Safety and Emergency Response Associated with Cold Climate Marine Operations

by

Knut Espen Solberg

Thesis submitted in fulfillment of
the requirements for degree of
PHILOSOPHIAE DOCTOR
(PhD)

Faculty of Science and Technology
Department of Mechanical and Structural Engineering
and Materials Science
2020

University of Stavanger
NO-4036 Stavanger
NORWAY
www.uis.no

ISBN: 978-82-7644-893-1
ISSN: 1890-1387
PhD: Thesis UiS No. 493

Abstract

This dissertation is developed by GMC Maritime and the University of Stavanger and is part of the industrial PhD program at the Norwegian Research Council.

The aim of the work is to identify the governing mechanisms associated with surviving a marine incident in a cold climate environment. Further, the work was to identify relevant measures mitigating the effects of the cold climate environment. The main focus has been the marine industry. Due to the combined effect of marine safety equipment and the resources delivered by SAR-providers on safety levels, some of these combined effects have been addressed.

Part of the aim has also been to produce new knowledge that questions some of the established truths found in the marine industry. Through international regulatory mechanisms, we wanted to contribute to shape the future regulatory development in a sustainable way.

The research has been designed around conducting full-scale experiments, utilizing a multi-discipline approach. Stakeholder involvement throughout the whole process has been important, to highlight the complex structures and ensure a preferred direction and focus.

Surviving a marine incident in a polar environment imposes additional challenges on the crew/passengers on a vessel. These challenges are to be mitigated through improved functionality delivered by the lifesaving appliances. Competence among crew/passengers also proved a vital parameter, strongly affecting the survival rate.

The effect of remoteness influences the available resources and the expected time to rescue. The increased expected time to rescue will contribute to exposing the personnel and equipment to the cold climate related challenges for an extended period, which again further affects the survival rate.

Surviving a marine incident in polar waters is possible if the correct mitigation measures are in place. Unfortunately, this will require the vessel operators to invest resources in acquiring the appropriate equipment and knowledge.

One of the governing regulations associated with polar marine activity is the IMO Polar Code, which is a functional set of requirements aimed to mitigate the additional risks associated with Polar marine operations. During the summer of 2019, an interim guideline for the Polar Code was approved by the IMO. This guideline addresses some of the key issues identified in our work as required for survival.

Preface

The work described has been submitted as part of the industrial PhD program at the Norwegian Research Council. The work has been financed by GMC Maritime and the Norwegian Research Council (grant number 251926). The dissertation has been developed at the University of Stavanger.

Acknowledgements

This thesis would not have come together if it had not been for the help obtained from individuals. The individuals represent organizations, but it has been the single individuals and their enthusiasm that has enabled the work.

First, I would like to thank Morten Molven at GMC Maritime. They have not only funded a major part of the work, but GMC Maritime have also provided support and enthusiasm. Despite the crisis in the offshore industry and hard economic times, they have provided me with the space and time required to complete the thesis.

Morten Mejlænder-Larsen at DNV GL is my former leader and is the assistance supervisor for this work. His insights into the industry have been valuable in determining the direction of the work.

To conduct the SARex projects, it has been essential to obtain equipment, knowledge and a platform/vessel.

From the first day of the project, Erik Moster at Norsafe and Søren Hansen at Viking-Life were key individuals, selling the project internally to their respective organizations; they provided knowledge from the supplier part of the industry, in addition to the equipment necessary for conducting the SARex exercises. Without this equipment, the exercises could not have been executed.

Andreas Kjøl from Viking Supply (now employed at the Norwegian Coastal Administration) is not only one of Norway's most experienced ice navigators, he is also Norway's most enthusiastic cold climate marine operation expert. Working with him has been very fulfilling, and he has contributed much to the project, on both an academic and personal level.

Further, Jan Erik Jensen from the Petroleum Safety Authority Norway has been important for providing valuable input. His drive for knowledge

and flexibility, to adapt general marine experience to standards relevant for the offshore industry, has made the project valid and relevant for the offshore operators. His ‘know-how’ from winter wave surfing was utilized to the full extent during the survival exercises.

The Norwegian Maritime Authority has been invaluable, especially Turid Stemre, Jan Reinert Vestvik, Erik Landa and Bodil Pedersen. Not only have they contributed to shaping the project to ensure industry relevance, personnel from the Norwegian Maritime Authority have also actively participated in every exercise, being cold, wet and hungry along with the other participants. Implementation of the result in the international marine industry would have been extremely difficult, if they had not contributed to the process. The open dialog and trust have been greatly appreciated.

Siv Gaalaas, Specialty Director - International Maritime Regulation and Polar Affairs at the Ministry of Trade, Industry and Fisheries has been very helpful in the implementation of the project results in the political arena, including lifting the findings into the sphere of the Arctic Council.

Espen Olsen at the Governor of Svalbard’s office has organized local participation in Longyearbyen. This has been essential when addressing issues where an increased understanding of SAR-operations is to be obtained. His use of new technology and ability to find creative solutions to problems regarded as insignificant have been greatly appreciated, as the methodology questions our established truths and contributes to developing knowledge and improving the current procedures.

Robert Brown from the Offshore Safety and Survival Center (OSSC) at Memorial University, Newfoundland, has been part of the project from day one. His ability to link our activities to the research being conducted internationally, in Canada and at Transport Canada, has enabled us to see the greater picture. However, not bringing his bagpipes to the exercises, to play for the participants in the lifeboat/life raft, was a disappointment

for some, while others were very relieved at the fact that the bagpipes remained in Newfoundland.

Maritimt Forum Nord and the Norwegian Shipowners Association have actively participated in the project and contributed with economic support. These contributions are greatly appreciated.

The active participation of the officers and crew of KV Svalbard has been essential for the execution of the SARex projects. Their ability to adapt and remain positive, despite the cold and misery, has made the exercises a positive encounter for the external participants. This includes the bosun, Ottar Sletta, who organized and ensured all the practicalities were in place. His ability to motivate the young enlisted men and women impressed all external parties and was critical for the conduction of the exercises.

KV Svalbard was responsible for the safety associated with the SARex activities. The combination of Gudmund Johansen's (now at University of Tromsø) skepticism, Stig Andersen's humbleness and Thomas Andersen's positivity enabled us to conduct potentially hazardous operations in a safe manner. The way they organized the sites of the exercises made everyone feel well attended to.

The SARex exercises would not have been possible without the support of the Norwegian Coast Guard. Endre Barane, former captain of KV Svalbard, Ove Tobias Gudmestad and I were the 'fathers' of the project. Barane not only enabled access to the vessel KV Svalbard; being one of Norway's most experienced Arctic captains, he provided valuable knowledge in shaping the project and was essential for executing it in a safe manner. The numerous discussions before, during and after the exercises contributed to ensuring the project was on the right course and were greatly appreciated.

Ove Tobias Gudmestad is the supervisor of this thesis. His openness to alternative thinking and the trust he has shown me during the study have been highly valued. Without this, the SARex exercises would never have become a reality. His ability to take even the most complicated scientific challenge into the perspective of a farmer from Jæren has opened my eyes and increased my understanding of many of the complicated issues discussed through the years.

When times were tough, I fell back on calling my dad, Knut Solberg, as I have always done. Being an engineer with an above average interest in technical challenges, his advice was not only supportive but also increased the overall quality of my work. Knowing that I can always call him gives me great gratification.

Lastly, I would like to thank my family, Mathilde, Knut Øyvind, Emmy Sofie and Josefine. They have put up with me being mentally absent for parts of the time, in addition to computers, dataloggers, wires and soldering irons spread over a major part of the house. Without their support, this project would never have been completed.

List of papers/scientific reports

The work conducted in relation to the PhD has been done in a cumulative way, with each result being founded on the previous work. The work has been based on the following key activities:

- Data collection and analysis
- Production of scientific papers/reports
- Communication of the results/presentations

The following data collection and analysis activities have been carried out, leading to the development of scientific papers. For more information, see attached "Enclosed Papers".

Paper No.	**Title**	**Journal/Proceedings, year**	**Authors**
1	SARex, Assessment of Polar Code requirements through a full-scale exercise	23rd IAHR International Symposium on Ice, Ann Arbor, 2016	Solberg, K. E.; Gudmestad, O. T.
2	Heat loss of insulated pipes in cross-flow winds	36th International Conference on Ocean, Offshore & Arctic Engineering, OAME 2017/ Journal of Offshore Mechanics and Arctic Engineering, 2017	Kvamme, B. O.; Peechanalt, J; Amith, Y. A.; Solberg, K. E.; Gudmestad, O. T.;
3	Risk reduction as a result of	The Interconnected Arctic — UArctic	Solberg, K. E.; Brown,

	implementation of the functional based IMO Polar Code in the Arctic cruise industry	Congress 2016, Springer 2017	R.; Skogvoll, E.; Gudmestad, O. T.
4	Implications caused by SARex on the implementation of the IMO Polar Code on survival at sea	Computational methods in Offshore Technology, COTech2017	Solberg, K. E.
5	On exercises for search and rescue operation in the polar region	International Conference on Ships and Offshore Structures, ICSOS 2017	Solberg, K. E.; Gudmestad, O. T.
6	Identification of key elements for compliance of the IMO Polar Code requirement of minimum 5 days' survival time	36th International Conference on Ocean, Offshore & Arctic Engineering, OAME 2017	Solberg, K. E.; Barane, E.; Gudmestad, O. T.
7	Findings from two Arctic search and rescue exercises north of Spitzbergen	Polar Geography, 2019	Gudmestad, O. T.; Solberg, K. E.
8	Survival in cold waters - learnings from participation in cold water exercises - a regulatory perspective related to the Norwegian offshore industry	Computational methods in Offshore Technology, COTech2019	Jensen, J. E.; Solberg, K. E.; Gudmestad, O. T.

9	Thermodynamic optimization of life raft designed for polar regions	Port and Ocean Engineering under Arctic Conditions, POAC 2019	Solberg, K. E.
10	Time to rescue for different paths to survival	To be submitted to the Norwegian Maritime Administration and Polar Geography, 2019	Solberg, K. E.

The results have also been communicated to industry through participation at industry-related events/venues. These include:

Year	Event/Venue	Location
2016	Sjøsikkerhetskonferansen	Haugesund, Norway
2016	North American Shipping Forum	Montreal
2016	INTSOK Conference	St. Johns, Newfoundland
2017	Norwegian Seafarers Union	Oslo
2017	Norwegian Maritime Authority	Haugesund, Norway
2017	International Maritime Organization	London
2017	Arctic SAR TTX	Iceland
2017	Workshop	Tromsø
2017	North American Shipping Forum	Montreal
2017	Royal Institute of Naval Architects	London
2018	North American Shipping Forum	St. Johns, Newfoundland
2018	Norwegian Maritime Authority	Haugesund, Norway
2018	International Maritime Organization	London
2019	Norwegian Coastguard Academy	Bergen
2019	Norwegian Maritime Authority	Haugesund, Norway
2019	International Maritime Organization	London
2019	Kickoff workshop Arcsar project	Rome
2019	Arctic Council, Arctic Shipping Best Practice Information Forum	London
2019	Arctic Council, EPPR workshop	Høvik

The above-mentioned activities and papers have contributed to spreading the knowledge and implementation of the results in the industry. This has further led to active use of the scientific results by partners to modify/develop the following:

- Products
- Procedures

- Educational courses
- Class rules
- International rules

The work conducted has played a part in the development of IMO documents. Many of the findings identified in this thesis have been implemented in the document “Interim guidelines on life-saving appliances and arrangements for ships operating in Polar waters” (International Maritime Organization, 2019a). The document was approved by IMO in June 2019.

Table of contents

Table of figures

1 Introduction

More marine activity is taking place in cold climate regions than ever before. Much of this activity is linked to passenger/cruise activities. A large number of vessels, ranging from large cruise vessels carrying thousands of passengers to smaller open boats taking tourists to local tourist destinations, are part of this development. For the Svalbard area, this activity is expected to increase in the coming years (Brunvoll, 2015). There is, however, limited understanding of the risks imposed by this activity and the requirements this activity imposes on the suppliers of search and rescue services.

The marine industry has traditionally functioned in a retrospective way, and regulations have been developed after large-scale accidents. These accidents can be regarded by many as black swans, as they have not been predicted or foreseen (Taleb, 2007). An example of this is the sinking of the ‘unsinkable’ vessel, RMS Titanic. The development of the International Maritime Organization (IMO) Polar Code (International Maritime Organization, 2015) is an example of the contrary. It has been implemented before a major incident in the Arctic/Antarctic region before it has taken place.

Increased marine activities are experienced at both high and low latitudes. This exerts new challenges on all levels of the industry, from flag states and classification societies to vessel operators and equipment manufacturers.

The level of activity is increasing in areas where, previously, little activity has been encountered. This represents a challenge for the SAR communities.

Currently, there is limited cooperation within the marine industry, mainly managed through international regulations and the SAR community, which is a matter of national priorities.

1.1 Motivation and objectives

Having worked within the marine industry for about 20 years, I have witnessed many large projects, involving a substantial number of highly skilled people. Unfortunately, many of the projects have resulted in marginal change, especially seen in relation to the budget allocated for the task.

By initiating this PhD, I wanted to make a difference. By making a difference, I needed to produce results that were not only accepted by the academic community. They also had to be accepted by the key players within the marine industry. The results needed to shed enlightenment on a topic of relevance and in a language/format that was accepted by both parties. Furthermore, the results needed to be communicated not only to the academic community but, more importantly, to high-level international/national decision makers and key players within the marine industry.

Through this PhD, I was hoping to contribute to saving a substantial number of lives, if an incident occurred.

1.2 Norwegian Research Council – framework

The objective of the Norwegian Research Council Industrial PhD program is (The Research Council of Norway, 2019):

> *The overall objectives are to boost the research efforts and long-term competence-building for Norwegian trade and industry, and to enhance interaction between academia and industry, promoting knowledge transfer from researchers to society at large.*

The scheme is designed to support long-term, industry-oriented research that has a high level of scientific merit. This means that the results and insights generated by the PhD have not only to be produced but also need to be communicated to the relevant players. The material produced has to be written in a format, utilizing wording that is accepted by the industry. Lastly, the results and insights have to provide value for the industry.

The framework motivates cross-discipline collaboration across traditional silos, combining regulatory, commercial, practical and safety aspects. To attract motivated partners, the topics to be explored had to be narrow enough to enable a scientific approach and wide enough to provide new insight and knowledge relevant to the industry.

1.3 The birth of SARex

In the fall of 2015, Endre Barane from the Norwegian Coastguard and myself attended a workshop in Bodø. During the workshop, there were several scientific studies showing, scientifically, how people would cope in a survival situation. Both Barane and I had spent a substantial amount of time in the Arctic climate. We felt that several of the discussions marginalized the challenges associated with a marine incident taking place in a cold climate environment. Many of the studies also looked only at single elements and did not assess the challenge from a holistic perspective.

Later that evening, we discussed the issue. We both agreed that it was time for the marine industry to understand the real challenges associated with surviving a marine incident in a cold climate, and the best way to do this was to show them, through an exercise that was as close to reality as possible. When we departed, we had agreed that, if I could get relevant personnel and equipment together, he would enable access to KV Svalbard.

The next day, I called Ove Tobias Gudmestad and asked if he could get academia involved. He replied that this was not the standard methodology for initiating a scientific project, as we had no funding, no budget and no project plan. However, if both industry and the Norwegian Coastguard believed in the project, he would provide academic content.

Now, four years later, the project has developed and executed an undertaking with a budget of about NOK 50 million, most key marine cold climate players have been involved and we have accomplished a profound change in the course of the development of marine industry operation in cold climates.

Due to the efforts made in this project, a substantial number of lives would potentially be saved if a marine incident were to take place within the Polar Code areas.

1.4 Research question

With the increase in marine activity experienced at high latitudes (Brunvoll, 2015), the probability of a marine incident is increased. As the vessels operating in the region are carrying more personnel, the challenges associated with a rescue operation are increased. In the event of an incident, it is important that the lifesaving appliances provide the functionality required for survival until rescue.

The topic of interest is also relevant for all vessels where the SOLAS (Safety Of Lives At Sea) Convention (International Maritime Organization, 2004) applies.

The research question is:

What are the key mechanisms determining the probability of survival following a marine incident in cold climate, and what are the relevant mitigation measures?

More specifically, the research question addresses:

- *How is the IMO Polar Code* (International Maritime Organization, 2015) *to be interpreted to mitigate the additional risks associated with polar marine activities in the event of an incident/accident?*
- *What are the dominating risks following a marine incident in the Arctic?*
- *Do SOLAS-approved lifesaving appliances provide the functionality required to enable survival for the duration of the time to rescue?*
- *How does reduced access to onshore infrastructure influence a survival scenario?*

1.5 Thesis limitations

The challenge of survival from a holistic perspective is extremely multi-disciplined. Addressing all the individual elements is beyond the scope of this thesis.

To narrow down the scope of this thesis, workshops and discussions with key players within the maritime industry have been conducted. The overall conclusions from the discussions highlight the fact that assessment of human functionality is of key importance for all aspects of survival. Without the adequate human functionality, most of the provided resources would be of marginal value.

Due to the importance of maintaining a relatively high human functionality through-out a survival situation, this thesis will focus on the interrelationship between human functionality and the provided resources relevant for a marine incident. The provided resources are based on regulatory requirements applicable for vessel operations in the Polar areas.

The most efficient way to avoid a high casualty situation is to prevent an incident from occurring. This study does not address operational risk-reduction measures prior to an incident, e.g. vessel operation, lack of adequate bathymetric data and risk of iceberg collisions (Sollid, M. P., Gudmestad, O. T., 2018).

1.6 Research methodology

Surviving a marine incident involves different mechanisms, many of which are interrelated, with non-linear relationships. Extensive scientific work has been conducted on the individual mechanisms. However, little research that encompasses the challenge in a holistic way has been performed.

Much of the work is closely linked to the interpretation and implementation of the IMO Polar Code (International Maritime Organization, Shipping in polar waters, 2019), and there has been a strong focus on maintaining an up-to-date view of the political, legal and economic processes taking place among relevant stakeholders. Engaging in discussions with relevant stakeholders has been accomplished through active communication of project results. The outcome of this activity has been brought back into the project through feedback mechanisms, actively shaping the work to be commenced.

The results have further been implemented in the industry. A main focus has been the work conducted at IMO, London, resulting in approval (June 2019) of the interim guidelines on lifesaving appliances and arrangements for ships operating in polar waters. These guidelines apply to all vessels operating within the Polar Code area and will have a profound impact on the safety levels in the region.

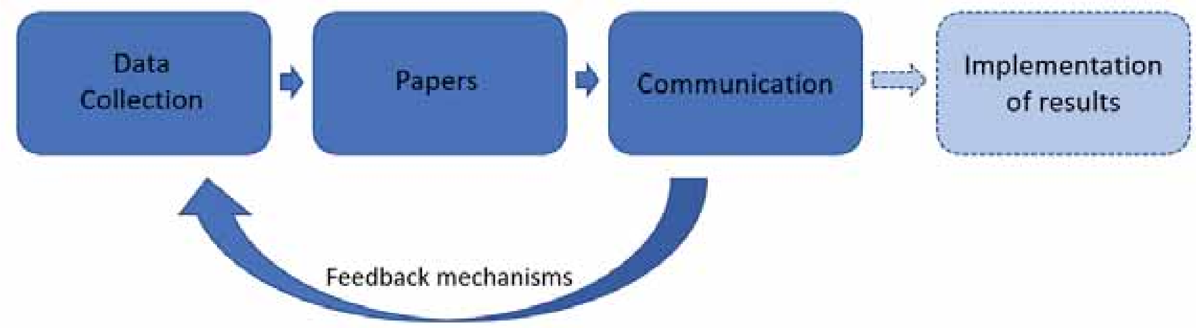


Figure 1 Workflow utilized in the PhD

Currently, there is no best practice methodology when assessing the research question, and the following methodology has been developed:

1. Clarification of the definitions/expressions utilized in the regulatory framework.
2. Identification of quantifiable parameters essential for the topic of concern.
3. Design of full-scale experiments where the quantifiable parameters of interest are revealed.
4. Risk analysis evaluating the risk associated with the full-scale experiments.
5. Evaluation of the results from the full-scale experiments.
6. Establishment of consensus among all parties involved in the full-scale experiment.

The above described methodology has been utilized when conducting the SARex1, SARex2 and SARex3 exercises.

In addition, several in-depth studies have been conducted, addressing key elements essential for survival. These included modeling of heat loss from a life raft and verification of the model, and quantification of the concept, “Time to Rescue”.

2 Maritime regulatory regime

The marine industry is organized and regulated in a complex manner, incorporating the following main instruments:

- **Flag state requirements –** Each flag state has its own national marine legislation. This is typically based on interpretation of international IMO requirements. Each flag state has the right to implement its own requirements, as long as they are not discriminatory. However, implementing stricter requirements then the minimum IMO requirements can result in a reduced commercial attractiveness.
- **Port state requirements –** Each port state has the right to enforce its own additional requirement, as long as the requirement is not discriminatory. Examples of port state requirements can be compulsory pilot services or compulsory vessel routing.

Other port state requirements do not have to directly address marine activities but can influence the marine activity, e.g. activity restrictions in National Parks or SAR-insurance requirements when onshore. This is based on national legislation.

- **Commercial requirements –** Many commercial operations are executed by vessel charters. The chartering contract can define additional requirements imposed on the vessel owner. This typically addresses equipment and systems required for commercial operation. In many cases, this equipment is not part of the IMO requirements, e.g. rate of flow for cargo pumps.

As all vessels are to have a valid insurance certificate, the insurance companies can impose and enforce requirements on vessel owners/operators through commercial mechanisms.

2.1 Stakeholders

Working with regulatory development within the marine industry on an international level requires an in-depth understanding of both the evident and at times hidden agendas of the different stakeholders. The main stakeholders affecting work related to marine safety can be summarized as follows:

- **IMO –** The International Maritime Organization (IMO) is a special agency under the United Nations. It currently has 172 member states, usually represented by their maritime administration. The IMO is organized through five committees, each with several sub-committees.

The work associated with lifesaving appliances is anchored in the legal instrument, the SOLAS Convention, which is administered by the Maritime Safety Committee (MSC).

Many of the decisions made in the IMO are based on finding common denominators and reaching a consensus among the member states. This process involves finding the equilibrium between political, economic and national interests.

- **National interests –** In Norway, the marine industry is governed by Fiskeri og Næringsdepartementet, and the national interests are administered by the Norwegian Maritime Authority (Sjøfartsdirektoratet, 2017). The Norwegian Maritime Authority (NMA) not only administers and enforces our national requirements but also administers our maritime registers (NIS/NOR registers). The vessels registered in our national registers are to comply with our maritime regulations. In most cases, the vessel owners are companies registered in Norway. Due to the income generated by the taxes imposed on the vessel owners, the individual nations strive to have commercially competitive regulations, within both the maritime regime and the taxation scheme.

A variety of national interests affected by the marine industry can entail national regulations, imposing requirements on the marine industry. This is typically seen in issues involving the environmental risk/footprint generated by the marine industry.

- **Classification societies –** Classification societies interpret the regulations defined by the flag states and coastal administrations. In some cases, they act on behalf of the flag state; at other times, they act as objective third parties. It is, however, important to note that classification societies are commercial entities. This ‘forces’ the societies to compete against each other in an aggressive market. As a result, the societies have to balance the need for conservative interpretation of the regulations with the cost imposed on the vessel owner/operator to keep a fleet registered under their rules.

- **Vessel owners/operators –** The vessel owners/operators have to cover the cost associated with the regulatory requirements. The owners/operators also have to obtain insurance, which again is only valid if the vessel complies with the flag state requirements, typically enforced by class.
- **Equipment suppliers –** The equipment suppliers provide the vessel owners/operators with equipment that enables them to achieve regulatory compliance. The safety equipment is usually evaluated on regulatory compliance, price, capacity, weight and volume, with regulatory compliance being regarded as the ‘ticket to trade’.
- **Ship officers/crew –** The training of the vessel crew is defined in the IMO STCW (Standards of Training, Certification and Watchkeeping for Seafarers) Convention, and their interests are safeguarded through unions, e.g. Norsk Sjømannsforbund (Sjømannsforbund, 2017). The unions promote the interest of the officers/crew and have representatives present at the IMO.
- **Cargo owners/Passengers –** The safety of the cargo/passengers is protected by no individual organization. Their safety is the responsibility of the operator/transportation provider. For a vessel carrying cargo, this risk is managed through contracts and insurance schemes.

