to Catastrophic Events"

Abstract: The past two years have shown both the power of nature and the complexity of preparing for and responding to extreme events such as earthquakes, tsunamis, hurricanes/typhoons, and floods. These events, and future catastrophic events, will require coordination and collaboration between multiple government and non-government organizations across national and state borders. This collaboration will require the discipline necessary to share common processes and procedures, and the agility to improvise plans and actions as situationally required. Information technology must be used to create an eRegion, enabling the shared situational assessments and adequately supporting the collaborative, distributed decision making to produce required decisions and future action plans. The role of information technology in developing these capabilities is discussed in the context of two seismic scenarios, the US New Madrid Seismic Zone, and the Adriatic Seismic region.

53. (Mendonça, D., Jefferson, T., & Harrald, J. 2007) "Collaborative adhocracies and mix-and-

match technologies in emergency management”

Abstract: Large-scale emergencies--commonly called extreme events— create sudden and profound changes in human systems and the built environment, leading to response activities that range from planned to improvised, as conducted both by established and ad hoc organizations. Indeed, despite improvements in information and communication technology (ICT), the role of improvisation, adhocacy, and other emergent phenomena in emergency response has not diminished. As reported in many years of research on human response to extreme events, successful response is likely to require personnel to think in ways that differ—sometimes radically—from the original plan.

This article investigates how the process of ICT design may be undertaken in order to achieve emergent interoperability during emergency response. The question of ICT design is approached as a research problem whose solution is bound with the underlying cognitive, behavioral, and communication phenomena that ICT is intended to support. The article concludes with a description of current and recommended lines of research that, if pursued, may enable the design of ICT to support the types of organizations that actually conduct response. The result is denoted emergent interoperability, since it underscores the importance of a disciplined approach to achieving flexibility and improvisation.

54. (Kum, S., & Sahin, B. 2015) “A root cause analysis for Arctic Marine accidents from 1993 to 2011”

Abstract: The aim of this paper is to investigate the marine accidents/incidents which are recorded by Marine Accident Investigation Branch (MAIB) as occurring north of 66°33' in the years from 1993 to 2011 to reveal their causes by using root cause analysis. Due to the global warming, increase of ice melt in North Pole is expected in the future. In the further years, number of vessels and shipping traffic will dramatically increase in the Arctic region. Thus, navigation will become more difficult in the Arctic Region. Consequently, to guide the vessels navigating in this region, an analysis of the previous marine accidents/incidents occurring in the Arctic region is required to improve the safety. Therefore, Root Cause Analysis (RCA) is proposed to clarify the causes and prevent the future incidents from happening. As an empirical study, fault trees of collision and grounding for the Arctic Region is constructed. Fuzzy Fault Tree Analysis (FFTA) is applied to this problem in order to propose a recommendation to reduce the occurrence probabilities. Risk levels of each factors are determined by expert consultations. In this study, Accident to Person is found as the most observed incident. Negligence/careless of injured person has the highest priority for root causes of marine accidents. In order to combat this phenomenon, scientific results of this study can open up a dialog between law makers and shipping companies those aim to decline incidents. Furthermore, it is assumed to contribute representatives developing crew training manuals and competence requirements as well as opening Arctic navigation training centers.

55. (Lewandowski, M. J., Fitzpatrick, M., & Kamradt, N. F. 2010). *Maritime Mass Rescue Interventions: Availability and Associated Technology*

Abstract: Since 2006, the U.S. Coast Guard (CG) Research and Development (R&D) Center (RDC) has worked with the CG Search and Rescue (SAR) program and the network of district Passenger Vessel Safety Specialists (PVSS) to address potential shortcomings in mass rescue operations. In 2007, the RDC completed a Mass Rescue Operations Scoping Study (MROSS) that identified the largest potential response gaps were associated with CG response to significant numbers of survivors from a passenger vessel casualty. The recommendation from that study was to develop equipment or techniques to effect rapid evacuation and rescue of multiple survivors. This project built on the MROSS by validating the most likely mass rescue incident scenarios based on incidents since 2003, examining response activities (including response gaps), and defining functional requirements of potential response interventions. The project also conducted extensive market research, including a published Request for Information (RFI) and liaison with industry, and determined the potential availability of intervention equipment. The project then revalidated intervention requirements. This report presents the background methodology and results, and lists conclusions and recommendations.