Each individual passenger on board a cruise ship/passenger ship is paying the cruise operators to manage their individual safety. As most passengers do not have the knowledge required to assess the safety of the individual vessel during the individual voyage, they rely on the vessel/cruise operators. Their motivation for safeguarding their passengers is the risk of economic implications caused by an incident/accident. It is, however, important to note that the cruise operator/transportation provider is a commercial entity. This implies keeping the cost low. To stay commercially competitive, they are often forced to keep the cost related to safety equipment at a minimum but still within the levels defined by the regulatory regime.

Due to the complexity and variety of agendas among the stakeholders, regulatory development does not always follow logical paths. When designing and implementing new requirements, both politics and large-scale economic implications are to be considered.

2.2 Regulatory rationale

The International Code for Ships Operating in Polar Waters (International Maritime Organization, 2015) is referred to by many as the Polar Code. The code was introduced to the marine industry in recent years and applies to all vessels operating within the IMO Polar Code area.

Figure 2 The extent of the IMO Polar Code in the Northern Hemisphere (International Maritime Organization, 2015).

The code is a supplement to existing IMO instruments, e.g. the SOLAS Convention (International Maritime Organization, 2004) and its intention is to mitigate the additional risks present for people and the environment when operating in polar waters. The IMO Polar Code is a goal-based ruleset. Being goal-based provides flexibility and gives the operator the ability to interpret and adapt the requirements to their individual operations, e.g. a winter operation in the polar pack ice will demand a different functionality related to lifesaving appliances than a summer operation in the Svalbard region.

The main legal instruments addressed in this thesis are the IMO Polar Code (International Maritime Organization, 2015) and the SOLAS Convention (International Maritime Organization, 2004).

3 Qualitative risk studies addressing survivability

Surviving a marine incident involves mitigation of numerous risks. There are various standards addressing the topic on how to perform relevant risk analysis, e.g. *Escape, Evacuation and Rescue from offshore installations, Annex B – Examples of Arctic EER Risk Analysis and Operational Systems, Draft* (International Organization for Standardization, 2019). There is observed a discrepancy between the methodologies utilized for identification and mitigation of Polar risks in literature. There is also observed a lack of consistency in definition of the risk acceptance criteria. As a result, it is to be believed that there is no consensus across marine industrial activities related to conduction of risk assessments related to Polar operations.

Another profound observation is the fact that most scientific work, standards and regulations focus on escape, evacuation and rescue. In a real scenario there is a fourth element, survival. The survival element will take place on a timeline in between evacuation and rescue. The challenges related to the survival element is highly related to factors present in the Polar environment - long response time and limited SAR resources, in addition to high survivor vulnerability to the environment.

The element defined as survival is believed to cover a range of topics essential for maintaining the level of human functionality that enables rescue.

Many studies addressing the various aspects associated with survival have been conducted. What most of these projects have in common is the fact that they typically address only a few of the mechanisms at play, and they do not address the challenge from a holistic perspective. Examples of papers addressing elements essential for survival are *Thermal requirements for surviving a mass rescue incident in the Arctic*

– *Project update* (Boileau, R., Mak, L., DuCharme, M. B., Cheung, S., 2010) or *Design of an ice strengthened lifeboat* (Brown, R. P., Gatehouse, E. G., Reynolds, A., 2008). There has also been conducted substantial amount of work associated with survival from a military perspective. The aim of these studies mainly focusses on military operations and resources with highly trained military personnel, e.g. Thermal regulation under extreme activity, the importance of nutrition (Teien, 2014). In many cases, the boundary conditions are widely different from a marine incident involving seafarers and passengers, utilizing standard equipment, typically defined in the SOLAS Convention (International Maritime Organization, 2004) and the IMO Polar Code (International Maritime Organization, 2015).

The value offered by previous studies provide precious input for an overall understanding of the concept of survival. However, tying the different studies/elements together to form a holistic approach is a difficult task due to the large dependencies and natural variations within the boundary condition parameters. As this thesis is aimed towards the marine industry, IMO definitions/assumptions are utilized where appropriate.

3.1 Dominating risks in a marine survival scenario

Design of a complete model for a marine survival scenario would have to include numerous hazards. These hazards would typically include elements associated with:

- Sea ice
- Sea spray icing
- Extreme wind speeds
- Wave action
- Dangerous wild life
- Medical conditions

- Injuries/unfavorable actions emerging during the evacuation process
- Equipment failure
- Psychological stress reactions
- Heat loss
- Lack of adequate SAR infrastructure

An extensive list of polar specific hazards relevant for cold climate marine operations is found in the IMO Polar Code, Chapter 3 (International Maritime Organization, 2015).

Risk is regarded as the product of probability multiplied by consequence. From a risk perspective all hazards mentioned above have a high consequence as they potentially have an outcome resulting in loss of life. A generic assessment of the probability associated with the individual hazards has limited value as it is highly dependent on time of year and area of operation and type of operation.

The “Dependency” are elements that are required for the mitigation measure to be implemented, e.g. mitigation of a hazard called “lack of communication” would not only be dependent on a functioning VHF-radio. It will also be dependent on an operator with adequate knowledge and body functionality to ensure proper operation. An assessment of the dependencies can give an indication of the robustness of the mitigation measure. A simplified risk matrix, including dependencies is found below.

Hazard	**Description**	**Mitigation measure**	**Dependency**
Sea ice	Sea crushing survival craft	Evacuation onto ice	Adequate equipment Adequate body functionality
Sea spray icing	Sea spray icing accumulating on the survival craft	Removal of ice	Survival craft design Adequate equipment Adequate body functionality
Extreme wind speeds	Wind blowing away/ripping apart equipment/shelters	Tying down equipment/shelters	Adequate equipment Adequate body functionality
Wave action	Waves crushing survival crafts Wave action causing injury to survivors	Proper design of survival crafts Physical ability for survivors to remain in their seats	Proper design of survival craft Adequate body functionality

Dangerous Wildlife	Dangerous wildlife destroying equipment or killing survivors	Fight off wildlife	Adequate equipment Adequate body functionality
Medical condition	Unfavorable medical condition causing lack of functionality	Reliant of help from other survivors	Adequate body functionality among other survivors to provide help
Injuries/unfavorable actions emerging during the evacuation process	Injuries/unfavorable actions causing lack of functionality	Reliant of help from other survivors	Adequate body functionality among other survivors to provide help
Equipment failure	Failure of essential equipment	Proper design Increased redundancy Repair of equipment	Adequate equipment Adequate body functionality
Psychological stress reactions	Psychological stress reactions causing lack of functionality	Increase drills/training of both crew and passengers	Increase awareness of the issue in the vessel Safety Management System

		Reliant of help from other survivors	Adequate body functionality for the other survivors
Heat loss	High heat loss causing development of hypothermia	Increase insulation layers Increase activity levels	Adequate equipment Adequate body functionality
Lack of adequate SAR infrastructure	Lack of SAR infrastructure causing additional strain on the survivors during the rescue phase	Ensure the survivors are in a physical state that enables rescue	Adequate equipment Adequate body functionality

Figure 3 Simplified risk matrix

Based on the above it is evident that there are two dependencies that are relevant for most hazards:

- Adequate equipment – adequate equipment addresses the equipment required for execution of the mitigation measure. This will cover a wide variety of equipment, depending on mitigation measure of interest. Most of the technology and equipment required is currently available.
- Adequate body functionality – adequate body functionality relates to both the physical and psychological ability (including training) required for the survivors to conduct the tasks required for implementation of the mitigation measures.

To enable development of a holistic risk model addressing survivability it is essential to define and preferably quantify physical and psychological functionality among the survivors. This has not only to be considered during the surviving process, but also the functionality present at the starting point of the survivor scenario is important as there is a huge spread within the natural variation among the people of interest. E.g. the physical abilities present in a fit 20-year-old male seafarer, versus the physical abilities present in an 80-year-old passenger

3.2 Scenario specific risk models

For a holistic risk study to be adapted to be utilized in a scenario specific risk model, it would be important to define a vast number of parameters relevant for the specific operation of interest. From a marine perspective many of these variables are defined through regulatory requirements. However, it is important to acknowledge that there are large variations within the interpretation of the regulatory framework.

Quantification and alignment of the above-mentioned hazards will be highly dependent on the parameters associated with a unique operation of interest, e.g. time of year, geographical area, training and competence of individuals, functionality of available survival crafts, number of persons and available SAR resources. IMO Polar Code, Chapter 3.2 (International Maritime Organization, 2015) further states that the risk levels may differ and that the mitigation measures may vary within Polar Waters.

The IMO Polar Code Part 1-B – Additional guidance regarding the Introduction and Part 1-A, Chapter 2.2. Operational assessment (International Maritime Organization, 2015) further outlines the approaches associated with the development of an operational assessment. The operational assessment is to include scenario specific risk assessments relevant for the specific vessel of interest and its operational pattern, including the risks associated with Escape, Evacuation and Rescue, in addition to the requirement of minimum 5 days of survival.

The approach indicates the hazards to be considered and the development of a risk model. It is recommended to utilize the techniques found in Appendix 3 of the Revised guidelines for Formal Safety Assessment (FSA), (IMO document MSC-MEPC.2/Circ.12) and the standard ISO 31010, Risk Management – Risk assessment techniques (International Organization for Standardization, 2016).

Based on the methodology mentioned above, risk levels are to be assessed. If the risk levels are not regarded as acceptable, additional mitigation measures are to be implemented. However, as no quantifiable risk acceptance criteria is defined, the vessel operators are themselves to define what they regard as acceptable risk levels. Based on experience from Classification societies, a large discrepancy between accepted risk levels is observed between different vessel operators.

Risk assessments are a great tool for increasing safety levels. It is however important to keep in mind the interrelationship between the different parameters. Minor details can have major impacts on the overall probability of survival. An example would be et functionality of the gloves – inadequate functionality of the supplied gloves would in many cases ruin the ability to utilize the hands. The supply of food, water, radios and survival suits with zippers would be of limited use in a scenario incorporating inadequate gloves. Due to the reduced ability to utilize the hands, the survivors would not be able to access the potential of the resources provided.

Due to the lack quantifiable consensus-based risk acceptance criteria's and the highly complex interrelationships between the different parameters, risk assessments are to be used with caution. Development of a realistic and well-founded risk assessment require a high level of knowledge and experience from representative operational conditions, including vessel/equipment limitations and the knowledge and experience present among officers and crew.

4 Interpretation of the IMO Polar Code

Being a goal-based ruleset, correct interpretation of the rules is of key importance for reducing risk.

As the primary target of this thesis has been safety, Chapter 8, Lifesaving appliances and manning, of the IMO Polar Code has been our main focus.

The term ‘survival’ is frequently used in the code but not defined. Based on discussions with project partners, including medical personnel, it has become clear that survival is only possible if the casualty is able to maintain adequate functionality to safeguard individual safety when exposed to the environment for a prolonged period. Based on the SARex exercises, the project chose to define the following as the overarching goal for IMO Polar Code, Chapter 8:

> *The equipment required by the Polar Code is to provide functionality that enables the casualty to maintain the* ***motivation to survive*** *and the ability to* ***safeguard individual safety****, which means to maintain* ***cognitive abilities, body control*** *and* ***fine motor skills****, in addition to* ***preventing the development of fatigue*** *for the maximum expected time until rescue.*

It is assumed by many that the stay in the survival craft is a passive ‘waiting game’, in which the survivors wait for the SAR parties to arrive. Based on SARex, we believe that surviving in a survival craft for five days will require active participation by the survivors. Active participation means to conduct basic tasks like:

- Alerting SAR units

- Coordinating the different survival craft
- Managing onboard resources
- Keeping lookout
- Rationing food/water supplies
- Conserving body heat (preventing condensation)
- Ensuring blood circulation (moving limbs regularly)
- Relieving oneself (going to the ‘bathroom’)
- Caring for sick/injured personnel
- Actively participating in the evacuation from the survival craft to the rescue vessel

Conducting the above tasks will require cognitive abilities, body control and fine motor skills.

In addition to the above-mentioned abilities, maintaining the motivation to conduct the required tasks is also of great importance. Maintaining motivation requires preventing the development of both peripheral fatigue and central fatigue. Fatigue is defined as *extreme tiredness resulting from mental or physical exertion or illness*. However, quantification of the terms, ‘motivation’ or ‘fatigue’, is difficult.

It is clear that reduced functionality within the physical domain will, in many cases, also result in the development of fatigue and reduced motivation to continue the fight. Based on discussions with doctors and physiologists, a hypothermic state will, in most cases, represent the *start of the end* in a cold climate survival scenario lasting for a minimum of five days. This is not only because regaining heat is difficult but also because the development of fatigue accelerates when the survivor is in a mild hypothermic state. It is of great importance that the survivors never reach even a mild hypothermic state, as recovery will be difficult.

There are variations within a population, concerning ability to handle cold, physical abilities in relation to body core temperature and metabolism. When interpreting the Polar Code, it is beneficial to avoid criteria based on body temperature readings, due to large individual and diurnal variations. Body functionality is the preferred parameter that defines the potential survivability of personnel.

Survival is dependent on carrying out the right actions at the right time (safeguarding individual safety). The following functionality parameters have been identified as critical for carrying out the activities essential for survival (ability to safeguard individual safety):

4.1 Cognitive abilities

All actions essential for survival are initiated through cognitive processes. Being able to comprehend the situation and to carry out relevant actions requires cognitive abilities. Staying mentally fit is also important for the ability to generate the motivation, and prevent the development of fatigue, required for survival.

There is a strong relationship between loss of cognitive abilities and reduction of body core temperature.

4.2 Body control

When the body’s core temperature falls below about 35.5 degrees C., the large muscle groups start a process of rapid contraction, resulting in shivering. Through the muscle contractions, the body produces heat, trying to increase the body’s core temperature. These contractions are not controllable, and the person is unable to attend to his/her own needs or carry out the actions required to ensure survival.

Seen from a five-day perspective, the contractions can only endure for so long before the muscles are exhausted. The duration is dependent on individual health, age and fitness. If the person is not brought into a warm space, a further decrease in body core temperature is experienced when the shivering stops.

4.3 Fine motor skills – extremities

Survival is dependent on carrying out actions (see above). Many of these actions require fine motor skills and are carried out by the use of hands, i.e. pushing the PTT (Push-To-Talk) button on a VHF radio, opening water rations and opening/closing zippers for venting.

4.4 Prevention of development of fatigue

Survival in a survival craft will require the participants to maintain the motivation to carry out the tasks required for survival. If a state of fatigue develops, the ability to carry out the required tasks is reduced. Quantifying fatigue/motivation is a difficult endeavor, and the causes behind development of fatigue can be both complex and interrelated. It is, however, clear that development of fatigue is affected by the following parameters:

- Physical pain – The pain can typically result from injuries, static non-ergonomic sitting positions, lack of ability to move and frostbite.
- Mental stress – Survival is dependent on maintaining motivation and focusing on survival. Mental stress will reduce these abilities. Mental stress can, for example, originate from the uncertainty associated with not being in control in a new environment or being separated from family members during the evacuation phase.
- Energy level – Consuming a higher level of energy and water than is being introduced to the body will reduce the energy level.
- Sleep deprivation – Not having the ability to sleep reduces the ability to maintain a high level of motivation.
- Lack of cognitive abilities – Maintaining a high level of motivation will require rational decision-making, which again is linked to cognitive abilities.

Due to the above arguments, it is evident that a certain amount of **basic comfort** is needed to prevent the development of fatigue over a prolonged period of time. There are great individual variations, which are linked not only to individual physical abilities but also to individual mental robustness.

5 Sources of data

5.1 SARex

There is little data available describing in a holistic way the challenges associated with surviving a marine incident. To be able to obtain data, several full-scale experiments/exercises were designed, organized and executed. The exercises were named SARex1, SARex2 and SARex3, and were carried out in April/May of 2016, 2017 and 2018.

	SARex1	**SARex2**	**SARex3**
Key aim of the exercise	Assess the functionality of standard SOLAS-approved lifesaving appliances with regard to providing survival for minimum 5 days (IMO Polar Code requirement (International Maritime Organization, 2015)).	Assess the functionality of high-end/modified SOLAS-approved lifesaving appliances with regard to providing survival for minimum 5 days (IMO Polar Code requirement (International Maritime Organization, 2015)).	Assess benefits of evacuation to shore with regard to providing survival for minimum 5 days (IMO Polar Code requirement (International Maritime Organization, 2015)).
Location	Wood Fjord, Svalbard	Lloyds Hotel, Svalbard	Fjortendejulibukta, Svalbard
Metocean conditions	Average ambient air	Ambient air temperature: 0 ^{o}C to -9 ^{o}C	Ambient air temperature: 3 ^{o}C to -6 ^{o}C

	temperature: -9 ^{o}C Water temperature: -1.2C Wind: 2 m/s	Wind: 0m/s to 18 m/s	Wind: 3 m/s
Vessels	KV Svalbard	KV Svalbard	KV Svalbard and Polarsyssel
Equipment resources	Viking life raft Norsafe lifeboat	Viking life raft Norsafe lifeboat	Viking PSK & GSK Survitec PSK & GSK

Figure 4 The SARex exercises

Figure 5 Map of exercise area on the northwestern part of Svalbard (map from Norwegian Polar Institute)

All experiments had to consider the following restrictions:

- No injury to personnel (participants or safety crew) was acceptable.
- The experiments were to be conducted in a way involving the least amount of risk possible and still provide scientific data.

All experiments had to consider the following restrictions:

- No injury to personnel (participants or safety crew) was acceptable.
- The experiments were to be conducted in a way involving the least amount of risk possible and still provide scientific data.
- To increase the relevance of the results, the experiments were to be conducted in conditions representative of the activity conducted by the marine industry.
- To maintain relevance for the marine industry, the experiments were to be regarded as a ‘best’ case.
- As the experiments involved a substantial number of people, everyone was encouraged to present their views, and common consensus was to be established among all participants with regard to the key findings.
- Each experiment was to build on the knowledge obtained in the previous experiments.
- The documentation of the quantifiable results was to be generated by scientific personnel.

5.1.1 SARex abortion criteria

Each participant was to be extracted from the exercise if a predefined condition was reached. To ensure consistency concerning abortion of the exercise, a clear set of abortion criteria was defined. Due to safety issues, the participants were to leave the exercise when one of the following conditions appeared:

Pt. 1 – Reduction in cognitive abilities

Pt. 2 – Lack of body control (e.g. uncontrolled shivering)

Pt. 3 – Severe loss of functionality of extremities (e.g. fingers)

Both Pt. 1 and Pt. 2 take place when the body’s core temperature approaches 35.5 °C. Based on our interpretation of the Polar Code and the workshops with the medical staff, this was defined as *the start of the* *end.* In a real scenario, the participants would have survived for a period beyond this point, but they would no longer have the ability to take care of themselves.

There are large personal variations in the duration of the further cooling process before a fatal state occurs. The duration depends on a combination of parameters like heat loss, age, fitness and BMI.

5.2 Methods of data collection

Identification of key parameters essential for enlightening the research question requires splitting the problem into manageable pieces. As an experiment/exercise only can assess a limited number of variables, selection of parameters of relevance was an important part of the exercise planning. As there was a limited budget associated with the activities, both equipment and participant participation were based on a volunteer principle.

When addressing variables related to human performance it was regarded as important to maintain a minimum of 5-10 persons per group to limit the impact of individuals performance on the overall result. The actual number of persons in each group was highly affected by available equipment and available participants, and all groups were constructed to be as equal as possible.

Collection of data during full scale exercises, involving a substantial number of persons and several major logistical resources like vessels and helicopters can be challenging. It requires finding the compromise between the following elements:

- Data importance
- Practical execution
- Effect induced by measurement activity on overall exercise execution and results
- No-play risk induced by measurement activity

The extreme environment, encompassing low temperatures, wet environments (e.g. sea spray and snow), ability for participants to conduct physical activities, lack of access (e.g. located in a free-floating life raft) puts a sever limitation on data collection activities.

Identification of the optimum balance was done through a tight dialog between exercise execution team (Norwegian Coast Guard), medical doctors and academia. Typical data collection methods included the following methodologies:

- Self-score cards – the participants rated themselves on predefined parameters at regular intervals throughout the exercise. The work was conducted in close cooperation with academia.
- Recording of body temperatures – the body temperatures were recorded by medical personnel, and typically average ear temperatures were from both ears were recorded.
- Recording of body functionality, including motoric skills and cognitive abilities – the data was collected utilizing recognized practical test, e.g. ability to pick up small items during a predefined time interval and specially designed computer programs.

The data collection was done in 3 separate exercises. Each exercise was regarded as a stand-alone event and incorporated to a large degree different personnel. Even within certain academic fields (e.g. medicine related to development of hypothermia) there was observed a large degree of discrepancy between the individual priorities among the academic personnel. The different priorities included not only what data to be collected and its resolution, but also the collection methodologies. As the exercises were based on volunteer participation, the individual focus areas had to be prioritized.

It is also to be noted that a significantly higher degree of data accuracy could be achieved if the experiments were carried out in a controlled laboratory environment. However, this methodology was not preferred. The reason for not choosing this methodology was because we wanted to obtain results that were as realistic and representative as possible compared to a real scenario.

Most humans are adaptive, seeking alternative solutions to problems This includes learning from other people’s mistakes. In a survival situation this is an essential ability. If laboratory experiments were to be the basis of our work, it would have been difficult to capture this effect.

For more information on the data collection methods and the results, please see enclosed Appendix 1, Appendix 2 and Appendix 3.

5.3 Miscellaneous data collection activities

Based on the findings from the SARex exercises, it became evident that further studies utilizing a theoretical approach were required for essential risks. The following issues were assessed.

5.3.1 Heat loss on board a survival craft

Based on the findings from all the SARex exercises, it is evident that mitigating the development of hypothermia is essential for surviving an incident in the Arctic. To analyze the heat loss in a survival craft, it is necessary to have an overview of the theoretical background.

5.3.2 Theory

The three laws of thermodynamics define the fundamental properties of a thermodynamic system.

The laws can be summarized as follows:

> The first law of thermodynamics is also known as the Law of Conservation of Energy. It states that energy (as work or heat) cannot be created or destroyed within an isolated system.
>
> The second law of thermodynamics states that the sum of the entropies within an isolated system will always increase.
>
> The third law of thermodynamics states that the entropy of a system reaches a constant value as the system approaches absolute zero.

Heat transfer is the transfer of heat within or between different physical systems. The fundamental mechanisms of heat transfer are:

- Conduction
- Convection
- Radiation
- Advection

Heat transfer through conduction

Heat transfer through conduction (also called diffusion) is the exchange of particles' kinetic energy through the boundary layers of physical systems. The conductive heat transfer can be expressed through Fourier's law:

$$q_{cond} = U * A * dT = \frac{k}{s} * A * dT \qquad (1)$$

where:

q_{cond} =	Conductive heat transfer (Watt)	dT =	Delta temperature
U =	Coefficient of heat transfer (W/m^{2}K)	k =	Thermal conductivity of material (W/mK)
A =	Area (m^2)	s =	Thickness of material (m)

Heat transfer through convection

Heat transfer through convection takes place as a medium flow over a surface. Convective heat transfer can be divided into two sub-categories, free/natural convection and forced convection. Free/natural convection occurs when the movement of the medium is caused by differences in density produced as a result of temperature gradients within the medium.

Free/natural convection is described by:

$$q_{conv} = h_c * A * dT \qquad (2)$$

where:

q_{conv} =	Conductive heat transfer (Watt)	dT =	Delta temperature
h_c =	Coefficient of heat transfer (W/m^{2}K)	A =	Area (m^2)

Heat transfer through forced convection can be described through several empirical correlations. The Churchill-Bernstein correlation is valid for all ranges of Reynolds numbers and a wide range of Prandtl numbers (Kvamme, B. O., 2016). All fluid properties are evaluated at film temperatures. The correlation is expressed as:

$$\overline{\mathrm{Nu}}_D = 0.3 + \frac{0.62\mathrm{Re}^{1/2}\mathrm{Pr}^{1/3}}{\left[1 + (0.4/\mathrm{Pr})^{2/3}\right]^{1/4}} \times \left[1 + \left(\frac{\mathrm{Re}}{282000}\right)^{5/8}\right]^{4/5}$$

$$\left[\mathrm{Re}_D\mathrm{Pr} \geq 0.2\right]$$

(3)

where:

Re = Reynolds number

Pr = Prandtl number

Nu_D = Nusselt number

Heat transfer through radiation

Heat transfer through radiation is the heat transfer induced by electromagnetic radiation, mainly in the infrared spectrum. The radiation is emitted due to thermal agitation of the molecules. The heat transfer caused due to radiation can be described by the Stefan-Boltzmann law:

$$q_{rad} = \sigma * A * (Tsurf^4 - Tamb^4) \qquad (4)$$

where:

q_{rad} =	Radiative heat transfer (Watt)	Tsurf =	Surface temperature (Kelvin)
σ =	Stefan-Boltzmann Constant = 5.6703 10^{-8} (W/m^{2}K^4)	Tamb =	Ambient temperature (Kelvin)
		A =	Area (m^2)

Thermal resistance

Thermal resistance is the material’s ability to resist heat flow. Thermal resistance is the reciprocal of thermal conductance and is expressed as:

$$R = \frac{L}{K} \qquad (5)$$

where:

R =	Thermal resistance (Km^2/Watt)	K =	Thermal conductivity (Watt/mK)
L =	Thickness of material (m)		

Heat loss through ventilation

$$H_v = c_p\, \rho\, q_v\, (t_i - t_o) \qquad (6)$$

where:

H_v =	Ventilation heat loss (W)	q_v =	Air volume flow (m^3/s)
c_p =	Specific heat air (J/kg K)	t_i =	Inside air temperature (C)
ρ =	Density of air (kg/m^3)	t_o =	Outside air temperature (C)

The heat loss from a life raft was modeled, incorporating both conductive and convective mechanisms. The following variables could be altered:

- Water temperature
- Ambient air temperature
- Windspeed
- Insulation levels in clothes worn by inhabitants
- Insulation level in floor
- Insulation level in tubes
- Insulation level in canopy
- Number of persons inside life raft

Based on the above variables, the heat loss per person was calculated; see Chapter 5.5 Heat loss on board a survival craft.

5.3.3 Time to rescue

The SARex exercises have shown the importance of quick and efficient rescue in cold climate marine incidents, to minimize human loss. The reduced level of onshore infrastructure present in a larger part of the Arctic, in combination with reduced SAR capacities, represents a risk for the marine industry.

The survivors can follow different PTS (paths to survival), where PTS is defined as a unique combination of choices made by the survivors and the SAR community, e.g. abandonment to a survival craft, hoist and transportation by helicopter to medical facilities.

Different scenarios covering rescue and evacuation for different geographical distances and numbers of passengers were analyzed, utilizing a model. For each PTS, the anticipated TTR (time to rescue) was calculated for different numbers of passengers.

The model is based on the historical values associated with different SAR activities, e.g. time utilized to hoist one person. Further, rest time, maintenance time and required human resources were incorporated, based on regulatory requirements.

See Chapter 5.6 Time to rescue, for analysis.

5.3.4 Discussions IMO

During recent years, the results of the activities were communicated and discussed with the global marine community at the MSC (Maritime Safety Committee) at IMO. This provided useful feedback with regard to execution and relevance for the marine industry. Having this continuous dialog for several years enabled the projects to address topics of relevance.

The discussions also contributed to shaping the development of the guidelines accompanying the IMO Polar Code and generated a global consensus with regard to the challenges.

See Figure 3 Workflow utilized in the PhD, for a description of the interrelation between SARex and the discussions at IMO.

6 Results of data collected

1.1 SARex – general

The individual reports from the SARex exercises are to be found in the Appendix. These documents address broader topics of relevance, as this thesis only focuses on key elements.

Common to all the SARex exercises was that the functionality of exercise participants followed a three-stage development phase:

Stage 1 – Cooling phase

Everyone was well fed, dry and warm prior to entering a survival scenario. In the cooling phase, the participants became accustomed to their situation, and survival strategies were developed. During this period, the social structure was established with the lifeboat/life raft captain; a plan for how to distribute resources, e.g. water, was developed; and tasks, e.g. keeping lookout, were distributed.

During this phase, the participants were utilizing the reserves they had when entering the survival situation. In most cases, most participants were gradually becoming moist/wet from seawater and condensation. The wetness resulted in reduced functionality of the insulation layers and commencement of the development of hypothermia.

Stage 2 – Stabilization phase

As the rate of participants leaving/being pulled out of the exercise started to increase, the stabilization phase was entered. The reason for departing the exercise was dependent on the duration of the cooling phase but, in most cases, was the development of hypothermia, in combination with the development of fatigue, immobility and dehydration.

Several also had to leave the exercises early due to being ‘unlucky’, e.g., they could have been allocated a seat close to an open hatch or got wet in the evacuation phase.

Stage 3 – Survival phase

During the stabilization phase, there was a steep learning curve for the participants remaining in the survival craft. Evidently, the survival strategy did not function for those participants leaving the exercise. The remaining participants quickly learned, and it was observed that both survival strategies and equipment were modified and improved when reaching this phase.

As participants were departing from the survival craft, the space allocated for the individual remaining participants was increased. This enabled movement and an increase in activity level and blood flow to the extremities.

The reduced number of people on board also decreased the need for venting due to low O_2 levels.

At this point in time, it was not uncommon for the participants to feel fatigue, which resulted in an urge to lie down and rest. Substantial heat loss was experienced from the body parts that were in contact with the cold surfaces inside the survival craft/on shore. This again resulted in abortion criterion Pt. 2 being met.

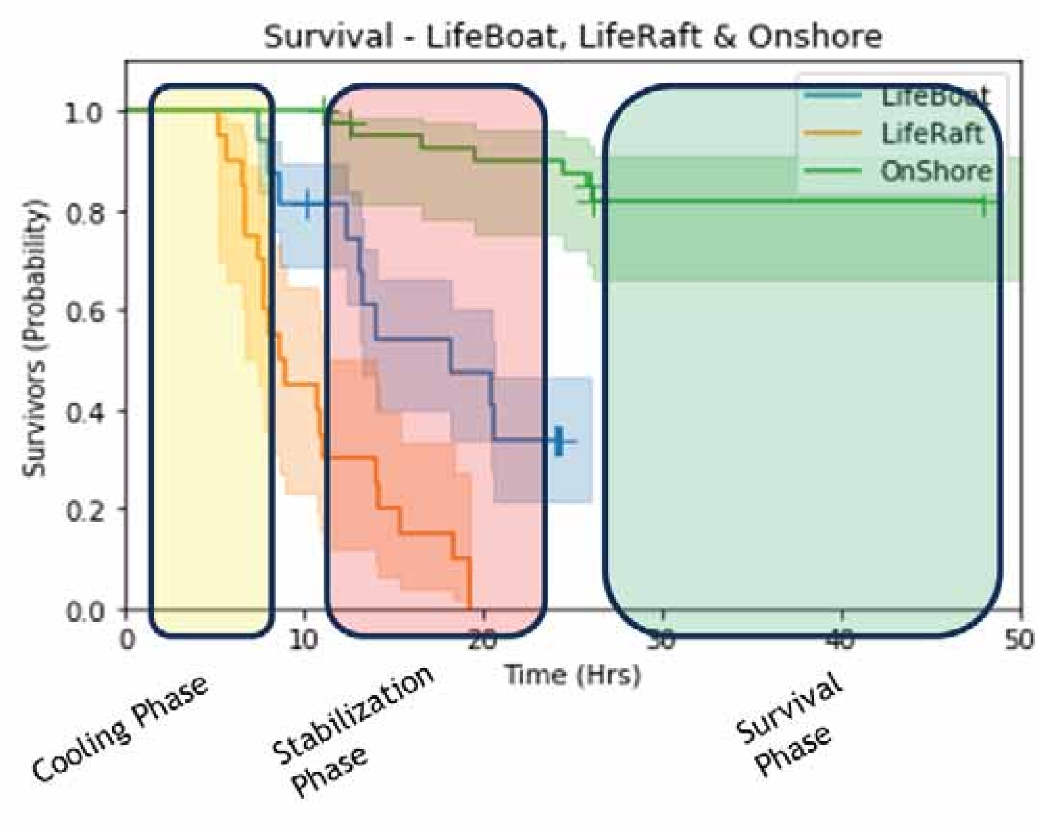


Figure 6 Phases of survival – typical paths followed by the SARex participants

6.1 SARex1

The SARex1 exercise was divided into three different parts, each addressing individual issues:

- Part 1 – Survival in lifeboat and life raft
- Part 2 – Search and rescue of stranded persons in lifeboat
- Part 3 – Equipment testing

6.1.1 Part 1 – Survival in lifeboat and life raft

During SARex1, a standard SOLAS (International Maritime Organization, 2004) approved lifeboat and life raft were utilized. By the time the survival craft had reached Phase 3, survival phase, several functionalities essential for survival had emerged. The combinations of these could enable further survival for the remaining participants. The following functionalities were available when the survival craft reached Phase 3:

- Improved survival strategies
- Sufficient space to allow movement
- Adequate O_2 levels inside survival craft
- Established survival craft routines, giving the participants the ability to predict and have the sense of being 'in control' of the situation.

The combination of the above parameters gave the remaining participants an increased probability of survival.

In SARex1, very few of the participants on board the life raft reached Phase 3, survival. The few that reached it only remained in this phase for a few hours before they had to abort the exercise. The reasons for only a few of the participants being able to progress to Phase 3 could be a combination of inadequate functionality provided by the equipment and psychological effects.

None of the participants was able to stay in the raft for the scheduled 24 hours. This proves that the complete rescue system associated with the raft (raft, equipment and personal protective equipment) does not provide adequate protection against the environment, from a five-day perspective.

A few of the participants on board the lifeboat were able to remain in the craft for the duration of the exercise. To a large degree, these participants chose to reject the temptation to lie down and rest, due to the heat loss experienced between the body and cold surfaces. This indicates the importance of motivation. However, it is uncertain whether these participants would have had the ability to maintain survival for an additional four days.

6.1.1.1 Personal protection

All participants were wearing standard long woolen underwear under regular shirt and pants. They were equipped with different types of SOLAS-approved personal protective gear. The following gear was utilized:

Neoprene survival suit – Neoprene survival suit with integrated soles, worn by 4 people.

Insulated survival suit – Insulated survival suit with integrated soles, worn by 6 people.

Non-insulated survival suit – Non-insulated survival suit with integrated soles, worn by 5 people.

Thermal protection vest – Standard SOLAS-approved thermal protection vest/aid, worn by 6 people.

Kampvest with bag – The standard life jacket utilized by the Norwegian Coast Guard. The participants were wrapped inside a plastic bag during their stay in the survival craft, worn by 6 people.

Kampvest without bag – The standard life jacket utilized by the Norwegian Coast Guard, worn by 4 people.

Nordkapp drakt – The offshore working suit utilized by the Norwegian Coast Guard. The suit had integrated boots with steel toes and loose neoprene gloves, worn by 2 people.

Survival suit 307 – The standard survival suit utilized by the Norwegian Coast Guard. The suit had integrated soles, worn by 2 people.

The different types of personal protection offered different advantages/disadvantages. It is clear, however, that the survival suits exhibited a major advantage over the different types of vests. Arranging the different personal protection aids, based on time spent in the survival craft, gives an indication of the relative fitness of the equipment; see Figure 5.

1. Survival suit, insulated – 39 hours
2. Nordkapp drakt – 36 hours
3. Survival suit, non-insulated – 30 hours
4. Survival suit, neoprene – 30 hours
5. Kampvest with TPA – 24 hours
6. Thermal protection vest – 17 hours
7. Kampvest without TPA – 15 hours
8. Survival suit 307 – 9 hours

It is important to note that only two people utilized survival suit 307. The large discrepancy for the neoprene survival suit between the lifeboat and the life raft was due to leaks in the seams. No problems with leaks were experienced in the lifeboat, while, in the life raft the leaks caused wetness, with a loss of insulating capability in the layers of clothes.

Results of data collected

	Survival suit, neoprene	Survival suit, insulated	Survival suit, uninsulated	Thermal protection vest	Kampvest with TPA	Kampvest without TPA	Nordkapp drakt	Survival suit 307
Average lifeboat (hours)	22.3	22.3	16.0	11.0	15.2	10.0	24.3	N/A
Average life raft (hours)	7.6	17.5	14.4	6.4	8.6	6.0	13.2	9.4
Average total	30.0	39.9	30.4	17.4	23.7	15.9	37.5	9.4

Figure 7 Hours stayed on board as function of protection aid

6.1.2 Part 2 – Search and rescue of stranded persons in lifeboat

The aim of Part 2 was to assess the challenges related to rescuing a large number of people from a survival craft in a cold climate environment. This challenge is closely linked to the IMO Polar Code requirement of a minimum survival time of five days.

Forty people were stowed in the lifeboat, which was located a few hundred meters from the main vessel, and the exercise took place under near perfect conditions, with little wind and few waves. The participants wore a variety of items of personal protective equipment.

The participants were instructed along the following lines:

- 5 patients were assumed to be hypothermic and deeply comatose
- 15 patients had a mix of non-lethal injuries
- 20 participants were assumed to be uninjured but more or less mildly hypothermic

The exercise revealed the following issues:

- Due to very little space in a filled survival craft, entry of the survival craft by the *KV Svalbard* crew was difficult. As a result, obtaining a situation overview, identifying the number of persons and the different types of casualties was a challenge.
- Upon arrival at the lifeboat, it is important that the crew on board the MOB (man over board) boat maintains strong leadership, reducing the risk of panic or unfavorable behavior among the passengers to be rescued.
- Rapid triage upon arrival in the SAR vessel is essential – there is no time for interviewing/ interacting with every individual victim.
- It may be useful to have medical personnel from the main vessel on board the MOB boat, to provide analgesia and other treatment allowing for an efficient transfer of the injured.

- It is difficult to treat injured persons in a lifeboat full of people. Prioritize evacuation of the non-injured, to enable treatment and handling of the injured.
- It is challenging and time-consuming to move non-ambulatory persons between vessels.

During the exercise, the following points were noted with regard to the reception facilities on board the SAR vessel:

- Good procedures on board the SAR vessel are essential for a well-prepared reception of the evacuees.
- Conducting an efficient triage requires clear procedures and puts considerable mental pressure on the individuals involved in the task.
- The vessel’s hospital was not actively in use, as it was too remote.
- Premade plans were activated, and large areas on board the ship were available for triage and treatment. Thus, quite large groups of (non-injured) people could be handled on board with little preparation.
- Heavily injured/hypothermic casualties placed a great strain on the medical personnel on board the SAR vessel. With limited medical resources, with regard to both personnel and infrastructure, it is to be recognized that only a limited number of heavily injured/hypothermic casualties can be treated without outside assistance.

The Polar Code states that people should be able to survive for up to five days in a raft or a lifeboat, but it does not define the condition in which they should find themselves at the end of this period. If just a small degree of hypothermia is allowed to develop, one can expect great challenges when attempting to transfer the victims between vessels. Dexterity, arm/leg coordination and cognitive function rapidly deteriorate, even in mild hypothermia. There were no good alternatives for transferring the large number of immobile passengers present.

6.1.3 Part 3 – Equipment testing

Prior to the test, the following objectives were defined:

- Test maneuverability of life raft when in ice-infested waters
- Test feasibility of evacuating from life raft to an ice floe
- Test feasibility of pulling the life raft onto an ice floe and moving it onto the ice
- Test feasibility of erecting the tents (supplied in group survival kits) in polar conditions
- Validate the usage scenarios of the included equipment
- Test capacity limitations in the life raft when wearing survival gear and having the required survival kits

Figure 8 Captain Barane crawling back onto the ice after swimming in the survival suit ©Trond Spande

The raft was moved to a field of rubble ice. Rubble fields are likely to be present in the marginal ice zone. Paddling the life raft in ice rubble proved impossible, and no distance was covered in these conditions.

Evacuating from the life raft to the fast ice proved to represent no additional challenge. One passenger went onto the ice and held the life raft in place as the other passengers evacuated. As more people gathered on the ice, the ice floe started sinking, and the evacuated passengers had to move further onto the ice to avoid breaking the ice edge. Four passengers were still in the life raft while the life raft was pulled onto the ice. The life raft was then pulled with ease along the snow-covered ice surface by the participants. The cylinder with the compressed gas had been removed prior to the exercise, which made pulling the life raft easier.

Figure 9 Relocating the raft with oars to the packed sea ice ©Lars Gunnar Dahle

onto the ice is the raft's When designing a group survival equipment package, it is important to consider the fact that the personnel that are to utilize the equipment are wearing personal protective equipment, e.g.

limiting movement, thick neoprene gloves restricting fine motor skills, non-breathing material, causing accumulation of sweat and moisture.

Both the weight and the volume of the group survival equipment are important parameters regarding both the transportation and storage of the equipment. The total number of individual components is also of importance because the correct utilization of each component requires knowledge and training. Basing the group survival equipment on standard safety equipment standards, striving to implement components of multipurpose use, will reduce the number of individual parts and minimize the need for additional training of the crew.

6.2 SARex2

SARex2 (Solberg, K.E., Skjærseth, E., Gudmestad, O. T., 2017) followed much the same structure as SARex1 (Solberg, K. E., Gudmestad, O. T., Kvamme, B. O., 2016). The exercise contained three different parts, each addressing individual aspects of surviving a marine incident in cold climate conditions.

- Part 1 - Study the adequacy of modified lifeboats, life rafts and Personal Protective Equipment (PPE) for use in cold climate conditions and in compliance with the IMO Polar Code
- Part 2 - Assess helicopter as a means of evacuation in a cold climate environment
- Part 3 - Assess the reliability of EPIRBs (emergency position-indicating radiobeacon) and Personal Location Beacons (PLBs) in a cold climate environment

SARex2 was structured around further development of the findings from SARex1.

6.2.1 Part 1 – Survival

SARex2 was an important vehicle for understanding the challenges of sustaining survival on board a lifeboat or a life raft in a cold climate environment. The following items were identified as essential for maintaining survival:

6.2.1.1 Air quality

With the lifeboat stored on the deck of KV Svalbard, an air quality and ventilation test was carried out. During the test, the vessel was filled to its full capacity and, with the hatches closed, the air quality was monitored.

During the air quality and ventilation test, the buildup of CO_2 increased rapidly during embarkation and reached a level of around 5,200-5,700 ppm before the hatches of the lifeboat were closed. During trial 1, the CO_2 levels reached about 23,000 ppm after about 31 minutes.

In trial 2, the participants had high pulse rates and were conducting exercise within the available space, to simulate the oxygen consumption/CO_2 production present when people are experiencing the uncontrollable shivering associated with a reduced body core temperature. During trial 2, the CO_2 concentration rose to 38,000 ppm during the 25-minute trial.

Findings from the study, “Survivability of occupants of totally enclosed motor propelled craft” (Light, 1992), indicate that levels of CO_2 reach 35,000 ppm to 36,000 ppm after about 40 minutes, when filling a 42-person lifeboat with 42 persons during summer conditions (air temperature of 17 degrees). This study harmonized well with our results.

The O_2 levels decrease linearly down to about 18% in trial 1 and down to about 17% in trial 2. Based on the rate of change, it is evident from the graph that increased physical activity was taking place during trial 2.

Each trial lasted only about 30 minutes. If the trials had progressed for an extended duration, critical levels of CO/O2would have been reached (Malesky, 2017).

The levels identified are all way above what is to be regarded as satisfactory from a survival perspective. This applies both to long-term and short-term exposure.

6.2.1.2 Allocated space, reducing the ability to move

Maintaining the ability to move is essential for maintaining primary body functions and preventing medical conditions like blood clots.

The space allocated for each seat is defined through regulatory requirements (Nedvedova, 2019) or in class rules (Det norske Veritas, 2009).

The space available for movement is correlated with the utilized capacity of the survival craft (the capacity of the survival craft divided by the number of persons on board). The capacity calculations are based on the standard IMO definition of a standard maximum linear width of 430 mm and a body weight of 75 kg. A study of offshore workers conducted in Canada (Kozeya et al., 2008/2009) indicates that 85% of the studied population were heavier than the IMO definition of 75 kg and that 98% of the workers had a shoulder breadth greater than the 430 mm defined in the IMO requirements.

If a survival craft is filled to 100% of its capacity, the desired space for movement will not be available. This will increase the probability of blood clots, generate pain and contribute to the development of fatigue.

6.2.2 Ergonomics

The LSA (Life Saving Appliances) Code (International Maritime Organization, 2017) does not sufficiently consider the human element, especially the significance of human behavior when packed together on uncomfortable seating for a long period, such as five or more days. All exercise participants felt some degree of pain and discomfort with the seats provided in the lifeboat. Improvements to seating ergonomics should be considered. Backrests seem to be necessary, and the seats should be as deep as possible and upholstered using an insulating material. Seats with at least the same dimensions as for free-fall lifeboats (LSA Code 4.7.2.2) should be considered and would offer a great improvement, considering the expected time of rescue of five days.

The lifeboat we used for the exercise had three ‘beds’ for sleeping, giving each person three hours’ sleeping time in a 24-hour period. With improved seats, the need for such beds might be reduced, but provision of such beds would not only increase the comfort but also enable treatment of casualties with injuries or illness.

6.2.2.1 Ability to stay warm

Hypothermia represents one of the greatest challenges associated with cold climate survival.

The ability to stay warm is highly correlated with human heat loss. To reduce the heat loss, it is important to consider the internal temperature of the survival craft, including surfaces in contact with the personnel, in relation to the insulation layer provided by the personal protective equipment (PPE). In a cold climate environment, the maximum possible achievable insulation layer should be aimed for.

Due to the waterproof nature of PPE, condensation buildup inside the PPE is to be expected, and it is of great importance that the materials maintain their insulation abilities, despite being saturated with water.

Condensation buildup should also be combated through operational means.

The ability to stay warm is also related to metabolism, which correlates with both activity level and calorie/water intake. Increasing both activity levels and rations will significantly improve the probability of survival.

The challenge of hypothermia can be greatly reduced by the installation of heaters in the lifeboat.

In the life raft, the floor represents a significant source of heat loss. Studies conducted by Defence R&D Canada (DuCharme, 2007) show that the effect of an inflated/elevated floor is to significantly reduce heat loss from the raft, which harmonizes with our results.

6.2.2.2 Calorie/water intake

Most of the participants in this exercise lost about 2 kilo of body weight during the exercise. This loss is mostly generated by the loss of water. If the duration of the exercise were to be extended, all the participants would have experienced serious dehydration. It is also believed that the calorie intake from the rations was not adequate to compensate for the energy required to counterbalance the heat loss, especially in the life raft.

The combination of the above factors not only reduces the ability to stay warm but also negatively affects both the cognitive abilities and the motivation to survive.

A study conducted by the Norwegian Defence Research Establishment (Teien, 2014) showed a core temperature difference of 0.4^{o}C between participants receiving sufficient rations and those not receiving sufficient rations. It can be expected that insufficient rations will contribute to a higher probability of developing hypothermia.

6.2.2.3 Comfort – cognitive abilities and fatigue

Survival is dependent on the micromanagement of all the small details. Typical tasks include drying the inside of survival suits, maintaining enough rest and venting the survival craft to prevent buildup of CO_2. To be able to prevent the development of fatigue and maintain the cognitive abilities required to conduct all the small tasks, a minimum of comfort is required. This includes:

- No high degree of intense body pain for a prolonged period of time. Pain can typically be caused by bad ergonomics or frostbite.
- Ability to move to prevent blood clots, claustrophobic reactions and the development of fatigue.
- Ability to communicate with other people in the survival craft, to prevent mental disorder.
- Ability to conduct basic human tasks (e.g. relieve themselves), to ensure the personnel maintain the feeling of being in control of the situation.

Maintaining cognitive abilities and preventing the development of fatigue for an extended period of time are not things that should be taken for granted, as there are large human variations with regard to mental robustness and the ability to handle stress.

6.2.3 Part 2 – Helicopter evacuation

Part of the exercise was to utilize a helicopter for the evacuation of casualties from a lifeboat. Based on the time utilized by the helicopter, it would have taken theoretically 3.1 days to evacuate 700 people on board (the number of passengers and crew on a relatively small cruise liner) from enclosed lifeboats at the evacuation speeds experienced in the exercise (the helicopter base was to be 90 min. away). In a real scenario, the process could have been speeded up, but additional challenges like immobility due to injuries or hypothermia would, on the other hand, have slowed down the process considerably.

There are many limitations, with regard to helicopter evacuations in a large incident scenario. Evacuation by helicopter alone is not a feasible solution for the evacuation of a substantial number of people, and marine SAR resources should be available at the scene of the accident.

6.2.4 Part 3 – Testing of reduced duty cycle on beaming performance of EPIRBs

EPIRBs is the main tool for the communication of distress. The ability of SAR resources to beam in on the signal at close range is an essential asset for the location of casualties.

It is evident that the range in which the 121.5 MHz beacon is functional is limited to a few nautical miles when being utilized in combination with a marine SAR capacity. Based on the tests carried out by SARex2, a reduced duty cycle on the EPERB does not interfere with the direction-finding abilities on the rescue vessel.

Multipath reception occurs when the main signal, following the direct line of sight (LOS) path, and reflections of the signal arrive at the reception with a shift in phase. If the signals are shifted by 180 degrees, they will cancel each other out. The difference in the direct path length and the reflected path length is called the excessive path length. The path lengths of concern are described through what is called the Fresnel Zone (Kapusuz, 2014). The effect of multipath reception is considered a source, reducing the efficient range of the beaming capacities at low elevations (e.g. a marine resource with an antenna located at 20 meters above sea level).