56. (MacKinnon, S., Igloliorte, G., & Carran, A. 2008) "UNDERSTANDING PASSENGER SHIP EVACUATION THROUGH FULL-SCALE HUMAN PERFORMANCE TRIALS"

Abstract: IMO MSC circular 1033 [1] outlines the guidelines for evacuation analyses of new and existing passenger ships. This requirement coupled with recent advancements in computer technology has led to the development of sophisticated computer-based simulation of the evacuation process on passenger ships. In order for these simulation tools to provide accurate and useful results, it is imperative they use realistic data for passenger movement throughout the evacuation process. However, due to the nature of ship abandonment, quantifying human performance in actual abandonment situations is very difficult. For this reason, simulation inputs must rely on results of controlled, well-defined experiments. This paper outlines experiments conducted to quantify human performance during abandonment using a variety of life saving appliances for ambulatory and non-ambulatory individuals wearing personal floatation apparatus. Evacuation analysis using commercially available software with these data is also presented as it relates to improving ship design for evacuation of non-ambulatory persons.

57. Spencer, J. M., & Sheridan, S. C. (2015). Web-based hypothermia information: a critical assessment of Internet resources and a comparison to peer-reviewed literature. *Perspectives in Public Health* 135 (2). 85 - 91.

Abstract: Aims: Hypothermia is a medical condition characterized by a drop in core body temperature, and it is a considerable source of winter weather-related vulnerability in mid-/high-latitude areas. Heat vulnerability research, including assessments of internet-based resources, is

more thoroughly represented in the peer-reviewed literature than cold-related vulnerability research. This study was undertaken to summarize available web-based hypothermia information, and then determine its scientific validity compared to the peer-reviewed literature.

Methods: This research takes a similar approach used by Hajat et al. for web-based heat vulnerability research, and utilizes this framework to assess hypothermia information found on the internet. Hypothermia-related search terms were used to obtain websites containing hypothermia information, and PubMed (medical literature search engine) and Google Scholar were used to identify peer-reviewed hypothermia literature. The internet information was aggregated into categories (vulnerable populations, symptoms, prevention), which were then compared to the hypothermia literature to determine the scientific validity of the web-based guidance. The internet information was assigned a Strength of Recommendation Taxonomy (SORT) grade (developed by the American Academy of Family Practitioners) of A, B, or C based on the peer-reviewed evidence.

58. Yun, G., & Marsden, A. (2010). Methodology for estimating probability of success of Escape, Evacuation, and Rescue (EER) strategies for arctic offshore facilities. *Cold Regions Science and Technology*, 61(2), 107-115.

Abstract: Offshore oil and gas production platforms must have Escape, Evacuation, and Rescue (EER) plans and resources to protect personnel in the event of a major accident. However, for offshore platforms in arctic regions, existing solutions may not be sufficient due to the extreme environmental conditions. This paper presents a methodology for evaluating the relative probabilities of success of arctic EER strategies to (1) help prioritize technology development and data collection efforts needed to develop and select a robust EER strategy and (2) analyze the predicted probabilities of success of various EER strategies in more detail once the input parameters are better known. The methodology is based on well known risk assessment tools (event trees and Monte Carlo simulation) that can easily be adjusted to account for the appropriate level of detail. As an example, the method is applied to hypothetical EER strategies composed of various combinations of helicopters, ice-breaking platform supply vessels, Air Cushioned Vehicles, Tracked Amphibious Vehicles, and ice-strengthened lifeboats. Input parameters used in the analysis include prevalence of various environmental conditions by month (low temperature, high seas, low visibility, etc.), ability to deploy craft in a hazardous situation, ability to transit over ice ridges, ability to transit heavy seas, operator competence, etc.

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