With today’s technology, only transmitting a carrier with no information coded into the signal is not very efficient. Utilizing technology in which the rf signal also contains information, e.g. an AIS signal, is more efficient. A technology like that described above will not only increase the battery time or transmission power, it will also enable the SAR organization to obtain the position of the lifeboat/life raft, either through the information coded into the signal or by homing in on the signal.

6.3 SARex3

SARex3 was divided into three parts, each addressing a separate challenge.

- Part 1 – To study the gap in functionality between typical Personal Survival Kits (PSK) and Group Survival Kits (GSK), as provided by the industry, with regard to survival on ice/land and the requirement for a minimum of five days' survival, as defined in the IMO Polar Code. Based on the observations, assess the key mechanisms determining the success of survival.
- Part 2 - Study the additional challenges associated with rescuing a large number of people from land/ice in a cold climate environment.
- Part 3 – Assess the functionality of the utilization of MBR (Marine Broadband Radio) for developing an improved common operational picture among the different emergency response providers.

6.3.1 Part 1 – Survival on shore

The exercise participants followed the same phases as identified in the previous SARex exercises (2016 and 2017). This can be regarded as a sign of realism in the exercise. Each phase proved longer than in the previous exercises; in addition, a higher 'survival rate' was observed at the end of the exercise. This is regarded as an indication that the participants, to a greater degree, were able to compensate for the heat loss through increasing metabolism, in combination with higher insulation levels. Compared with staying for a prolonged time in a survival craft, where increasing metabolism was impossible, the participants were able to move and conduct high intensity activities when required. Through movement, discomfort as a result of inactivity was neglected, e.g. back pains and 'sleeping' feet as observed in the earlier

SARex exercises. The ability to move was also observed to increase spirits and motivation.

The cumulative effect of the above-mentioned parameters will increase the probability of survival when evacuating onto land/ice, compared to staying in the survival craft. We consider this to be an important finding from the exercises.

Prevention of local frostbite is very important, to be able to conduct adequate physical activity.

6.3.1.1 Activity levels

A majority of the participants experienced a high level of heat loss, due to inadequate insulation layers in the equipment. To compensate for the heat loss, it was essential to maintain a high level of metabolism/activity. Brisk walking, squats and push-ups with regular intervals will produce 100-300 Watt, depending on the intensity. This can be continued for a very long time for fit individuals, but it is obvious that elderly people, people with disabilities, or individuals in a bad physical shape will have a considerable disadvantage in this respect, with a reduced survival prognosis in cold climate.

To increase survival rates for all individuals, it is essential that they are furnished with equipment that provides enough insulation, not requiring high-intensity activities to compensate for the heat loss.

6.3.1.2 Rations

The water rations proved to be too small. If the participants in the exercise were to survive for five days, dehydration would be a significant issue. Most of the participants would have a loss of TBW (total body water) level well beyond 10%. This would significantly influence the outcome of a five-day survival scenario. Some individuals would most likely perish as a direct consequence of dehydration, while the majority would not be able to safeguard themselves, with the development of hypothermia as a direct consequence of the low TBW level.

6.3.1.3 Training

Adequate training of group leaders proved to be essential for survival. It was observed that some group leaders were able to identify individuals within the group that were developing fatigue and hypothermia. Quick reaction and initiation of ‘tailor-defined’ activities enabled these individuals to regain their body temperature and remain in the exercise.

Utilization of the survival equipment is also to be included in the training of group leader personnel. During favorable conditions, one of the groups took more than one hour to pitch a tent. Under unfavorable conditions, this could have resulted in the loss of several group members, due to not being able to get shelter from the elements.

6.3.1.4 Fatigue

Fatigue is to be regarded as a symptom of the cumulative effect of inadequacy within the above-mentioned elements. Quantifying fatigue from a scientific perspective is difficult. It is, however, clear that symptoms of fatigue were emerging as the exercise progressed.

Prohibition of the development of fatigue would be one of the main tasks for the group leaders. It is of vital importance that the group leaders have an understanding of both the effects and the underlying causes of the development of fatigue. Through this understanding, the group leaders could guide their fellow survivors and modify survival strategies, to adapt to the situation. This would be a constant dynamic process, taking into account elements like:

- Available equipment
- Available rations
- Available human resources

- Changing weather conditions

6.3.2 Part 2 – Evacuation from the shore

Many of the challenges associated with evacuation of a large number of people from the shore were related to SAR system setup, training of SAR personnel and availability of resources. Many of the findings obtained in this part of the exercise are to be regarded as low-level, addressing issues specifically relevant for Longyearbyen, and will not be further treated in this thesis.

6.3.3 Part 3 – Utilization of MBR

Using the MBR radio as a direct point-to-point network allows for full network bandwidth. A network with many enabled radios has to take the timeslot usage and the configuration of resources into consideration, as each radio will occupy network resources. A single hop between two radios will allow for up to 15 mbps one way and will provide more possibilities than in a large network setup.

Multi-hop relayed networks will have limitations, as the bandwidth will be cut in half over each hop. Each relay must have at least double the number of timeslots given to each endpoint. This can be avoided using two radios back to back, with separate frequencies to maintain the benefits of a point-to-point network.

The long reach LOS (Line Of Sight) and partial NLOS (Non Line Of Sight) capabilities of the MBR radio are preferred when you have the best possible height of the antenna. Stationary land-based sites will provide the best coverage when placed on high terrain.

In a real emergency situation, public Internet access would not be allowed, to preserve bandwidth. Being able to communicate with everyone with a cellular handset would, however, be preferable. The Internet access could be restricted by a firewall, which could only allow certain services for the emergency responders. The traffic itself could also be shaped by QoS (Quality of Service), to prevent it from interfering with the prioritized voice and video transmission.

The user interface should be self-explanatory, and the emergency responders must have equipment that can easily be switched on and off without the need for any configuration to make that equipment work. It is also to be recognized that training by emergency response providers in both the establishment and use of the system is to be required for reliable operation.

6.4 Heat loss on board a survival craft

Through the SARex exercises, heat loss was identified as a key challenge to surviving a marine incident in cold climate. Further exploration of the topic was conducted, to obtain a better understanding of the challenges facing the casualties in a cold climate marine incident.

6.4.1 Methodology

A system will always strive to reach a state of thermal equilibrium. Due to the first law of thermodynamics, the Law of Conservation of Energy, the following is valid:

$$Q_{\text{introduced}} = Q_{\text{lost}} \tag{7}$$

Assessing a life raft floating at sea, the thermal energy introduced to the system by the participants is to be equal to the thermal energy lost to the surrounding environment, to remain in thermal equilibrium. If the system loses more energy to the environment than what is introduced by the participants, the participants will experience a cooling effect. This effect can be simplified:

$$Q_{\text{produced by participants}} = Q_{\text{lost to sea}} + Q_{\text{lost to air}} + Q_{\text{lost to ventilation}} + Q_{\text{lost to radiation}} \quad (8)$$

The energy produced by the participants will have different paths before reaching the ambient air or the seawater.

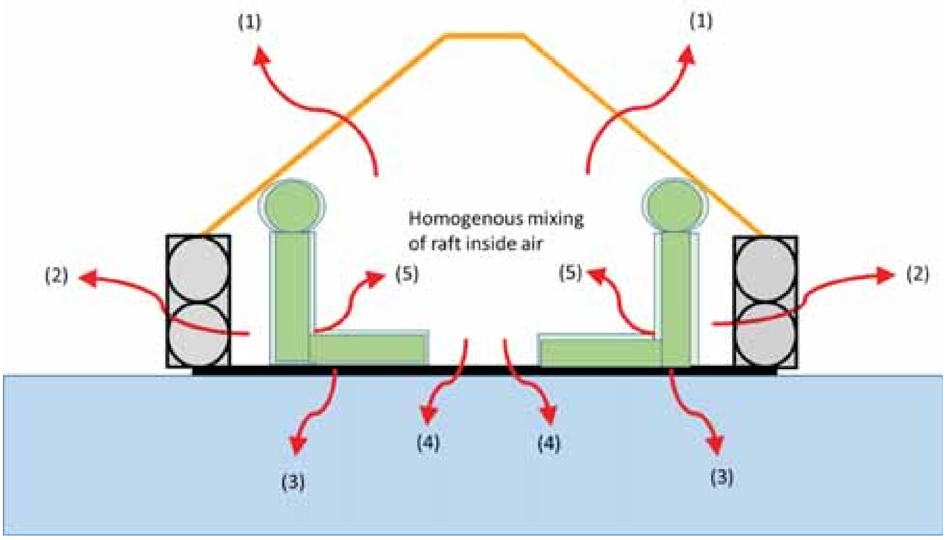


Figure 10 Heat loss mechanisms from life raft (cross section)

6.4.1.1 $Q_{\text{produced by}}$ participants

The energy introduced by the system is equivalent to the cumulative energy produced by the humans inside the raft. At low body temperatures, the body commences muscle activity, to prevent further cooling. This is visible as a cold-induced shivering response.

The energy produced by the participants will be conducted through the PPE and either to the internal air of the life raft, see (5) in Figure 8 Heat loss mechanisms from life raft (cross section) or directly through the bottom of the life raft to the sea, see (3) in Figure 8 Heat loss mechanisms from life raft (cross section).

6.4.1.2 $Q_{\text{lost to sea}}$

The energy lost to the sea is a function of the conductive heat transfer from the bottom and the back sides of the legs of the participants, through the clothes, PPE and raft bottom, into the sea, see (3) in Figure 8 Heat loss mechanisms from life raft (cross section).

Conductive heat transfer also takes place from the inside air of the raft, through the bottom to the sea, see (4) in Figure 8 Heat loss mechanisms from life raft (cross section).

$Q_{\text{lost to air}}$

The energy lost to the ambient air from the participants follows the path described below:

- Conductive heat transfer from the participants, through the clothes and PPE to the inside air of the raft, see (5) in Figure 8 Heat loss mechanisms from life raft (cross section).
- The inside air is assumed to mix due to convective processes, in addition to venting activities, breathing and movement of the raft participants. This is assumed to generate an evenly distributed temperature profile of the raft's inside air.
- The energy in the inside air is further transported through the canopy, see (1) in Figure 8 Heat loss mechanisms from life raft (cross section) and sides (2) in Figure 8 Heat loss mechanisms from life raft (cross section) of the raft, through conductive heat transfer processes.
- The heat conducted through the canopy/sides is transferred to the ambient air, through convective heat transfer processes.

It is important to note that the energy transferred through the canopy and sides, through conductive heat transfer processes, is equal to the cumulative energy loss, through convective processes, to the ambient air and through radiation.

6.4.1.3 $Q_{\text{lost to}}$ radiation

The difference in raft surface temperature and ambient temperature will define the energy lost through radiation. It is assumed that the energy lost to radiation through the bottom of the raft to the sea is negligible.

6.4.1.4 $Q_{\text{lost to ventilation}}$

The energy lost due to ventilation is proportional to the ventilation rate. The required ventilation rate depends on the oxygen consumption induced by the raft participants. In general, 1 liter of oxygen is consumed for every 20.9 kJoules generated (Department of Physics and Astronomy, Georgia State University, u.d.). A person producing 100 Watts will require 360 kJoules per hour. Burning 360 kJoules will require 17.22 liters of oxygen per hr. Given an oxygen consumption of 20.9% in ambient air, this gives an air consumption of 82.4 liter per hour. As the mixing of fresh air with ‘used’ air is not ideal, and venting of air with higher CO2 concentrations is required in a real scenario (Solberg, K.E., Skjærseth, E., Gudmestad, O. T., 2017), a higher ventilation rate is to be expected in a real scenario; ref. Thermal protection and microclimate of SOLAS-approved lifeboats (Mak L. M., Brown, R., Farnworth, B., Kuczora, A., 2010).

6.4.2 Mathematical correlations

The raft can be regarded as an enclosed system exposed to the water and the air.

Due to the first law of thermodynamics, the Law of Conservation of Energy, the following mathematical relationships are valid:

1. The whole system is to be in equilibrium, implying the total energy introduced to the system is equal to the energy lost.

$$Q_{\text{produced by participants}} = Q_{\text{lost to sea through cond.}} + Q_{\text{lost to inside air}}$$

$$= Q_{\text{lost to sea through cond.}} + Q_{\text{lost to sea from inside air}} + Q_{\text{lost to ambient air through cond. canopy}} + Q_{\text{lost to air through cond. sides}} + Q_{\text{lost to ventilation}} + Q_{\text{lost to radiation}} \qquad (9)$$

2. The energy being conducted through the canopy is equal to the energy being transported from the canopy to the ambient air, through convective heat transfer processes.

$$Q_{\text{lost to air through canopy cond.}} = Q_{\text{lost to air through canopy conv.}} \qquad (10)$$

3. The energy being conducted through the sides of the life raft is equal to the energy being transported from the sides of the life raft to the ambient air, through convective heat transfer processes.

$$Q_{\text{lost to air through cond. sides}} = Q_{\text{lost to air through conv. sides}} \qquad (11)$$

The following parameters are known:

- Properties of ambient air
- Properties of seawater
- Properties of insulation barriers:
  - PPE
  - Life raft bottom
  - Life raft sides
  - Life raft canopy
- Temperature, surface area and energy produced by the human body
- Rate of ventilation

There are three unknown parameters important for the calculation of the heat loss. The unknown parameters are:

- T_{internal} air – the temperature of the internal air inside the life raft
- T_{surface} canopy – the surface temperature of the canopy
- $T_{\text{surface side}}$ – the surface temperature of the sides

Solving the above three equations reveals the following relationships:

Based on equation (10)   (10):

$$t_{canopy} = \frac{U_{canopy}}{h+U_{canopy}} * t_{int} + \frac{h}{h+U_{canopy}} * t_{amb} \qquad (12)$$

Based on equation (11):

$$t_{tube} = \frac{U_{tube}}{h+U_{tube}} * t_{int} + \frac{h}{h+U_{tube}} * t_{amb} \qquad (13)$$

Inserting equation (12) and equation (13) (13) into equation (9), and solving for t_{int} reveals the following relationship:

$$t_{int} = \frac{U_{ppe} * A_{ppeAir} * t_{body} - U_{ppe+floor} * A_{ppefloor} * (t_{body} - t_{water}) + U_{floor} * A_{floorExpAir} * t_{water}}{U_{floor} * A_{floorExpAir} + U_{canopy} * A_{canopy} - \frac{U_{canopy}^2 * A_{canopy}}{h + U_{canopy}} + U_{tube} * A_{tube} - \frac{U_{tube}^2 * A_{tube}}{h + U_{tube}} + U_{ppe} * A_{ppeExpAir} + C_{pAir} * \rho * air_{vol} * t_{amb}}$$

$$+ \frac{\frac{U_{canopy} * A_{canopy} * h}{h + U_{canopy}} * t_{amb} + \frac{U_{tube} * A_{tube} * h}{h + U_{tube}} * t_{amb} + C_{pAir} * \rho * air_{vol} * t_{amb}}{U_{floor} * A_{floorExpAir} + U_{canopy} * A_{canopy} - \frac{U_{canopy}^2 * A_{canopy}}{h + U_{canopy}} + U_{tube} * A_{tube} - \frac{U_{tube}^2 * A_{tube}}{h + U_{tube}} + U_{ppe} * A_{ppeAir} + C_{pAir} * \rho * air_{vol} * t_{amb}}$$

(14)

The total energy lost by the life raft is given by the following equation:

$$Q_{total}$$

$$= Q_{cond\ lost\ to\ water} + Q_{conv\ lost\ air\ tubes} + Q_{conv\ lost\ air\ canopy} + Q_{ventilation}$$

$$= U_{ppe+floor} * A_{ppefloor} * (t_{body} - t_{water}) + U_{floor} * A_{floorExpAir} * (t_{int} - t_{water)} +$$

$$h * A_{tube} * (t_{tube} - t_{amb)} + h * A_{canopy} * (t_{canopy} - t_{amb)} + c_p * \rho * q_v * (t_{int} - t_{amb})$$

(15)

Abbreviations:

Abbreviation	**Description**	**Denomination**
U_{ppe}	Heat transfer coefficient personal protective equipment (PPE)	Watt/Kelvin meter^2
U_{floor}	Heat transfer coefficient life raft floor	Watt/Kelvin meter^2
$U_{ppe+floor}$	Heat transfer coefficient personal protective equipment (PPE) and life raft floor	Watt/Kelvin meter^2
U_{canopy}	Heat transfer coefficient life raft canopy	Watt/Kelvin meter^2
U_{tubes}	Heat transfer coefficient life raft tubes	Watt/Kelvin meter^2
A_{ppeAir}	Area of personal protective equipment exposed to air	meter^2
$A_{ppeFloor}$	Area of personal protective equipment exposed to life raft floor	meter^2
$A_{floorExpAir}$	Area of life raft floor exposed to air	meter^2
A_{canopy}	Area canopy	meter^2
A_{tube}	Area tubes	meter^2
h	Convective heat transfer coefficient	Watt/Kelvin meter^2
$Q_{ventilation}$	Energy lost due to ventilation	Watt
$Q_{radiation}$	Energy lost due to radiation	Watt

$Q_{\text{cond lost to water}}$	Heat loss to water through conduction	Watt
$Q_{\text{conv air tubes}}$	Heat loss to air through conductive processes on the air tubes	Watt
$Q_{\text{conv canopy}}$	Heat loss to air through conductive processes on the canopy	Watt
σ	Stefan-Boltzmann Constant = 5.6703 10-8	Watt/Kelvin^4 meter^2
c_p	Specific heat air	Joules/kg Kelvin
ρ	Density of air	kg/m^3
q_v	Air volume flow	m^3/Sec

Figure 11 Abbreviations used in formulas

The above approach takes into account that only parts of the floor are covered by the life raft participants. The area covered is dependent on the number of people on board the life raft. There will be a conductive heat loss from the participants directly through the PPE and through the floor into the sea; see Figure 8. The remaining area of the floor will be exposed to the internal air; a conductive heat loss through the floor is considered for this area.

The heat loss caused by the need for ventilation is dependent on the participants’ oxygen consumption, which again is dependent on the metabolic rate/activity intensity. It is, however, assumed that, from a practical perspective, venting the minimum, replacing only the used oxygen is difficult to achieve. A ventilation rate is defined, which is equivalent to an oxygen consumption induced by a metabolic rate of 150 Watts per person.

6.4.3 Assumptions and simplifications

To be able to model a life raft, several assumptions and simplifications have been made. These assumptions and simplifications will influence the results but are not believed to affect them to a high degree, as the natural variations within a group of people represent the biggest uncertainty:

- There is a high variability within the metabolic rate of a population, during extreme events when the body can produce several hundred Watts (Xu, X., Tikuisis, P., Gonzalez, R., Giesbrecht, G., 2004).
- There is a high variability within a population with regard to physical (and psychological) endurance. This is highly correlated with physical fitness and age.
- The effect of only 430 mm breadth (SOLAS requirement) will not only restrict ability to move limbs and generate heat but also enable conductive heat transfer between the different participants.
- The effect of wet evacuation / water being present inside (on the floor of) the raft is not considered.
- Lack of food/water reduces the ability to carry out activities with a high metabolic rate.

The mathematical methodology described is based on the following assumptions:

- Ideal and homogeneous thermal conditions within the air trapped inside the raft
- No heat lost to sea/water due to water spray
- No accumulation of an insulating ice/snow barrier on the canopy
- Homogenous design of the raft with no major thermal bridges from the inside to the ambient air/water
- Ideal conductive heat transfer takes place through the life raft bottom to the seawater

- Temperature of air at exhalation is defined at 30 degrees Celsius

The above-mentioned mechanisms are expected to represent a larger uncertainty/variability than the uncertainty resulting from the simplification represented in the mathematical modeling.

It can be expected that the model represents a 'best case' compared with a real survival situation. The model only considers the thermal challenges, and none of the additional challenges present when conducting a prolonged stay in a life raft are addressed.

6.4.4 Verification of model

Verification of model results was carried out at the training facilities of Falck Nutec at Nesodden. One of their modules in the survival training program is a stay (about 15 minutes) in a life raft. During one of these stays, the raft and two of the survival suits were fitted with temperature-recording devices. Due to the participants being part of an ongoing course, the measurements were conducted in a way that fitted into the course schedule.

Figure 12 Falck Nutec training facilities at Nesodden, Norway

The following conditions were present:

Parameter	Value

MetOcean parameters	
Wind	Average 2.5 m/s
Ambient air temperature	0.9°C
Seawater temperature	2.9°C
Precipitation	Light snow
Equipment	
Life raft	Viking-Life 20-person life raft, floor not
Survival suits	Hansen Protection helicopter suits
Undergarment	One layer of woolen underwear
Participants	
Gender	Male
Age	20 to 60 years
Number of participants	Test Run 1: 16, Test Run 2: 7

Figure 13 Conditions present during trials

6.4.4.1 Internal air temperature

The air temperature inside the raft was measured at three different levels. Little difference was observed between the three different measurement points, due to mixing processes taking place inside the raft.

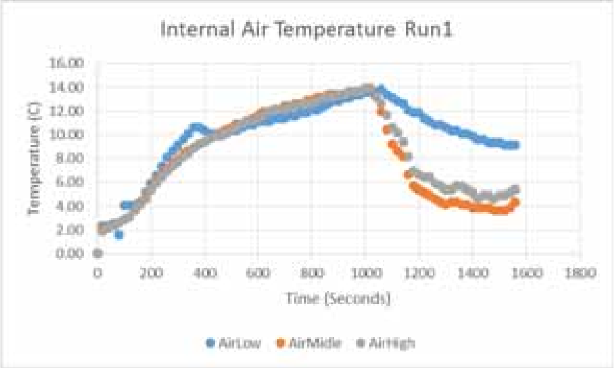


Figure 14 The internal air temperature (measured at different vertical locations) in the life raft, Run1, 16 people on board

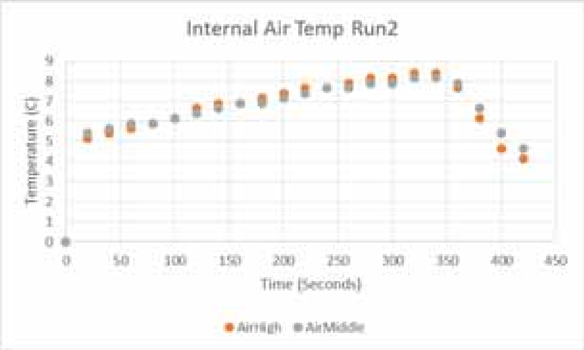


Figure 15 The internal air temperature in the life raft, Run2, 7 people

In Run1, the system had reached a relatively steady state equilibrium after about 1100 seconds. In Run2, the system had stabilized after about 340 seconds. Ideally, there should have been more time allocated to let the system stabilize but, due to the progression of the safety course, the measurements had to be aborted. The temperatures recorded at about 1100 seconds (Run1) and 340 seconds (Test Run 2) into the test were extracted and utilized for further analysis.

6.4.4.2 Canopy – outside surface temperature

The canopy surface temperature was measured by attaching sensors to the outside of the canopy. This proved difficult, due to snow, water and ice, and some sensors were attached by sticking them underneath a reflector strip. See images below for details.

Figure 16 Life raft logging system

Measuring the canopy temperature with an IR thermometer revealed local differences of more than 2 degrees C. This is assumed to originate from several different mechanisms at play:

- Distance from personnel inside life raft to the inside canopy surface
- Uneven temperature distribution inside life raft
- Insulation induced by inflatable canopy beam
- Flapping of canopy, due to people inside touching the canopy and wind-induced movement, reducing and generating movement of the insulating air gap enclosed in the double canopy
- Different degree of stretching of the material, depending on wind and pressure in inflated tubes

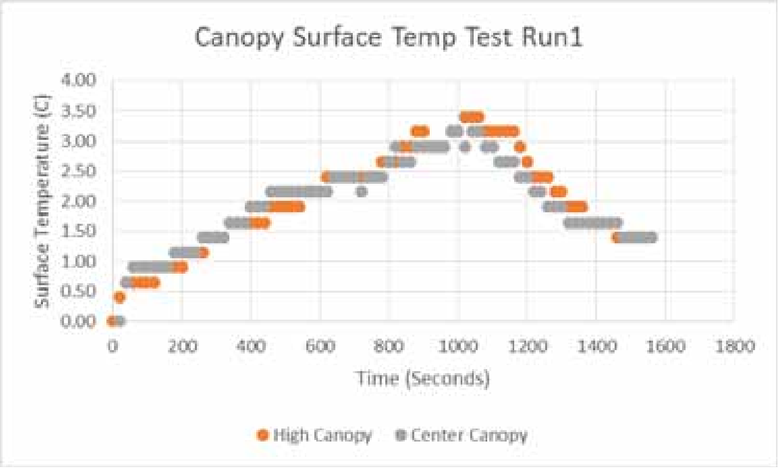


Figure 17 The surface temperature of the life raft canopy Run1

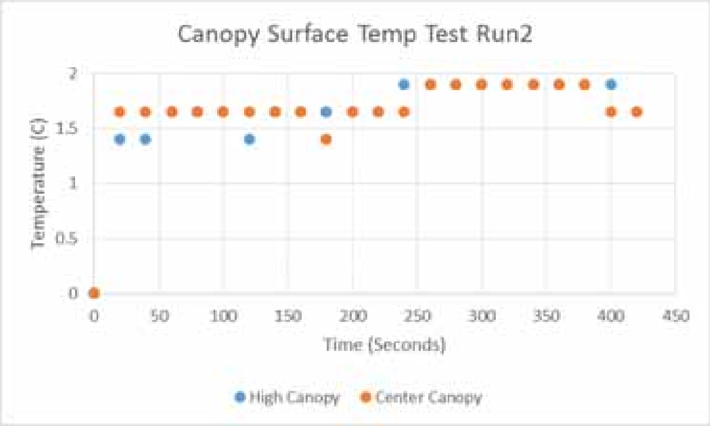


Figure 18 The surface temperature of the life raft canopy Run2

During Run2, the canopy temperature was also measured with an IR thermometer. The measurements revealed the following distributions:

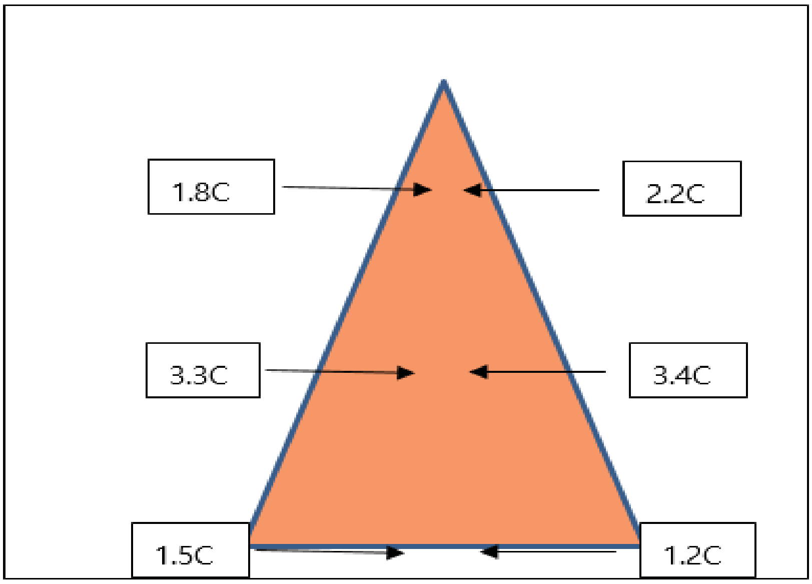


Figure 19 Canopy temperature distribution

It is evident that there are thermal bridges and fluctuations in the surface temperature of the canopy.

In Run1, 3.4 degrees Celsius was assumed to be representative of the canopy's outside surface temperature, while, in Test Run 2, 1.8 degrees Celsius was assumed to be representative of the canopy's outside surface temperature.

6.4.4.3 Tubes – outside surface temperature

The temperature was measured utilizing an IR thermometer. It was evident that being partly submerged, the outside surface temperatures of the tubes were greatly affected by the water temperature. Based on readings from the IR thermometer, 2.2 degrees Celsius was assumed to be the tubes' outside surface temperature in Run1, and 1.9 degrees Celsius was assumed to be the tubes' outside surface temperature in Run2.

6.4.4.4 Survival suit – outside surface temperature

The outside air temperatures of the survival suits were also measured. A sensor was attached to the pocket that was supposed to contain the 'buddy lines'. These pockets are located on the chest of the suit. There were significant variations with regard to the measured temperatures. This was due to the effects of the following parameters:

- Participant movement
- Contact area between the sensor and the suit
- Location of participant (e.g. facing a cold area)
- Amount of air trapped inside survival suit

This is based on the assumption that the participants had a surface area of 1.9 m^2 and a metabolic rate of 130 Watts per person. This harmonizes with the findings in "Assessment of thermal protection of life rafts in passenger vessel abandonment situations" (Mak, L. M., Kuczora, A., DuCharme, M. B., Boone, J., 2008). The thermal resistance values for PPE, including underwear, were calculated.

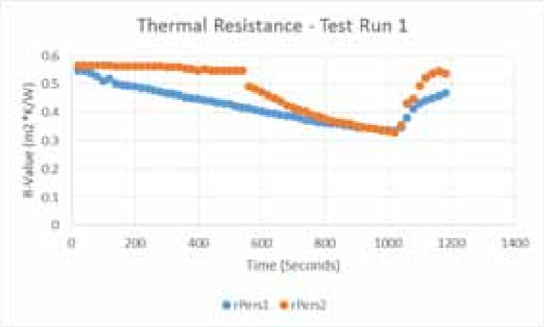


Figure 20 Thermal resistance for underwear and PPE, Run1

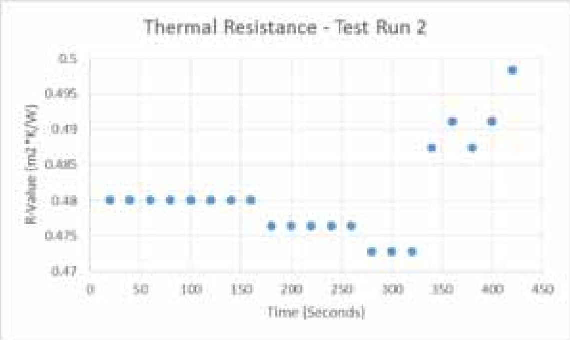


Figure 21 Thermal resistance for underwear and PPE, Run2

The rapid increase/variation in calculated values at the right end of the plots is due to experiment abortion and should be disregarded. Based on the measured parameters, a thermal resistance value of 0.5 m^2Kelvin/Watt was chosen.

6.4.5 Implementation of recorded values in model

The main measured parameters measured on the raft were implemented in the model. The recorded temperature values were used to adjust the model to represent a real scenario.

The following raft dimension parameters were utilized in the calculation:

- Raft external diameter = 3.75 m

- Raft height of canopy = 1.65 m
- Area raft canopy = 20.8 m^2
- Area bottom of raft = 16.9 m^2
- Surface area of tubes = 11.43 m^2

The following thermal resistance values were utilized in the calculations:

- Thermal resistance PPE (incl underwear) = 0.5 m^2 Kelvin/Watt
- Thermal resistance contact area PPE (incl underwear) and bottom when sitting (compressing insulation layer) = 0.35 m^2 Kelvin/Watt
- Thermal resistance raft bottom = 0.15 m^2 Kelvin/Watt
- Thermal resistance raft tube = 0.68 m^2 Kelvin/Watt
- Thermal resistance raft canopy = 0.6 m^2 Kelvin/Watt

The following metocean parameters were utilized in the calculations:

- Ambient air temperature = 273.9 Kelvin
- Ambient water temperature = 275.9 Kelvin
- Windspeed = 2.5 meter/second

Implementation of the above values in the model revealed the following results:

	Measured Values	**Modeled Values**
Run2 – 7 people on		
Internal air temp (^{o}C)	8.40	7.47
tempTube (^{o}C)	1.90	2.22
tempCanopy (^{o}C)	1.80	2.35
qTotal/Person (Watt)	121.37	125.57
Run1 – 16 people on		
Internal air temp (^{o}C)	13.90	14.22
tempTube (^{o}C)	2.20	3.57
tempCanopy (^{o}C)	3.40	3.85
qTotal/Person (Watt)	100.42	106.75

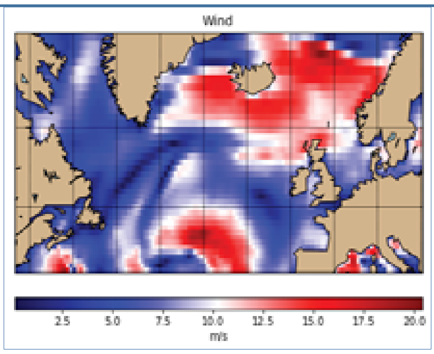
Figure 22 Measured values vs. modeled values

As seen above, there is a margin of error of 4.7% for Run1 and a margin of error of 3.5% for Run2 with regard to the total energy loss from the life raft. This figure does not take into account the potential margin of error associated with the conductive heat loss from the participants, through the bottom of the life raft to the sea or the heat loss arising as a result of ventilation (ventilation rate = 0).

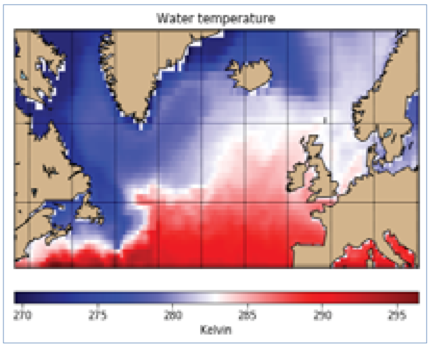
6.4.6 Results – heat loss on board a survival craft

Utilizing the above-mentioned model, the results have been plotted for an arbitrary date (01.01.2018) in the North Atlantic. The metocean data was downloaded (European Centre for Medium-Range Weather Forecasts, 2012) and plotted in a GIS format. The model results reveal that obtaining adequate cumulative thermal protection, reducing the heat loss per person to a significant degree, is possible, if the right measures are implemented, e.g. the importance of floor insulation to reduce the heat loss to the sea. This harmonizes with the results found in “Effect of wetness and floor insulation on thermal responses during cold exposure in a life raft” (DuCharme, M., Everly, K. A., Basset, F. A., Mackinnon, S. N., n.d.)

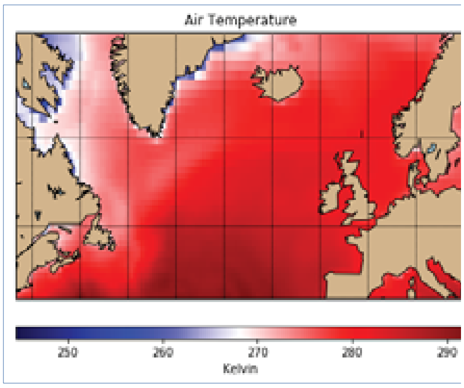
Each person inside the raft is assumed to wear normal jacket/shirt under the required SOLAS equipment.



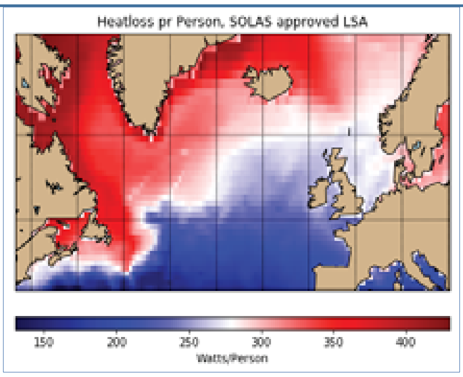
Wind speed at 10 meters



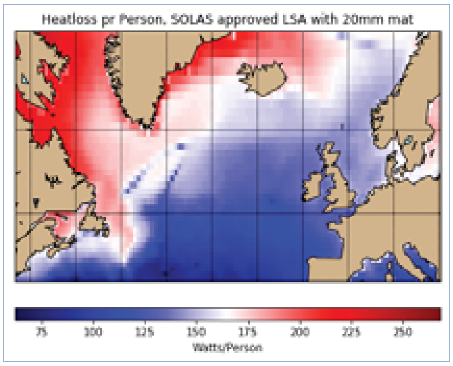
Seawater surface temperature



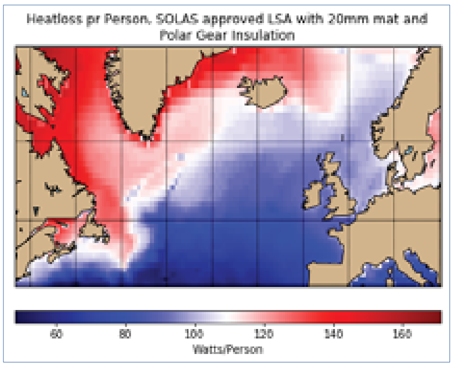
Ambient air temperature



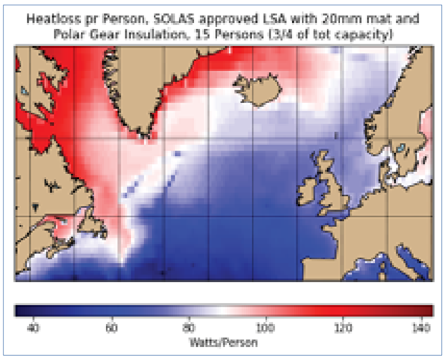
The individuals are wearing normal clothes under standard LSA equipment. The life raft is filled to 50% capacity.



The individuals are seated on a 20-mm closed foam insulation mat. The life raft is filled to 50% capacity.



The individuals are seated on a 20-mm closed foam insulation mat and are wearing polar gear insulation layers (4 clo). The life raft is filled to 50% capacity.



The individuals are seated on a 20-mm closed foam insulation mat and are wearing polar gear insulation layers (4 clo). The life raft is filled to 75% capacity.

6.4.7 Discussion – heat loss on board a survival craft

The cumulative energy produced by the participants in the raft is to compensate for the energy lost. The energy produced by the human body through metabolic processes is a complex study and will vary with age, weight, body surface area, fitness and physical activity level. The following table indicates general metabolic rates for different activities.

Activity Description	**W/m^2**	**W/person** (surface area 1.8 m^2)
Sleeping	46	83
Standing	70	126
Walking (2km/hour, level ground)	110	198
Walking (5km/hour, level ground)	200	360
Swimming	348	624
Running (15km/hour)	550	990

Figure 24 Metabolic rate for different levels of activities (Engineering ToolBox , 2004)

According to the requirements defined in the IMO Polar Code, you are to be able to survive for a minimum of five days (or until being rescued). Based on the “Activity Description” in the figure above, it is evident that the human body is able to produce up to 1000 Watts, but few people are able to produce this for an extended period of time. For a time-span of five days, it is not likely that a person is able to produce more than about 150 Watts on average.

It is important to note that there are many sources of uncertainty associated with the calculation. However, there is also a large natural variation among the participants in a survival scenario with regard to body weight, body surface area, metabolism, life raft ergonomics and movement. As long as there are no definitions, in respect of to the human abilities and survival strategies present in a real-time survival scenario, the uncertainty associated with the above-mentioned parameters is believed to outweigh the uncertainty associated with the model.

6.4.8 Conclusions – heat loss on board a survival craft

Calculating heat loss per person in a real-time survival scenario is dependent on many uncontrollable variables. Isolating and assessing these variables individually is a challenging task. Obtaining full-scale data describing the cumulative effect of these variables on survival rates is extremely challenging.

It is clear that a theoretical approach can reveal the significance of simple measures with regard to reduction of the heat loss per person. Utilizing a theoretical approach when optimizing a survival packet will help to gain an understanding of the impact caused by the different types of equipment or different combinations of equipment packages utilized to produce a cumulative insulation effect.

6.5 Time to rescue

Providing adequate SAR facilities dimensioned to handle the large passenger vessels in the Arctic is challenging from an economic, practical and logistical perspective. Large distances, lack of infrastructure and harsh metocean conditions represents risks that must be handled.

Time to rescue is a critical factor for surviving a marine incident. The IMO Polar Code (International Maritime Organization, Shipping in polar waters, 2019) utilizes a risk based approach and states that the vessel operators is to define the time to rescue and never use less than 5 days in their risk assessments. Based on experience from the classification society DNV GL, utilization of the minimum requirement of 5 days is the current industry standard when conducting risk assessments.

As the SAR resources is a national issue, there are no international requirements defining the adequacy of the resources in different geographical areas. Each geographical area must be evaluated on a case-to-case basis. The remoteness and lack of resources present within the IMO Polar Code area imposes a significant challenge.

The time required for rescue is highly dependent on the number of persons to be rescued, the number and type of evacuation platforms and the distance each evacuation platform must travel. In addition, the metocean conditions play a significant role when determining the efficiency of the operation.

For more information on the TTR (time to rescue) for different scenarios, utilizing different PTS (paths to survival) and assessment of the factors that influence the outcome, see Enclosed Paper Number 10 Time to rescue for different paths to survival.

7 Discussion

Most marine incidents follow the Anna Karenina principle (Presenso, 2018): all incidents with a successful outcome have several common denominators that mitigate every possible deficiency, while all incidents with tragic outcomes fail in their own way.

Based on the work conducted, it is evident that there are many mechanisms and variables determining the probability of survival. These include elements like:

- Metocean conditions
- Average human metabolic rate to be expected for a longer duration (e.g. five days)
- Level of relevant experience and knowledge among officers, crew and passengers

The combination of the above-mentioned parameters will determine the functionality that is to be provided by the lifesaving appliances. The total survival package will have to mitigate all the different risks to be encountered and ultimately define the total probability of survival.

For some of the key figures, the IMO Polar Code (International Maritime Organization, 2015) has explicitly defined methodologies on how to calculate the relevant values; e.g., for temperatures, a LMDLT (Lowest Mean Daily Low Temperature) for the area and time of operation is to be utilized. The methodology for calculation of the LMDLT is explicitly described in the IMO Polar Code (International Maritime Organization, 2015).

Other key figures are based on the individual operator’s judgment. This opens the door for large variations, and it has been experienced that the uncertainty/lack of scientific knowledge/data associated with parameters is used as an argument to minimize costs.

Based on the impressions from multiple discussions at IMO London, with vessel operators and SAR personnel, it is evident that there is a misconception concerning what is to be regarded as uncertainty and what is to be regarded as natural variability within a population. An example of this is the average metabolic rate that is to be expected among passengers on a cruise ship. There is currently no industry consensus around the methodology required for defining the figure, *minimum metabolic rate*, to be utilized in a survival scenario. This figure is highly important for defining the insulation required to reduce the heat loss to acceptable levels, further reducing the probability of the development of hypothermia. Unfit, elderly people are not able to achieve a high metabolic rate compared with fit, young people. As a result, vessels with unfit, elderly people should carry additional insulation layers, to compensate for the heat loss, if they are to strictly comply with the IMO Polar Code requirement of a survival time of a minimum of five days.

The uncertainty associated with these numbers is relatively low; however, there is a large natural variation among the passengers on a cruise ship – you will have some elderly people that are unfit, and you will have fit young people. If an operator was serious about saving lives in the event of a disaster, the lifesaving appliances would have to be dimensioned for the individuals that are able to achieve the lowest metabolic rate. The uncertainty associated with this number would be relatively low. However, dimensioning the insulation abilities for those individuals with the lowest metabolic rate would require extensive insulation, which would consume space and would also represent a significant cost.

In all the work that has been conducted, it has become evident that adequate training is essential for the micro-management of all the small details that are required to increase the probability of survival. Maintaining survival for a minimum of five days puts a completely different strain on the crew than if the survival period was to be only hours. Enabling survival for a minimum of five days will require training that covers topics ranging from medicine, psychology, cold climate effects, nutrition, leadership and site-specific knowledge (e.g. predominant weather to be expected, options for communication, possible onshore landing sites and ice regime).

Currently, this forms only a small part of the training required to obtain an IMO Polar Code certificate. Based on the experience from the SARex exercises, further attention should be directed this way, as proper training has proved to be essential for any survival situation that is to be extended beyond a few hours, disregarding the available equipment.

Survival can involve pushing the human body to its maximum physical and mental capabilities. The ethical guidelines for scientific work state that no lives are to be lost in the process. It is therefore difficult to measure and quantify the extreme conditions that can arise in a real situation. It is also difficult to simulate all the different variabilities between different types of operations/vessels. This includes variations within the following parameters:

- Time of year
- Area of operation
- Metocean conditions
- Number of passengers
- Physical/mental state of passengers
- Number of crew
- Physical/mental state of crew
- Available equipment
- Training
- Experience
- Remoteness
    - Available SAR resources
    - Available vessels of convenience
    - Available communication

    - Reliable weather predictions
    - Reliable bathymetric charts

Therefore, the results from this work do not represent a real scenario but indicate the different mechanisms at play, their non-linear interrelations and possible risk mitigation measures. This knowledge is vital not only to achieve a regulatory development that is efficient and verifiable but also for designing solutions to a goal-based regulatory framework.

7.1 Answer to research question

In this thesis, the aim was to identify the key mechanisms determining the probability of survival following a marine incident in cold climate. The thesis was also to identify relevant mitigation measures.

The IMO Polar Code specifically addresses a minimum survival time of five days, which was the basis for our work.

The task proved to be more complicated than anticipated, due to the following:

- As the IMO Polar Code is a relatively recent goal-based set of requirements, no consensus-based industry standard/best practice was identified.
- The non-linearities and interrelations between the mechanisms at play make the issue highly cross-disciplinary, taking into account subjects like:
    - Governing metocean conditions
    - Material properties, e.g. the cumulative level of insulation provided by the survival craft and PPE
    - Equipment functionality, e.g. knowledge required to utilize equipment or survival craft sea-keeping abilities
    - Human physiology, e.g. expected human metabolic rates
    - Human psychology, e.g. mental robustness

    - Leadership, e.g. the combined effect of experience, level of training and inter-personal abilities
    - Relevant training
    - Experience, e.g. experience from similar situations
- Practical limitations caused by the marine industry, e.g. equipment has to be stored on board a vessel
- Commercial aspects, e.g. costs and maintenance intervals
- Regulatory aspects, solutions have to be verifiable to enable regulators to issue letters of compliance/certificates

Due to the challenges described above, a holistic approach based on a risk methodology was chosen.

To increase the probability of survival, risk mitigation measures must be implemented. Due to the variety of mechanisms at play, each case will require individual adaptions. However, the following challenges have to be mitigated in prioritized order:

1. Access to adequate amounts of fresh air.
2. Insulation, to reduce the heat loss to an average metabolic rate that can be endured for a minimum of five days.
3. Adequate amounts of water, to enable rational thinking and maintain an adequate metabolic rate.
4. Leadership, to ensure proper use of equipment and mitigate psychological breakdowns.
5. Adequate amounts of food, to prevent the development of fatigue.

Based on the above, it is evident that clear recommendations with regard to priorities and methodology are important for the development of a sustainable survival package. Further recommendations will have to be determined on a case-by-case basis, based on the above parameters.

8 Conclusion

Surviving a marine incident involves two distinct actions:

1. Surviving until being evacuated from the scene of the accident.
2. Obtaining the right assistance/rescue.

There are additional risks associated with survival after a marine incident within the IMO Polar Code area. These challenges can be structured into the following categories.

8.1 Surviving until being evacuated

The following additional challenges are to be expected:

- Environmental loads:
  - Low temperature – rapid development of hypothermia due to large heat loss
  - Low temperature – lack of functionality of extremities, leading to lack of ability to conduct tasks essential for survival; e.g., ability to use fingers is essential for opening/closing of survival suits
  - Sea ice – exerts excessive forces on survival craft
  - Icing on structures, e.g. reducing stability
  - Icing on components, e.g. reducing functionality
- Prolonged time to rescue (minimum five days) will affect the following areas:
  - Increased need for appropriate rations, to prevent the development of dehydration and fatigue
  - Increased need for space, to enable movement
  - Improved ergonomics, to reduce the development of pain caused by static strain on the body
  - Increased need for psycho-social activities, to prevent the development of fatigue

  - Increased battery/fuel capacity
  - Improved leadership, to manage the situation

Based on the findings from the SARex exercises, regular SOLAS equipment does not provide the functionality required for survival for a minimum of five days.

8.2 Obtaining the right assistance/rescue

The most appropriate means of evacuating the casualties from the survival craft/scene of the incident to a safe location will depend on factors like:

- Number of persons to be rescued
- Condition of persons to be rescued
- Metocean conditions
- Available SAR resources
- Distance from nearest infrastructure/medical facilities

However, in most cases, initially all available SAR resources will be deployed to the area until adequate situational awareness is obtained.

Based on the findings from the SARex exercises, the following challenges could arise when the operation is taking place within the IMO Polar Code area:

- Reduced availability of SAR resources, resulting in:
  - Long response time
  - Inadequate functionality of deployed SAR resources
  - Inadequate capacity among the deployed SAR resources
- Reduced capacities at the onshore casualty reception facilities
- Lack of ability to conduct medical treatment in vicinity of the scene of the incident

- Lack of available medication potentially essential for survivors
- Lack of communication abilities, reducing the common situational awareness, resulting in reduced efficiency and increased logistical challenges

The impact of the risks mentioned above increases exponentially with the number of survivors. The rationale is:

1. The more survivors to be rescued, the longer the TTR, due to the excessive time utilized in the evacuation process.
2. An increased TTR will result in reduced functionality of the survivors.
3. Reduced functionality among the survivors will result in an increased probability of survivors requiring assistance in the process of evacuation or medical treatment immediately after being evacuated.
4. Supplying resources to assist in the process of evacuation or supplying medical treatment will exert a large strain on the SAR organization, e.g. transportation of a person on a stretcher will require a minimum of four people, and medical treatment of a heavily injured person will require as many as ten people.
5. When the strain on the SAR organization is beyond its limitations, providing adequate assistance is no longer possible, and lives will be lost.

Based on the above, it is evident that, due to the feedback mechanism, even a small reduction in the functionality of the survivors will result in a substantially higher strain on the SAR organization. In a polar environment, the level of human vulnerability to the environment is high, and the SAR organization is limited. The effects of the above-mentioned mechanisms are substantially more dominant in an incident involving many people.

The above principles indicate that the higher the number of potential survivors, the higher the level of functionality required on an individual survivor level, to enable efficient evacuation and minimize the resources tied up in medical treatment. This is a principle essential for providing a sustainable SAR operation with the limited available resources.

8.3 Cooperation across different sectors

One of the aims of SARex was to bring all parts of the marine industry, SAR providers and academia to the same table. Many of the SARex participants expressed gratitude because it was the first time that they had experienced the presence of all parties relevant for providing survival after a marine incident.

The marine industry's legal obligation is to get all passengers safely into the survival craft and, within the area defined by the IMO Polar Code, sustain survival for a minimum of five days or until the expected time of rescue. The regulatory framework describing the process is mainly defined in the SOLAS Convention (International Maritime Organization, 2004) and in the IMO Polar Code (International Maritime Organization, 2015). The cost associated with mitigation measures is to be covered by the vessel operator.

The rescue, including SAR personnel, casualty reception facilities, medical treatment and rescue coordination is a national responsibility, and the cost is covered by the respective nations.

There are limited legal or formal connections between the obligations held by the marine industry and the rescue organizations. As a result, limited coordination and cooperation among the relevant parties has been observed, despite the fact that they both are highly interrelated and have the same common goal – ensuring no lives are to be lost.

Based on the findings from this work, it is evident that mutual understanding is beneficial for all parties involved, and, hopefully, in the future, we will see an increase in activities involving industry, national SAR resources and academia.

8.4 IMO Interim guidelines on life-saving appliances and arrangements for ships operating in Polar waters

In the summer of 2019 IMO approved an interim guideline for vessels operating in polar waters (International Maritime Organization, 2019a). The aim is to provide guidelines for compliance with section 8.3 of part I-A in the IMO Polar Code (International Maritime Organization, Shipping in polar waters, 2019).

Many of the issues identified in the work conducted in association with development of this thesis have been communicated to IMO during the process. The following issues addressed in this thesis have been included in the guideline:

Issue addressed in thesis	Guideline recommendation
Ability to use hands	Gloves are not to be an integrated part of the survival suit
Adequate food rations to prevent development of fatigue	Food rations providing a minimum of 5,000 kJ (1,195 kcal) per person per day
Adequate water rations to prevent development of fatigue	At least 2 liters of fresh water per person per day
Adequate thermal protection (also when wet) to prevent	Protective clothing of a material with thermal properties taking into account performance of the material when wet and type of survival craft, including head

development of hypothermia	protection, neck and face protection, gloves/mittens, socks, boots, long underpants and sweaters
Adequate thermal protection (also when wet) to prevent development of hypothermia	All cold surfaces should be insulated, in particular the surfaces in direct contact with the persons, e.g. seats.
Adequate thermal protection (also when wet) to prevent development of hypothermia	In order to avoid exposure to cold air, toilet equipment should be provided inside the survival craft
Adequate thermal protection (also when wet) to prevent development of hypothermia	Life rafts should be provided with inflatable floors or equivalent and all persons should be wearing insulated immersion suits instead of thermal protective aids.
Adequate thermal protection (also when wet) to prevent development of hypothermia	Shelters should have insulated floor or other means to minimize heat transfer to the surface.
Adequate thermal protection (also when wet) to prevent development of hypothermia	Installed heating systems, if provided, and their power sources should be capable of operation during the maximum expected time of rescue.
Holistic approach to estimation of heat loss	The combination of a chosen type of shelter, type of personal thermal protection and other mitigating means should provide a habitable environment on ice or land, while adequately protecting against cold, wind and sun
Ability to move in survival craft to prevent sever pain and blood cloth	The seating capacity of each survival craft should be adjusted taking into account Polar clothing, additional equipment including all persons carrying

	their intended personal survival equipment and space for occupants to stand and move in turns
Ability to move in survival craft to prevent sever pain and blood cloth	Survival craft should be fitted with handholds or handhold lines to safeguard persons who are standing upright or moving inside the craft in a seaway
Ability to move in survival craft to prevent sever pain and blood cloth	Each seat in a lifeboat should be provided with a backrest
Ability to communicate inside survival craft	Effective means of communicating important messages from the person in charge of the survival craft, unless the Administration considers the survival craft small enough to ensure that all important messages can be heard by all persons on board, taking into account the noise level caused by the lifeboat engine, harsh weather, etc.
Adequate amount of fresh air to prevent buildup of CO_2	Survival craft should provide a habitable environment for all persons on board that prevent exposure to a long-term CO_2 concentration of more than 5,000 ppm for the maximum expected time of rescue. The ventilation should be considered in context with heating requirements to achieve a habitable temperature in the survival craft.
Adequate amount of fresh air to prevent buildup of CO_2	Entrances, hatches and means of ventilation should be designed and equipped in a way that they can be operated during icing condition to allow mitigation of ice accretion and remove the accumulated ice.
Ability to keep proper lookout	Means should be provided to avoid icing or dew on the windows of the lifeboat

	steering position, in order to maintain a proper lookout
	In order to avoid exposure to cold air, toilet equipment should be provided inside the survival craft
Ability to handle the equipment using only man power	The container for group survival equipment when fully loaded should have a size, shape and mass that enables it to be towed through icy water, and also allows two crew members to pull it out the water and tow it on ice or on land.

9 Philosophical considerations on the way forward

An engineering approach to a problem usually involves breaking the problem down into smaller and smaller pieces until they are managed, utilizing traditional engineering methodologies. However, if the maritime industry and its interrelationship with society is to be assessed from an overarching perspective, there is a profound difference. The principal question is: Who is to determine when an operation meets a risk acceptance criterion, the residual risk is negligible, and the operation is to be regarded as ‘safe’?

If a safe operation and essential equipment are to be assessed from the bottom of the regulatory hierarchy, beginning with the sub-suppliers, they tell us that they supply whatever equipment is requested by their customers, the vessel owners/operators. Further, the vessel owners/operators state that they obtain whatever equipment and knowledge is required by the class. The mandate of the ship classification societies is to interpret the different flag state rules and, being an ‘objective’ third party, they have limited opinions of their own. Lastly, the flag states refer to the IMO and try to avoid having additional and complementary national requirements. The IMO is consensus-based and will require global consensus, across continents, religions, cultures and national economic interests, to get regulations in place.

Every one of the above-mentioned entities has the possibility to increase safety levels beyond the current standard. However, this is rarely observed. Except for the flag states, all of the entities are organized in the free global market as a variety of corporate organizations. The main aim of a company is to maximize profit. This is typically done by increasing income and keeping costs to a minimum. Maintaining a regulatory regime that keeps the cost low makes the industry competitive. As the marine industry creates a significant amount of economic profit and jobs on a national level, the flag states are also highly influenced by the economic aspects of the industry.

A result of the above is that the marine industry and its interrelationship with society can be regarded as an independent organism that is mainly driven by profit generation. The only way to control the organism is by ‘feeding the beast’. Every day, the organism is fed by individual consumers fueling money into the system, by purchasing goods that need to be shipped, by purchasing cruises to remote destinations and by facilitating competitive onshore logistics operations that enable the organism to operate. The end-customers however have the power to alter the industry by changing their consumption behavior.

“Power to the people” has been a slogan used since the 1960s, and the rise of democracy has been a trend over the last century (Oxford, 2019). Democracy is based on the assumption that a benefit for the individual is also a benefit for society. The same mechanism is present in the free economic market, where the consumer determines the availability and prices of the different services. These systems have proved to function well in a homogenous population, on a relatively small scale.

As a system increases in size, e.g. the marine industry is highly international with a global footprint, it has proved difficult to turn large-scale trends with a diversified consumer base. This is especially true when dealing with implications that do not directly impact homogenously on all consumers.

Several large challenges loom just below the horizon, e.g. implications of climate change, pollution and global population growth. A major polar marine accident is only a small shadow compared to the challenges mentioned. However, the governing mechanisms are much the same – without a change in global public opinion, no major increases in safety levels will occur.

The marine industry has proved to be acting retroactively, e.g. the grounding of Exxon Valdez resulted in OPA90, the incidents involving the Herald of Free Enterprise and Estonia resulted in the ISM (International Safety Management) Code. The development and implementation of the IMO Polar Code is an example of the contrary and is, by many within the industry, met with skepticism.

Based on history, public opinion is not likely to change until a major event occurs. In the meantime, while we wait for the ‘perfect storm’, the symbiosis between society and industry will be governed through the principles of “*panem et circenses*” (bread and circuses), as defined by the Roman poet, Juvenal (Brantlinger, 1983), where public approval is obtained by the fulfillment of immediate needs and requirements.

10 Epilog

Deficiencies in a vessels SOLAS equipment (International Maritime Organization, 2004) will cause incompliance with the governing rules and regulations. Such a vessel would be detained and prohibited from leaving port as the functionality of the safety equipment would be regarded as not adequate to provide the functionality required for survival in the event of an incident involving the vessel.

Bad weather will also reduce the functionality of the safety equipment. A relatively high significant wave height will prohibit launching of the lifeboats/life rafts and evacuation of the vessel in distress would not be possible.

A vessel with compliant SOLAS equipment would not be restricted from leaving port, despite a valid weather forecast defining conditions where the functionality of the safety equipment is severely reduced. In this event, the vessel operators purposely put the vessel in a position where they should know that the safety is compromised.

This paradox imposed on the marine industry is relatively recent. In previous times the vessels traveled slowly, and the weather predictions were unreliable or unavailable. In more recent times the accuracy and availability of weather forecasts has improved significantly, and most vessels can avoid bad weather, if prioritized.

For vessels operating on the high seas, avoidance of bad weather is at times difficult. However, most cruise/passenger vessels operate in in coastal waters for a larger part of the time. Avoidance of situations where the functionality of the safety equipment is significantly reduced is perfectly possible with the current technology. This will require prioritizing safety and a willingness to bear the cost associated with the implications of the mitigation measures.

Slogans like “Never compromise on safety” is frequently observed in the marine industry. However, as the industry accepts the risks associated with lack of functionality of safety equipment associated with bad weather, safety is compromised every day, in all parts of the world. Operating with risk acceptance criteria’s that compromise on safety is not necessarily a bad thing – a human life has a price. It is, however, important that this fact is accepted and communicated to relevant parties; including the passenger who puts his/her life in the hands of the vessel operator.

11 Further work

The increase in activity in the polar regions is not only connected with a reduction in sea ice cover. The combination of market desires and new technology is providing the industry with the necessary motivation to venture into these new areas. Much of this new technology is not directly aimed at use in the cold climate regions. Adaption of the current newborn technology to reliably function in the polar regions will be a large part of future research and development efforts.

It is believed that the following trends will shape future development:

- Improved communication solutions
- Development and implementation of sensor technology according to stakeholders' needs
- Real-time processing and access to big data analysis (addressing internal issues on a vessel and external issues, e.g. local growler concentration)
- Implementation of environmental impact reduction measures
- Improved understanding of the governing environmental/safety regime, enabling regulators to adapt/develop regulations that are fit for purpose.

If oil and gas exploration is to be commenced in the High North, this will initiate a variety of research activities. Not only is sea ice cover important, but both oil price and distance to the markets are vital parameters that currently limit this activity.

Currently, there are no foreseen paradigm shifts looming on the horizon, and the development is expected to mainly be market-driven. However, as the activity increases, incidents will occur. As the risks and costs associated with marine incidents, including the cost associated with salvage operations, become publicly visible, both industry and national requirements are expected to be further developed, to ensure marine operations are kept within a more conservative risk-acceptancy criteria.

The Arctic is geopolitically interesting and is expected to remain so in the near future. A possible increase in military activity will fuel further development of new technology that eventually will reach the commercial markets. This includes topics like utilization of drones and improved spatial data.

From a marine perspective, there are still issues that will require in-depth studies to obtain the information required for sustainable marine operations. These include topics like:

- Recognition that Polar knowledge is essential, among both regulators and operators, for the development of fit-for-purpose regulatory regimes and to conduct safe marine operations in a Polar environment.
- Adequacy of training, as identified in the IMO Polar Code.
- The cross-discipline work required to develop a mutual understanding of the issue, “time to rescue”.
- Identification of the implications that remoteness/lack of resources/onshore infrastructure have on time to rescue/the outcome of a marine incident, in addition to salvage operations.
- Development of prescriptive industry standards/methodologies for lifesaving appliances that comply with the requirements defined in the IMO Polar Code.

12 Bibliography

(All Internet links accessed on 01.09.2019)

4hinitiative. (n.d.). *hydration-science*. Retrieved from https://www.h4hinitiative.com/hydration-science/hydration-lab/water-and-hydration-physiological-basis-adults/body-water-balance

Andreassen, N., Borch, O. J., Ikonen, E. S. (2018). *Managerial Roles and Structuring Mechanisms within Arctic Maritime Emergency Response.* The Arctic Yearbook.

Bercha, F. G. (2006). Arctic Escape, Evacuation, and Rescue - Past, Present, and Future. *International Conference and Exhibition on Performance of Ships and Structures in Ice.* Banff, Canada: ICETECH 2006.

Bercha, F. G. (2007). Recent Developments in Arctic EER. *Proceedings of the 19th International Conference on Port and Ocean Engineering under Arctic Conditions.* Dalian, China: POAC-2007.

Bercha, F. G. (2010). Arctic EER Today. *Proceedings of the 9th International Conference and Exhibition on Performance of Ships and Structures in Ice.* Anchorage, Alaska, USA: ICETECH 2010.

Boileau, R., Mak, L., DuCharme, M. B., Cheung, S. (2010). Thermal requirements for surviving a mass rescue operation in the Arctic - Project update. *International Conference & Exhibition on Performance of ships and structures in ice (ICETECH2010).* Anchorage: ICETECH.

Borch, O. J., et al. (2016). *Maritime activity in the High North - current and estimated level up to 2025. MARPART Project report 1.* Bodø: Nord Universitet.

Brantlinger, P. (1983). *Bread and Circuses: Theories of Mass Culture as Social Decay.* New York, USA: Cornell University Press.

Brown, R. P., Gatehouse, E. G., Reynolds, A. (2008). Design of an ice strengthened lifeboat . *8th International Conference & Exhibition on performance of ships and structures in ice (ICETECH).* Banff, Canada: ICETECH.

Brunvoll, R. (2015). *MASTERPLAN Svalbard mot 2025.* Sysselmannen Svalbard/MIMIR AS. Retrieved from http://www.sysselmannen.no/Documents/Svalbard_Miljovernfond_dok/Prosjekter/Rapporter/2015/14-%2020%20Masterplan%20Svalbard%20mot%202025.pdf

Department of Physics and Astronomy, Georgia State University. (n.d.). *Oxygen required for metabolism.* Retrieved from Hyperphysics: http://hyperphysics.phy-astr.gsu.edu/hbase/Biology/metab.html

Det norske Veritas. (2009). *DNV-OS-E406 , Design of free fall lifeboats.* Høvik: Det norske Veritas. Retrieved from https://rules.dnvgl.com/docs/pdf/DNV/codes/docs/2009-04/OS-E406.pdf

DNV GL. (2015). *DNVGL-OS-A201, Winterization for cold climate operations.* Høvik: DNV GL.

DuCharme, M. E. (2007). Effect of Wetness and Floor Insulation on the Thermal Responses During Cold Exposure in a Life Raft. *In Proceedings of 12 International Conference on Environmental Ergonomics, Piran Slovenia.*

DuCharme, M., Everly, K. A., Basset, F. A., Mackinnon, S. N. (n.d.). *Effect of wetness and floor insulation on thermal responses during cold exposure in a life raft.* Quebec: Defence R&D Canada.

Engineering ToolBox . (2004). *Met - Metabolic Rate*. Retrieved from Engineering ToolBox : https://www.engineeringtoolbox.com/met-metabolic-rate-d_733.html

European Centre for Medium-Range Weather Forecasts. (2012, Monthly update). *ERA-Interim Project, Single Parameter 6-Hourly Surface Analysis and Surface Forecast Time Series.* Retrieved from Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory: https://doi.org/10.5065/D64747WN

Gudmestad, O. T., Solberg, K. E. (2018). *SARex3: Evacuation to shore, survival and rescue.* Stavanger: University of Stavanger. Retrieved from https://uis.brage.unit.no/uis-xmlui/handle/11250/2578301

Gudmestad, O. T., Solberg, K. E. (2019). Findings from two Arctic search and rescue exercises North of Spitzbergen. *Polar Geography*.

International Maritime Organization. (2004). *SOLAS - International Convention for the Safety of Life at Sea.* London: International Maritime Organization. Retrieved from http://library.arcticportal.org/1696/1/SOLAS_consolidated_edition2004.pdf

International Maritime Organization. (2015). *IMO Polar Code - International Code for Ships Operating in Polar Waters.* London: International Maritime Organization. Retrieved from http://library.arcticportal.org/1908/1/POLAR%20CODE%20TEXT%20AS%20ADOPTED.pdf

International Maritime Organization. (2017). *Life-Saving Appliances, Including LSA Code, 2017 Edition.* London: International Maritime Organization.

International Maritime Organization. (2019a). *Interim guidelines on life-saving appliances and arrangements for ships operating in Polar waters.* London: International Maritime Organization.

International Maritime Organization. (2019b). *IAMSAR manual.* London: IMO Publishing.

International Maritime Organization, I. (2019). *Shipping in polar waters*. Retrieved from http://www.imo.org/en/mediacentre/hottopics/polar/pages/default.aspx

International Organization for Standardization. (2015). *ISO 19901-1:2015, Petroleum and natural gas industries-Specific requirements for offshore structures-Part 1: Metocean design and operating considerations.* Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization. (2016). *ISO 31010 Risk management - Risk assessment techniques.* Geneva: International Organization for Standardization.

International Organization for Standardization. (2019). *Escape, evacuation and rescue from offshore installations, Annex B – Examples of Arctic EER Risk Analysis and Operational Systems, Draft.* Geneva, Switzerland: International Organization for Standardization.

Jensen, J. E., Solberg, K. E., Gudmestad, O. T. (2019). Survival in cold waters - learnings from participation in cold water exercises - a regulatory perspective related to the Norwegian offshore industry. *Computational methods in Offshore Technology.* Stavanger: COTech 2019.

Kapusuz, K. Y. (2014). Determination of scattering center of multipath signals using geometric optics and Fresnel zone concepts. *Engineering Science and Technology, an International Journal , Volume 17, Issue 2*, 50-57. Retrieved from https://doi.org/10.1016/j.jestch.2014.03.004

Kozeya et al. (2008/2009). Effects of human anthropometry and personal protective equipment on space requirements. *Occupational Ergonomics, IOS Press*, pp. 67-79.

Kristiansen, B. S. (2019). *The Cruise Industry and the Polar Code - Implementing the Polar Code.* Tromsø: University of Tromsø.

Kvamme, B. O. (2016). *Master thesis: Validation of heat transfer coefficients.* Stavanger: University of Stavanger.

Light, I. M. (1992). *Survivability of occupants of totally enclosed motor propelled survival craft, OTH.* Aberdeen: Health and Safety Executive.

Mak L. M., Brown, R., Farnworth, B., Kuczora, A. (2010). Thermal Protection and microclimate of SOLAS approved lifeboats. *Proceedings of the 29th International Conference on Ocean, Offshore and Arctic Engineering.* Shanghai: OMAE.

Mak, L. M., Kuczora, A., DuCharme, M. B., Boone, J. (2008). Assessment of Thermal Protection of Life rafts in Passenger Vessel Abandonment Situations. *Proceedings of the ASME 27th International Conference on Offshore Mechanics and Arctic Engineering.* Estoril: OMAE.

Malesky, M. (2017, May 17). *Sciencing*. Retrieved from https://sciencing.com/minimum-oxygen-concentration-human-breathing-15546.html

Marchenko, N. A. (2009). Experiences of Russian Arctic Navigation. *Proceedings of the 20th International Conference on Port and Ocean Engineering under Arctic Conditions.* Luleå, Sweden: POAC 2009.

Marchenko, N. A. (2015). Ship traffic in the Svalbard area. *Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions.* Trondheim, Norway: POAC 2015.

Marchenko, N. A., Borch, O. J., Markov, S. V., Andreassen, N. (2015). Maritme activity in the high North-the range of unwanted incidents and risk patterns. *Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions.* Trondheim, Norway: POAC 2015.

Nedvedova, J. (2019). *Project report in Course Cold Climate Engineering: Ergonomics of seating in lifeboat in cold climate.* Tromsø: University of Tromsø.

Oxford, U. o. (2019, June). *Democracy*. Retrieved from Our World in Data: https://ourworldindata.org/democracy

Pedersen M. M. (2019). *Project report in Course Cold Climate Engineering: Leadership in survival crafts in Arctic waters.* Tromsø: University of Tromsø.

Petroleum Safety Authority. (2017). *Petroleum Safety Authority*. Retrieved from http://www.ptil.no/?lang=en_US

Presenso. (2018). *How the Anna Karenina Principle Applies to Predictive Asset Maintenance*. Retrieved from Medium

Corpoeration: https://medium.com/@presenso/how-the-anna-karenina-principle-applies-to-predictive-asset-maintenance-965887f20cd

Seligman, B., Bercha, F., Hatfield, P. (2008). ARKTOS Full-Scale Evacuation Tests. *Proceedings of the International Conference and Exhibition on Performance of Ships and Structures in Ice.* Banff, Canada: ICETECH.

Sjøfartsdirektoratet. (2017). *Sjøfartsdirektoratet*. Retrieved from Sjøfartsdirektoratet: https://www.sjofartsdir.no/

Sjømannsforbund, N. (2017). *Norsk Sjømannsforbund*. Retrieved from http://www.sjomannsforbundet.no/?gclid=CL2h8Yr989MCFZbJsgodigQKJA

Solberg, K. E. (2017). Implications caused by SARex on the implementation of the IMO Polar Code on survival at sea. *Computational methodsin Offshore Technology*. Stavanger: COTech2017.

Solberg, K. E. (2017). *SARiNOR2 - Berging og beredskap mot akutt forurensning i nordområdene*. Narvik: Maritimt Forum Nord. Retrieved from https://www.sarinor.no/wp-content/uploads/2018/02/SARINOR2_Endelig-rapport-2.pdf

Solberg, K. E. (2019). Thermodynamic optimization of life raft designed for polar regions. *Port and Ocean Engineering under Arctic Conditions*. Delft: POAC 2019.

Solberg, K. E., Barane, E., Gudmestad, O. T. . (2017). Identification of key elements for compliance of the IMO Polar Code requirement of minimum 5 days' survival time. *36th International Conference on Ocean, Offshore & Arctic Engineering*. OAME 2017.

Solberg, K. E., Brown, R., Skogvoll, E. Gudmestad, O. T. . (2017). Risk reduction as a result of implementation of the functional based IMO Polar Code in the Arctic cruise industry. *The Interconnected Arctic-UArctic Congress 2016.* Springer.

Solberg, K. E., Gudmestad, O. T. . (2016). SARex, Assessment of Polar Code requirements though a full-scale exercise. *23rd IAHR International Symposium on Ice.* Ann Arbor.

Solberg, K. E., Gudmestad, O. T. . (2017). On exercises for search and rescue operation in the polar region. *International Conference on Ships and Offshore Structures.* ICSOS2017.

Solberg, K. E., Gudmestad, O. T., Kvamme, B. O. (2016). *SARex Spitzbergen : Search and rescue exercise conducted off North Spitzbergen : Exercise report.* Stavanger: Stavanger University. Retrieved from https://uis.brage.unit.no/uis-xmlui/handle/11250/2414815

Solberg, K.E., Skjærseth, E., Gudmestad, O. T. (2017). *SARex2 : Surviving a maritime incident in cold climate conditions.* Stavanger: University of Stavanger. Retrieved from https://uis.brage.unit.no/uis-xmlui/handle/11250/2468805

Sollid, M. P., Gudmestad, O. T. (2018). Hazards originating from increased voyages in new areas of the Arctic. *24th IAHR International Symposium on Ice.* Vladivostok: IAHR.

Taleb, N. (2007). *The Black Swan: The impact of the highly improbable.* Random House.

Teien, H. K. (2014). *Termoregulering under ekstrembelastning, betydningen av ernæring.* Oslo: Forsvarets Forskningsinstitutt, avdeling for Beskyttelse og Samfunnssikkerhet.

The Research Council of Norway. (2019). *Industrial Ph.D. Scheme – Doctoral Projects in Industry*. Retrieved from The Research Council of Norway: https://www.forskningsradet.no/utlysninger/2019/narings-ph.d.--doktorgradsprosjekt-i-bedrift/

Xu, X., Tikuisis, P., Gonzalez, R., Giesbrecht, G. (2004). Thermoregulatory model for prediction of long-term cold exposure. *Computers in Biology and Medicine, Elsevier*, pp. 287-298.

13 Appendixes

Appendix 1	SARex Spitzbergen : Search and rescue exercise conducted off North Spitzbergen : Exercise report
Appendix 2	SARex2 : Surviving a maritime incident in cold climate conditions
Appendix 3	SARex3: Evacuation to shore, survival and rescue
Appendix 4	Interim guidelines on life-saving appliances and arrangements for ships operating in Polar waters
Appendix 5	Enclosed Papers

Intentionally left blank

Appendix 1 – SARex Spitzbergen

Search and rescue exercise conducted off North Spitzbergen : Exercise report

Abstract:

The objective of the SARex exercise, conducted north of Spitzbergen in ice-infested water in late April 2016, was to identify and explore the gaps between the functionality provided by the existing SOLAS (International Convention for Safety of Life at Sea) approved safety equipment and the functionality required by the Polar Code. The exercise was a joint collaboration between the Norwegian Coast Guard (using the Coast Guard vessel KV Svalbard as the exercise platform), experts from industry, governmental organizations and academia. The exercise scenario was to be along the lines of a "Maxim Gorkiy scenario", where an expedition cruise ship sinks in the marginal ice zone north of the coast of Svalbard.

Link for document:

https://uis.brage.unit.no/uis-xmlui/handle/11250/2414815

Intentionally left blank

Appendix 2 – SARex2

Surviving a maritime incident in cold climate conditions

Abstract:

To comply with the IMO Polar Code requirement regarding survival in a rescue craft until rescue or for a minimum of five days has proved to be a hard and complicated endeavor. Multiple mechanisms are at play and interact. As a result, survival is not only about providing the correct equipment with the right functionality, it is also about physical and mental robustness and the ability to conduct the right tasks for the duration of the stay.

The SARex exercise proved that the margins determining survival are very small and there is no room for error. Strong leadership is essential, and the rescue craft captain's knowledge and experience are critical factors for success. This is currently not addressed in the standard maritime training regime.

Maintaining an adequate body temperature is essential to mitigate the effects of hypothermia. This can be achieved by reducing heat loss. Maintaining a sustainable heat loss is a result of both the habitable environment provided by the rescue craft and the insulation provided by the personal protective equipment. As a result, there are strong dependencies between the functionality provided by the rescue craft and the functionality provided by the personal protective equipment.

Today's requirements with regard to water and rations do not seem to be adequate for a five-day survival scenario. All exercise participants lost about 2 kg of body mass during the first 24 hours in the rescue craft. This was mostly due to small water rations. The effect of dehydration will result in reduced blood circulation, causing freezing of extremities and loss of motivation and cognitive abilities.

Prevention of the development of fatigue and maintaining cognitive abilities are key elements to success, as survival for an extended period (e.g. five days) is not a ‘waiting game’. It is essential to continuously perform all the small tasks required for survival. Preventing the development of fatigue and maintaining cognitive abilities are closely linked to other mechanisms at play, e.g. seasickness, dehydration, hypothermia, energy level and pain level. A minimum degree of comfort on board the rescue craft will be required to survive for a prolonged period of time in that environment.

One element of the SARex was the evacuation of a lifeboat by helicopter. Evacuating a large number of personnel by helicopter proved not to be efficient. For larger incidents involving many casualties, marine SAR resources are essential for an efficient rescue.

The exercise also tested Emergency Position Indicator Radio Beacons (EPRIBs). It is evident that the functional range of the 121.5 MHz beacon is limited to a few nautical miles. Based on the tests carried out by SARex, a reduced duty cycle on the EPERB does not interfere with the direction-finding abilities on the rescue vessel.

It is, however, clear that, with today’s technology, only transmitting a carrier with no information coded into the signal is not very efficient. Utilizing technology where the RF signal (radio frequency signal) also contains information, e.g. an automatic identification system (AIS signal), is more efficient. Technology like that described above will not only increase the battery time or transmission power. It will also enable the SAR organization to obtain the position of the lifeboat/life raft, either through the information coded into the signal or by homing in on the signal.

It should be noted that the authors of the main part of this report are responsible for the analysis and the statements made in the report. The report may not reflect the opinion of the sponsors and the participants involved in the exercise.

Link for document:

https://uis.brage.unit.no/uis-xmlui/handle/11250/2468805

Intentionally left blank

Appendix 3 – SARex

Evacuation to shore, survival and rescue

Abstract:

The SARex3 exercise was conducted in May, 2018 in Fjortendejuli Bukta, North of Ny-Ålesund. Significant players within the industry was present, including flag state, vessel operators, vessel owners, equipment suppliers, emergency response providers and academia.

It is important to acknowledge that the findings from SARex are to be representative of a best-case scenario associated with an incident in the polar waters. This implies that the participants were on average fitter than the average seamen or passenger, and the metocean conditions were not to be extreme.

The first part of the exercise assessed the mechanisms associated with survival during an evacuation to shore. Compared with the findings from the SARex1 and SARex2 it was evident that there was a significant improvement of the survival rate when evacuating onto the shore, compared with a prolonged stay in a survival crafts.

The participants were supplied with a water ration of 1 liter per person per day, which proved insufficient in a 5-day survival perspective.

The project was also to assess the functionality provided by the different PSK (personal survival kits) and GSK (group survival kits) provided. This proved to be an impossible task due to great variations with regards to activity levels conducted by the individual participants to compensate for a heat loss caused by lack of insulating abilities in the equipment. It is of importance that IMO defines a level of heat loss that is regarded as acceptable for the human body to maintain for the expected time to rescue, a minimum of 5 days. Based on a predefined heat loss figure, equipment and combinations of equipment can be assessed in a

transparent way. Utilizing this methodology also opens up for approval of alternative solutions.

During SARex3 phase 2 of SARex3 about 50 casualties were to be evacuated from a remote beach onto the vessel Polarsyssel (owned by the Governor of Svalbard). The operation was led by representatives from the Governor of Svalbard and was executed by Røde Kors (Red Cross), Longyearbyen. The additional challenges represented by a large number of casualties should be addressed in the Operational Assessment (as defined in the IMO Polar Code) for vessel of relevance. The additional challenges should further be mitigated to maintain a reasonable risk profile, as time is a critical element in a survival situation in cold climate. Triage, transportation and treatment of a large number of casualties takes time, and requires a significant effort by the emergency response providers in addition to imposes additional strain on equipment, communication systems and the human element.

During SARex3 phase 3 Maritime Broadband Radios were tested. A remote relay station was erected at Enjabalstranda. The signals were beamed from the exercise area, via the relay station, to Ny Ålesund, and further transmitted to Longyearbyen and Oslo. The system proved reliable and live video feeds that were watched in Oslo in real time and live news updates were sent on the national tv-channel TV2. Representatives from Sysselmannen tested a software for increasing common operational picture between the different emergency response providers.

The MBR system proved reliable, but significant technical expertise was needed to initiate the system. As most “line of sight” systems it is necessary with base stations, connecting the data feed onto commonly utilized communication carriers like the internet. It is important to acknowledge the reduction in bandwidth (50%) for each relay station needed. This reduces the effective bandwidth provided by the system.

Link for document:

https://uis.brage.unit.no/uis-xmlui/handle/11250/2578301

Appendix 4

Interim guidelines on life-saving appliances and arrangements for ships operating in Polar waters

INTERNATIONAL
MARITIME
ORGANIZATION

E

4 ALBERT EMBANKMENT
LONDON SE1 7SR
Telephone: +44 (0)20 7735 7611 Fax: +44 (0)20 7587 3210

MSC.1/Circ.1614
26 June 2019

INTERIM GUIDELINES ON LIFE-SAVING APPLIANCES AND ARRANGEMENTS FOR SHIPS OPERATING IN POLAR WATERS

1 The Maritime Safety Committee, at its 101st session (5 to 14 June 2019), having considered a proposal by the Sub-Committee on Ship Systems and Equipment, at its sixth session, and recognizing the importance of life-saving appliances and arrangements for ships operating in polar waters, with a view to providing interim guidance outlining possible means of mitigating hazards in order to comply with section 8.3 of part I-A of the International Code for Ships Operating in Polar Waters (Polar Code), approved the *Interim guidelines on life-saving appliances and arrangements for ships operating in polar waters*, as set out in the annex.

2 Member States are invited to bring the annexed Interim guidelines to the attention of ship designers, shipyards, shipowners, ship managers, ship operators and other organizations or persons responsible for life-saving appliances and arrangements for ships operating in polar waters.

3 Member States are also invited to bring the annexed Interim guidelines to the attention of shipmasters, ships' officers and crew and all other parties concerned.

4 The Committee agreed to keep the Interim guidelines under review, taking into account operational experience gained with their application.

***

ANNEX

INTERIM GUIDELINES ON LIFE-SAVING APPLIANCES AND ARRANGEMENTS FOR SHIPS OPERATING IN POLAR WATERS

1 GENERAL

1.1 These Interim guidelines outline possible means of mitigating hazards in order to comply with section 8.3 of part I-A of the International Code for Ships Operating in Polar Waters (Polar Code) and are intended to assist ship designers and shipowners/operators, as well as Administrations in the uniform implementation of the Polar Code.

1.2 Compliance with these Interim guidelines does not necessarily mean that the ship complies with the Polar Code. There may be other hazards, conditions and mitigating means to be considered in the operational assessment required in section 1.5 of part I-A of the Code. The complexity of a prolonged survival time in a harsh environment should not be underestimated.

1.3 Survival after abandonment will rely on several factors, such as the types and combination of equipment, crew training and good leadership of each survival craft. The expected time of rescue is a defining factor for life-saving appliances and arrangements. Conditions that are not otherwise considered critical may become critical over time.

1.4 While equipment enhancement greatly improves survivability, the human element is a significant factor. The crew should have relevant knowledge of human behaviour in extended survival situations, medical first aid and the management of the resources available.

1.5 Key physical parameters for human survival and human behaviour in a crisis should be taken into account when considering life-saving appliances and arrangements for ships operating in polar waters.

1.6 All references to the LSA Code in these Interim guidelines mean the International Life-saving Appliance (LSA) Code, adopted by the Maritime Safety Committee of the Organization by resolution MSC.48(66), as amended.

1.7 Due to the variability of risk levels in polar waters, some of the mitigation means within these Interim guidelines may not apply to all operations. Any risk mitigation measures applied should be based on the results of the assessment, as required by the Polar Code and the operational limitations identified on the Polar Ship Certificate.

2 CONDITIONS TO CONSIDER

2.1 The Polar Code considers hazards that may lead to elevated levels of risks due to an increased probability of occurrence and/or more severe consequences. The sources of hazards listed in section 3 of the introduction of the Code should be considered for both normal operation and emergency situations.

2.2 These Interim guidelines are based on the following specific operational assessment criteria:

.1 maximum expected time of rescue;

.2 operation in low air temperatures (ships with an assigned Polar Service Temperature (PST));

.3 operation in ice;

.4 icing of life-saving appliances and arrangements;

.5 the effect of operation in high latitudes;

.6 operation in extended periods of darkness; and

.7 abandonment onto ice or land.

2.3 In the following provisions, the mitigating means are organized based on their relevance in relation to the specific conditions. Some means may be relevant to more than one of the conditions. The final relevance for each individual ship is dependent on the results of the operational assessment required by section 1.5 of part I-A of the Polar Code.

3 MAXIMUM EXPECTED TIME OF RESCUE

3.1 This section provides guidance for the type and amount of survival equipment related to the maximum expected time of rescue.

Personal and group survival equipment

3.2 The following equipment should be available for all persons after abandonment and for the maximum expected time of rescue, which can be stored in survival craft or be a part of the personal survival equipment or group survival equipment and the Polar Water Operational Manual (PWOM) should consider the location, stowage and transfer of life-saving equipment:

.1 insulated immersion suit or thermal protective aid provided with gloves should be provided with separate gloves, which shall be permanently attached to the suit/protective aid;

.2 food rations providing a minimum of 5,000 kJ (1,195 kcal) per person per day which should be increased as necessary taking into account the operational assessment;

.3 at least 2 litres of fresh water per person per day: de-salting apparatus or means to melt ice or snow may supply the amount exceeding the requirements of paragraphs 4.1.5.1.19 and 4.4.8.9 of the LSA Code and there should be a tank or a container of adequate size to collect water from the de-salting apparatus and rainwater collectors;

.4 anti-seasickness medicine;

.5 protective clothing of a material with thermal properties taking into account performance of the material when wet and type of survival craft, including head protection, neck and face protection, gloves/mittens, socks, boots, long underpants and sweaters;

.6 sunglasses or ski goggles appropriate for the expected conditions to protect persons from snow blindness, UV rays, snow ingress and/or cold;

.7 drinking vessel, preferably with a screw cap;

.8 polar survival guidance;

.9 a seasickness bag in addition to the one required by the LSA Code;

.10 anti-bacterial gel or hand wipes;

.11 blanket of a material with thermal properties suitable for use on the planned route, for each person on board; and

.12 other equipment in accordance with section 9.1 of part I-B of the Polar Code, as deemed necessary.

3.3 Personal survival equipment should be packed in a waterproof floatable carrier bag. The personal survival equipment may be stored at the assembly or embarkation stations and should be clearly marked with the size of the person they are intended for (if applicable). The content should include, as a minimum, all equipment needed during the abandonment and the initial part of the survival phase. The carrier bag should also function as each person's personal storage area for equipment handed out during the survival phase in order to keep the survival craft or shelter tidy and habitable.

Capacity of survival craft

3.4 The capacity of each survival craft should comply with the following:

.1 The seating capacity of each survival craft should be adjusted taking into account polar clothing, additional equipment including all persons carrying their intended personal survival equipment and space for occupants to stand and move in turns.

.2 Where additional personal and group survival equipment is carried in accordance with paragraphs 8.3.3.3.2 and 8.3.3.3.3 of chapter 8 of part 1-A of the Polar Code, adequate space for the stowage of the equipment should be provided. The total combined weight including additional equipment may not exceed the weight determined for the type approval of the survival craft.

Equipment in survival craft

3.5 The following equipment should be available in the survival craft:

.1 Effective means of communicating important messages from the person in charge of the survival craft, unless the Administration considers the survival craft small enough to ensure that all important messages can be heard by all persons on board, taking into account the noise level caused by the lifeboat engine, harsh weather, etc.

.2 In addition to the tools required in paragraph 4.4.8.27 of the LSA Code, the lifeboat should be provided with tools and critical spare parts for minor adjustments of the equipment and components to ensure operability during the survival phase.

3.6 Notwithstanding the requirement in paragraph 4.4.8 of the LSA Code that all lifeboat equipment should be as small and of as little mass as possible, it is important that all items are robust to retain their functionality for the maximum expected time of rescue.

3.7 Survival craft should be of a type complying with the following:

.1 Survival craft should be fitted with handholds or handhold lines to safeguard persons who are standing upright or moving inside the craft in a seaway.

.2 Survival craft should provide a habitable environment for all persons on board that prevent exposure to a long-term CO_2 concentration of more than 5,000 ppm for the maximum expected time of rescue. The ventilation should be considered in context with heating requirements to achieve a habitable temperature in the survival craft.

.3 Each seat in a lifeboat should be provided with a backrest.

4 SHIPS OPERATING IN LOW AIR TEMPERATURE

4.1 This section applies to ships intended to operate in low air temperatures, as defined in the Polar Code, part I-A, regulation 1.2.12.

4.2 All life-saving appliances and arrangements should remain operational and ready for immediate use at the polar service temperature (PST) or at the temperatures specified by the LSA Code, whichever is the lowest. The manufacturer should provide information of additional tests including temperature ranges which the equipment is intended for. This information should be a part of the operating and maintenance manual.

4.3 In the survival craft, the combination of personal survival equipment, ventilation, insulation and heating means, if provided, should be capable of maintaining a habitable inside air temperature when the outside air temperature is equal to the PST. All cold surfaces should be insulated, in particular the surfaces in direct contact with the persons, e.g. seats.

4.4 Installed heating systems, if provided, and their power sources should be capable of operation during the maximum expected time of rescue.

4.5 Means should be provided to avoid icing or dew on the windows of the lifeboat steering position, in order to maintain a proper lookout.

4.6 In order to avoid exposure to cold air, toilet equipment should be provided inside the survival craft.

4.7 Liferafts should be provided with inflatable floors or equivalent and all persons should be wearing insulated immersion suits instead of thermal protective aids.

4.8 Survival craft and containers for group survival equipment in their stowed position should have means to mitigate the freezing of drinking water supplies.

4.9 Lifeboats should be provided with suitable low temperature grade fuel and lubrication oil for the engine and suitable low temperature grade oil for the steering gear, as necessary, or be fitted with a heating system to maintain fuel and lubrication oil at the appropriate viscosity for operation.

5 SHIPS OPERATING IN ICE

5.1 This section applies to Category A and B ships and ice strengthened Category C ships.

5.2 All survival craft should be arranged for launching in such a way that they will not be damaged or cause sufficient impact to injure persons on board.

5.3 Survival and rescue craft and their fittings should be so constructed as to prevent damage from contact with ice when loaded with its full complement of persons and equipment.

5.4 A survival craft should withstand a controlled deployment into the ice conditions expected for the operational area and its propeller, rudder or other external fittings should be capable of operating in such conditions.

6 SHIPS OPERATING IN CONDITIONS WITH RISK OF ICING OF LIFE-SAVING APPLIANCES AND ARRANGEMENTS

6.1 This section applies to ships operating in conditions where ice accretion is likely to occur on life-saving appliances and arrangements.

6.2 Means should be provided to ensure the function of launching appliances, release mechanisms, hydrostatic release units and marine evacuation systems in the expected conditions of icing.

6.3 Lifeboats and rescue boats should maintain positive metacentric height (GM) when loaded as required by paragraph 4.4.5.1 of the LSA Code and with an additional ice load of 30 kg/m^2 on exposed horizontal surfaces and 7.5 kg/m^2 for the projected lateral area of each side of the lifeboat.

6.4 Means for removing ice should be provided for all survival craft likely to accumulate ice.

6.5 Entrances, hatches and means of ventilation should be designed and equipped in a way that they can be operated during icing condition to allow mitigation of ice accretion and remove the accumulated ice.

7 SHIPS OPERATING IN HIGH LATITUDES

7.1 This section applies to ships operating in areas of high latitudes.

7.2 Lifeboats and rescue boats on ships proceeding to latitudes over 80°N should be fitted with a non-magnetic means for determining heading. It should be possible to supply the means with power from two independent batteries.

8 SHIPS OPERATING IN EXTENDED PERIODS OF DARKNESS

8.1 This section applies to all ships operating in polar waters during extended periods of darkness.

8.2 Survival craft exterior and interior lights should be capable of being in operation for the extended periods of darkness during the maximum expected time of rescue. Lifeboat searchlights should be capable of being in continuous operation for the maximum expected time of rescue.

9 ABANDONMENT TO ICE OR LAND

9.1 This section applies to ships where the assessment required by paragraph 1.5 of part I-A of the Polar Code identifies a potential of abandonment onto ice or land.

9.2 Special consideration should be given when operating in areas with dangerous wildlife. Additional flares and/or a flare gun should be provided.

Shelter

9.3 The combination of a chosen type of shelter, type of personal thermal protection and other mitigating means should provide a habitable environment on ice or land, while adequately protecting against cold, wind and sun.

9.4 When determining the capacity of the shelters, the expected environmental condition in the operating area should be considered. For ships operating in low air temperature, the calculation should take into account that it might be unsafe for persons to stay outside the shelter, even for short periods. Hence, the same considerations as for survival craft should be taken into account.

9.5 Shelters should have insulated floor or other means to minimize heat transfer to the surface.

Group survival equipment

9.6 The container for group survival equipment when fully loaded should have a size, shape and mass that enables it to be towed through icy water, and also allows two crew members to pull it out the water and tow it on ice or on land.

9.7 Unless the group survival equipment is carried in the survival craft, means should be provided to launch the containers to water, ice or land without damage to the container or its contents. Means to launch such containers should be independent of the ship power system.

____

Appendix 5
Enclosed Papers

Paper No	Paper	Published
1	SARex, Assessment of Polar Code requirements through a full-scale exercise	23rd IAHR International Symposium on Ice, Ann Arbor
2	Heat Loss of Insulated Pipes in Cross-Flow Winds	36th International Conference on Ocean, Offshore & Arctic Engineering, OAME 2017/ Journal of Offshore Mechanics and Arctic Engineering
3	Risk reduction as a result of implementation of the func-tional based IMO Polar Code in the Arctic cruise industry	The Interconnected Arctic — UArctic Congress 2016, Springer 2017
4	Implications caused by SARex on the implementation of the IMO polar code on survival at sea	Computational methods in Offshore Technology, COTech2017
5	On exercises for search and rescue operation in the polar region	International Conference on Ships and Offshore Structures, ICSOS 2017
6	Identification of key elements for compliance of the IMO Polar Code requirement of minimum 5 days survival time	36th International Conference on Ocean, Offshore & Arctic Engineering, OAME 2017
7	Findings from Two Arctic Search and Rescue Exercises North of Spitzbergen	Polar Geography, 2019
8	Survival in cold waters - learnings from participation in cold water exercises - a regulatory perspective related to the Norwegian offshore industry	Computational methods in Offshore Technology, COTech2019
9	Thermodynamic optimization of liferaft designed for Polar regions	Port and Ocean Engineering under Arctic Conditions, POAC 2019
10	Time to rescue for different paths to survival	To be submitted to the Norwegian Maritime Administration and Polar Geography

Paper number 1

SARex, Assessment of Polar Code requirements through a full-scale exercise

Paper number 2

Heat Loss of Insulated Pipes in Cross-Flow Winds

Paper number 3

Risk reduction as a result of implementation of the functional based IMO Polar Code in the Arctic cruise industry

Chapter 26

Risk Reduction as a Result of Implementation of the Functional Based IMO Polar Code in the Arctic Cruise Industry

Knut Espen Solberg, Robert Brown, Eirik Skogvoll, and Ove Tobias Gudmestad

Abstract The IMO Polar Code states that equipment and systems providing survival support for passengers/crew should have adequate thermal protection for a minimum of 5 days. Based on participant workshops where suppliers, regulators, users and academia were present, the following three functionality requirements were identified as essential for survival: Maintaining cognitive abilities; No uncontrollable body shivering and Functionality of extremities.

Following the participant workshops, a field trial was conducted in Wood Fjord, Northern Svalbard, during the last week of April 2016. The goal of the trial was to identify the gaps in functionality provided by life-saving equipment currently approved by SOLAS and the functionality required to comply with the minimum requirement of 5 days survival, according to the IMO Polar Code.

The trial demonstrated that when utilizing standard SOLAS approved equipment, compliance with the functional Polar Code requirement of protection from hypothermia cannot be expected beyond 24 h of exposure.

K.E. Solberg (✉) • O.T. Gudmestad
Mechanical and Structural Engineering and Materials Science, Faculty of Science and Technology, University of Stavanger, Stavanger, Norway
e-mail: Knut.Espen.Solberg@gmc.no

R. Brown
Ocean Safety Research, Marine Institute, Memorial University, St. John's, Canada

E. Skogvoll
Faculty of Medicine, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

K. Latola, H. Savela (eds.), *The Interconnected Arctic — UArctic Congress 2016*, Springer Polar Sciences, DOI 10.1007/978-3-319-57532-2_26

26.1 Introduction

Cruise ship activity in polar regions has increased in recent years and the trend is expected to continue. With the successful transit of the Crystal Serenity through the Northwest Passage in 2016, there are currently several expedition cruise vessels being commissioned. The increase in the cruise ship industry is also expected to take place around the Svalbard island (Brunvoll 2015).

The International Code for Ships Operating in Polar Waters (The IMO; International Maritime Organization Polar Code) is a supplement to existing IMO instruments, and the intention is to mitigate the additional risks present for people and environment when operating vessels in polar waters (International Maritime Oranization 2016). The code enters into force on 01.01.2017 for newbuilds, and on 01.01.2018 for existing vessels.

Contrary to most of the existing IMO instruments, the International Code for Ships Operating in Polar Waters provides a risk-based approach (ABS 2016) to regulating activity in this area. This means that marine operators are to identify risks and mitigate them through a holistic approach.

According to *IMO Polar Code, Chapter 8 – Life-saving appliances and arrangements*, the life-saving equipment is to provide adequate functionality to ensure human survival for a minimum of 5 days for the anticipated weather conditions (cold and wind) and potential for immersion in polar water.

In an effort to better understand the performance requirements for polar survival equipment, a set of field trials was undertaken with human participants in Wood Fjord, Northern Svalbard in the last week of April 2016.

The goal of the field trials was to identify the gaps in functionality provided by regular SOLAS approved life-saving equipment and the functionality required to comply with the minimum requirement of 5 days survival, according to the IMO Polar Code (Solberg et al. 2016).

26.2 Methods

Two life saving appliances (LSAs) were deployed to the water surface – a 25 person life raft and 50 person lifeboat with 19 and 18 participants, respectively. The participants were mainly personnel from the Coast Guard. The majority of the participants were young men in their early 20s. Due to their training from the Coast Guard, they were accustomed to cold climate conditions and were in general physically fit (completed a 3000 m run in less than 15 min).

All participants wore long woolen underwear under regular shirts and pants. The participants were equipped with different types of SOLAS approved personal protective equipment (PPE). The following gear was utilized:

Neoprene survival suit – Neoprene survival suit with integrated soles, 4 pieces.
Insulated survival suit – Insulated survival suit with integrated soles, 6 pieces.

Non-insulated survival suit – Non-insulated survival suit with integrated soles, 5 pieces.

Thermal protection vest – Standard SOLAS approved thermal protection vest/aid, 6 pieces.

Kampvest with bag – The standard life jacket utilized by the Norwegian Coast Guard. The participants stayed inside a plastic bag (TPA-Thermal Protection Aid), 6 pieces.

Kampvest without bag – The standard life jacket utilized by the Norwegian Coast Guard, 4 pieces.

Nordkapp drakt – The offshore working suit utilized by the Norwegian Coast Guard. The suit with integrated steel toe boots, and loose neoprene gloves, 2 pieces.

Survival suit 307 – The standard survival suit utilized by the Norwegian Coast Guard with integrated soles, 2 pieces.

The participants were constantly monitored by medical personnel and were omitted from the trial when any of the following predefined criteria were met:

- Loss of cognitive abilities
- Loss of body control (uncontrollable shivering)
- Loss of functionality of body extremities

When the participants commenced the exercise, they were warm and dry. There was no water present in the rescue crafts on commencement of the exercise. Introducing water inside the rescue craft would significantly have reduced the participants' survival time (DuCharme 2007).

During the exercise, body core temperatures were monitored and recorded for selected participants. All participants went through a medical examination immediately after aborting the exercise, where cognitive abilities, functionality and body temperature were assessed and documented.

26.2.1 Exercise Validity

The intent of the exercise was to simulate a cruise ship incident during the cruising season in Svalbard. The following boundary conditions were observed:

- Average ambient air temp = –9 °C
- Average wind speed = 2 m/s
- Water temperature = –1.2 °C
- Participant health = above average
- Participant insulation layer = average
- Additional stress factors = marginal

A higher wind speed would be expected to reduce the survival times considerably and the weather conditions observed should be regarded as a "best case".

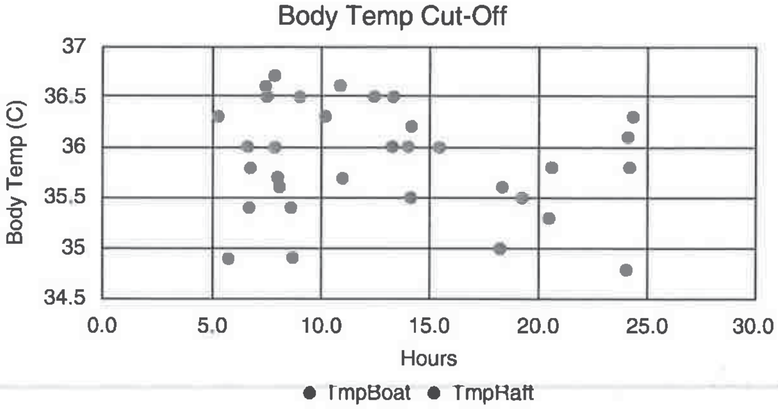


Fig. 26.1 Body Temp Cut-Off – the individual body temperatures at time of abandoning the exercise

As the participants were, on average, not only younger but also fitter than the average cruise ship passenger, the participants' physical condition gave them a higher probability for survival.

The abortion criteria gave a consistent cut-off point for participants, with all aborting the exercise with a core body temperature between 34.7 °C (mild hypothermia) and 36.7 °C (normal) (Fig. 26.1).

In a real scenario, most survivors would be very strongly motivated to stay alive and would be expected to survive for an extended period after our abortion criteria were met. It is however unlikely that the majority of the participants would survive for another 4 days, as required by the Polar Code, using equipment currently approved by SOLAS.

26.3 Results and Discussion

Based on the Kaplan-Meier Survival Plot (Fig. 26.2) it was evident that the cooling process started immediately after the exercise commenced. The first participants aborted the exercise from the raft after about 6 h.

Eight hours into the exercise, the engine in the lifeboat was turned off, removing an essential heat source. After this point in time, neither of the LSAs had a heat source, except what was generated by the participants.

In the life raft, the last participants aborted the exercise after 19 h, while several persons remained in the lifeboat after 24 h.

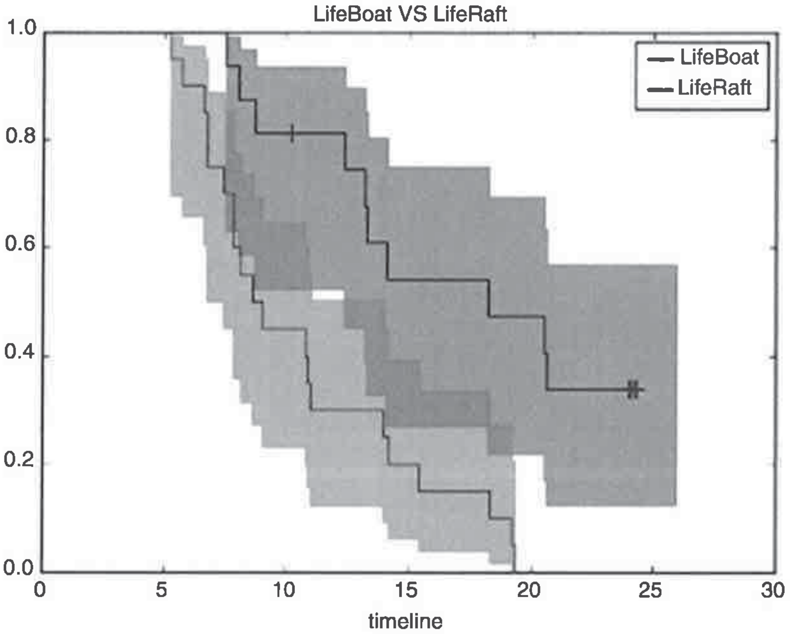


Fig. 26.2 Kaplan-Meier Survival Plot – indicating the fraction of participant survival on the Y-axis and the time spent in the rescue craft in hours on the X-axis (based on abortion criteria)

26.3.1 *Hazard Curve*

The data from the lifeboat plotted as a hazard curve (with confidence interval) shows that the highest hazard was experienced after about 15 h. At around this time, the rate of participants leaving the exercise was at its highest (Fig. 26.3).

The hazard curve for the lifeboat has distinct features: a period of low hazard, a period of increasing hazard and a period of decreasing hazard. For the life raft, the same features could be identified but by the time the life raft reached the survival phase, no participants were left.

The analysis of the hazard curve was broken down into three different phases (Fig. 26.3).

26.3.2 *Stage 1 – Cooling Phase*

During the first 7.5 h, all participants remained in the life-boat. Everyone was well fed, dry and warm prior to entering the rescue craft. In this phase, the participants became accustomed to their situation. During this period, the social structure was established with the lifeboat captain, including a plan on how to distribute resources, e.g. water in addition to distribution of responsibilities, e.g. keeping lookout.

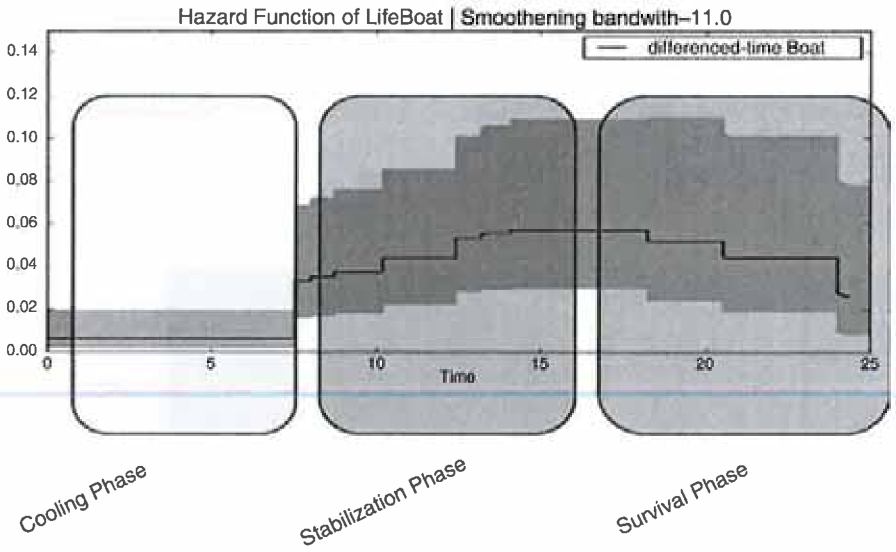


Fig. 26.3 Rescue Craft Phases – an illustration of the different phases, cooling phase (*yellow*), stabilization phase (*red*) and survival phase (*green*), with the timeline (hours) on the X-axis and the Hazard coefficient on the Y-axis for the lifeboat

During this phase, the participants were exposed to the cold natural environment, with an ambient air temperature of about −9 °C and a sea water temperature of −1.2 °C.

26.3.3 Stage 2 – Stabilization Phase

From about 7.5 h into the exercise, participants were starting to abort the exercise. The rate increased steadily until it reached its peak at about 16 h.

Those first to leave were in general participants with only life vests/thermal protective aids. Many of them being wet, typically from condensation inside the rescue craft. The moisture caused an increased heat loss due to evaporative and conductive cooling, which reduces the insulating capabilities of the clothes.

Several also left the exercise early due to significant cooling of their extremities, with the most dominant area of concern being the hands. Cooling of the hands occurred typically because of conducting tasks that required fine motor skills, e.g. opening/closing zippers and opening water bags.

The lifeboat engine was turned off 8 h into the exercise. To increase the internal air temperature, hatches remained closed for the majority of the time. CO_2-level meters showed an alarmingly high CO_2 concentration, and the craft had to be ventilated about every 15 min, depending on the number of participants on board. This process contributed to reducing the interior air temperature. Low O_2-levels also turned out to be a major concern for the participants in the life raft as identified in previous projects (Baker Andrew et al. n.d.).

26.3.4 *Stage 3 – Survival Phase*

From 16 h onwards, the rate at which participants aborted the exercise slowly decreased until the trial was complete after 24 h. As participants left the rescue craft, space was made available, giving the remaining participants the opportunity to move, generate heat and increase the blood flow to the extremities. The reduced number of persons on board also decreased the need for venting due to increased CO_2 levels.

This far into the exercise the participants were starting to feel fatigue, which resulted in an urge to lie down and rest. Substantial heat loss was experienced from the body parts that were in contact with the cold surfaces inside the rescue crafts. This again resulted in abortion criterion Pt. 2 being met.

By the time the rescue craft had reached Phase 3, the survival phase, the following conditions essential for improving survivability had emerged: Sufficient space to allow movement; Reduced CO_2 levels inside rescue crafts; Established rescue craft routines, giving the participants the ability to predict and remain in "control" of the situation.

26.3.5 *Habitable Environment*

When a rescue craft is filled with close to 100% of its capacity, the heat generated by the occupants results in a relatively high internal air temperature (Fig. 26.4). From the figure it is also evident that the heat generated by the lifeboat engine adds a significant amount of heat, keeping the internal air temperature stable until it is turned off at about 500 min into the exercise.

The temperature reductions observed at regular intervals for the life raft-curve are a result of the occasions when the participants opened the canopy for venting.

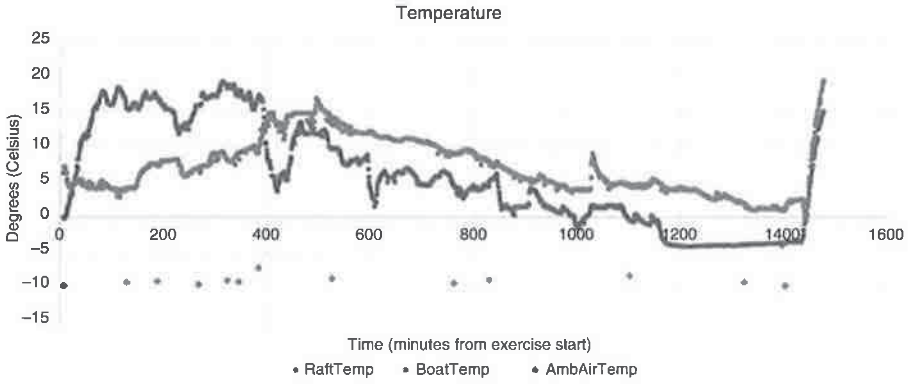


Fig. 26.4 Internal air temperature – the internal air temperature inside the rescue crafts

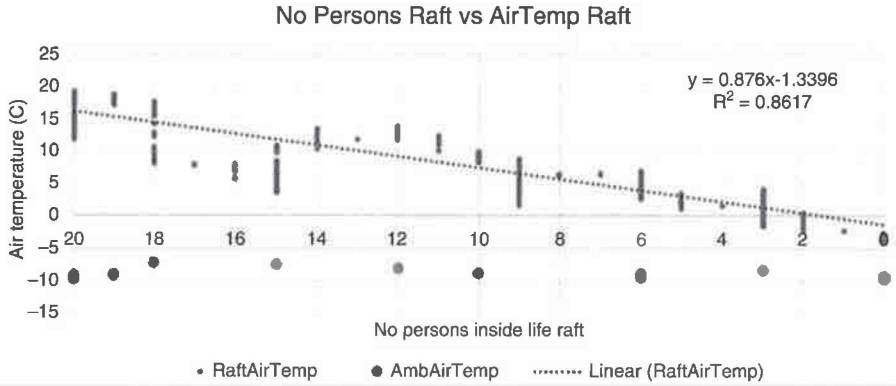


Fig. 26.5 Air Temperature vs. People in the Raft – the internal air temperature is plotted in relation to the number of people inside the life raft

The ambient outside air temperature for the duration of the exercise was relatively steady at between −7 and −10 °C. The decrease in the interior temperature is correlated to the number of persons present inside the rescue craft. This relationship is clearly visible in Fig. 26.5: Air Temperature vs. People in the Raft.

Lack of space resulting in lack of ability to move body limbs was also identified as a major challenge by the participants during the post exercise interviews. The reduced ability to move caused a lack of blood circulation. SOLAS approved LSAs are dimensioned for an average person with a weight of 75 kg and a shoulder breadth measurement of 400 mm. Our identification of lack of space harmonizes with the research done by (Kozey et al. 2008/2009). Based on measurements of offshore workers in Eastern Canada wearing marine abandonment immersion suits they recommend downgrading the rescue craft capacity by approximately 15% to accommodate the actual size of occupants wearing insulated PPE.

26.3.6 *Rescue Craft Moisture*

Moisture in the insulation layers of PPE reduces its effective insulation value and has a detrimental effect on the survival rate (Michel B. DuCharme et al. n.d.). All participants were wet when they aborted the exercise. In respect of the participants wearing survival suits, the moisture came from their own body's perspiration. The participants wearing only life jackets experienced moisture accumulating in their clothing from the condensation inside both rescue crafts. This moisture inside the life raft caused great concern as it condensed on the inside of the canopy and accumulated on the floor of the raft where people were sitting.

26.3.7 Additional Stress Factors

Prior to the trial, all participants were briefed on the risks involved and the safety system in place.

When a walrus appeared in the exercise area, only a few meters from the raft, the participants in the life raft had to keep a sharp lookout, and the canopy had to remain open for a prolonged period. Normal routines also had to be abandoned. This diverted the participants' focus from staying warm and resulted in a few participants having to abort the exercise.

On board the lifeboat, one person had to stay outside for some time to assemble the radar reflector, usually a short and uncomplicated task. Due to the cumbersome survival suit, neoprene gloves, cold metal parts and snow on the deck, this job took longer than usual. The participant also had to remove his gloves to complete the task, resulting in cooling of the extremities and degraded fine motor control. Despite returning to the lifeboat, he did not recover the use of his hands and had to abort the exercise some time later.

The ability to manage additional tasks will in many cases cause additional stress. The majority of the participants were focused on staying warm. In a cold climate survival situation, conducting additional tasks that divert the focus from staying warm, will reduce the probability of survival.

26.3.8 Psychological Aspects

In a real situation, the motivation to survive will likely be stronger than in an exercise scenario, but there will also be additional stress factors. All participants expressed the importance of a well-trained lifeboat/life raft captain. This person has a key role in establishing routines and distributing the available resources. The captain of the rescue craft also has an important role in creating routines and predictability. This is of key importance for remaining motivated and utilizing the individual resources in a sustainable manner.

Confident leadership will greatly influence the survival rate of those on a rescue craft. The longer the stay in the craft, the more important is the leadership.

26.3.9 Personal Protection

Assessing the different PPE based on time spent in the LSA gives an indication of the relative functionality of the equipment and how well it protects the participants. See Table 26.1: Personal Protective Equipment for more information. The different types of PPE offered different levels of protection, however, it is clear that the survival suits gave a major advantage over the different types of vests.

Table 26.1 Personal Protective Equipment – the hours that people stayed in the rescue crafts utilizing different personal protective equipment

	Survival Suit Neopren	Survival Suit Insulated	Survival Suit non-Insulated	Thermeal protection West	Kamp-vest with bag	Kamp-vest no bag	Nordkap Drakt	Survival Suit 307
Average Life boat (h)	22.3	22.3	16.0	11.0	15.2	10.0	24.3	
Average Raft (h)	7.6	17.5	14.4	6.4	8.6	6.0	13.2	9.4

While the number of participants within each test condition makes it difficult to state findings as being statistically significant, the results still point to performance gaps between protective survival equipment currently approved through SOLAS and what is now required by the Polar Code.

The large discrepancy for the neoprene survival suit between the lifeboat and the life raft was due to water ingress in the suits. The leaks were not experienced as a problem in the lifeboat, while in the life raft the leaks caused wetness, with a loss of insulating capability in the layers of clothes.

Stochastic studies predict a 50% probability of survival when immersed to the neck in 5°C water for about 3 h in heavy seas, wearing a long-sleeved shirt, light sweater, and jacket (Tikuisis and Keefe 2005). Few studies have however been conducted, investigating the long term effects of heat production caused by shivering response, and there are limited predictive models for long-term exposure to cold (Xu et al. 2005). Significant individual variations with regards to the ability to produce heat induced by the body's shivering response represents a large spread in the data material.

26.4 Conclusions

The trial described here was the first of its kind to be carried-out in the field since publication of the IMO Polar Code. Results suggest that there are gaps in performance for survival equipment currently approved by SOLAS compared to what is required by the Polar Code. It is clear that individual motivation and knowledge play an important role in a survival scenario. Conducting simple tasks like unzipping the survival suits at regular intervals for ventilation and drying out the insulating layer can greatly influence the outcome for that individual. The Polar Code states that equipment is to protect the passengers/crew from hypothermia. When utilizing standard SOLAS approved equipment, compliance with the functional Polar Code requirement of protection from hypothermia is not expected beyond 24 h of exposure in relatively benign polar conditions. With few exceptions, all of the participants had reached the abortion criteria well before 24 h. In a real accident scenario, the participants would have survived for an extended period beyond this point, but for how long is uncertain.

It is very unlikely, however, that a majority of the participants would have survived inside the LSAs for another four days, due to continued loss of core temperature and few opportunities for heat generation. To increase the survival rate, modifications to the functionality of the equipment would be required. These include:

- Higher degree of insulation in the personal protective aids
- A defined level of insulation in survival craft to balance the expected heat loss and ventilation needs for extended survival in polar regions
- Increased space per person to enable movement to ensure blood circulation
- CO_2 measurement devices/alarms inside the rescue craft
- Active ventilation systems to ensure a safe microclimate inside the rescue craft
- Larger and extended range of food and water rations
- Enhanced training of lifeboat/liferaft captains for long term survival situations in polar regions

References

ABS (2016) IMO polar code advisory. Huston, American Bureau of Shipping (ABS)

Andrew B et al (n.d.) Carbon dioxide accumulation within a totally enclosed motor propelled survival craft. Memorial University/National Research Council Institute for Ocean Technology, St. John's

Brunvoll R (2015) MASTERPLAN Svalbard mot 2025. Sysselmannen Svalbard. Hentet fra http://www.sysselmannen.no/Documents/Svalbard_Miljovernfond_dok/Prosjekter/Rapporter/2015/14-%2020%20Masterplan%20Svalbard%20mot%202025.pdf

DuCharme ME (2007) Effect of wetness and floor insulation on the thermal responses during cold exposure in a life raft. In: Proceedings of 12 international conference on Environmental Ergonomics, Piran Slovenia

DuCharme MB, Evely K-A, Basset F, MacKinnon SN, Kuczora A, Boone J, Mak L (n.d.) Effect of wetness and floor insulation on the thermal response during cold exposure in a liferaft. Defence R&D Canada, Quebec City

International Maritime Oranization (2016) POLAR code, international code for ships operating in polar waters. IMO Publishing, London, ISBN 978-92-801-1628-1.

Kozey JW et al (2008/2009) Effects of human anthropometry and personal protective equipment on space requirements. Occupational Ergonomics 8:67–79

Solberg et al. (2016) SARex Spitzbergen, Search and rescue exercise conducted north of Spitzbergen, Exercise Report. University of Stavanger, Stavanger. ISSN 0806-7031/ISBN 978-82-7644-677-7. Hentet fra https://brage.bibsys.no/xmlui/handle/11250/2414815
Tikuisis P, Keefe AA (2005) Stochastic and life raft boarding predictions in the Cold Exposure Survival Model (CESM v3.0). Defence Research and Development Canada, Toronto
Xu X, Tikuisisb P, Gonzaleza R, Giesbrechtc G (2005) Thermoregulatory model for prediction of long-term cold exposure. Computers in Biology and Medicine 35:287–298

Paper number 4

Implications caused by SARex on the implementation of the IMO polar code on survival at sea

Implications caused by SARex on the implementation of the IMO polar code on survival at sea

K E Solberg
GMC Maritime AS
University of Stavanger, Stavanger, Norway

E-mail: knut.espen.solberg@gmc.no

Abstract. The International Code for Ships Operating in Polar waters goes into effect on 01 January 2018 for all ships. This puts additional strain on vessel owners and operators as they will have to comply with an additional set of requirements. This includes the functional requirement of a minimum of 5 days survival time. The SARex exercise has elaborated on the issue of survival in close cooperation with the different stakeholders associated with the marine industry. Being an objective third party is important when organizing and executing these activities as all of the stakeholders has different agendas and priorities. Developing sustainable solutions is a balancing act, incorporating economic and political aspects as well as technology and requires a mutual common understanding of the mechanism involved.

1. Introduction

The extent of maritime activities taking place in the polar regions is increasing. Much of this activity is related to passenger transfer/cruise ship activity or offshore activity. Traditionally there were no extra requirements for vessels operating in cold climate environments, despite the additional challenges represented. As a result, many operators did not take into account the added risk associated with their cold climate operation.

2. The International Code for Ships Operating in Polar Waters - Regulatory rationale

The International Code for Ships Operating in Polar Waters is also known as the *International Maritime Organization (IMO) Polar Code* (International Maritime Oranization, 2016), and will go into effect on 01 January 2018 for all ships.

The International Code for Ships Operating in Polar Waters is a functional set of requirements, and utilizes a risk-based approach. It aims to mitigate the additional risks associated with marine activities in Polar waters. Having a risk-based approach induces additional strain on the chain involved in regulating, designing and conducing marine operations in a polar environment, as the risks are to be identified, assessed and mitigated through a holistic approach incorporating all aspects of the system.

Functional requirements are utilized in the offshore oil and gas industry on the Norwegian shelf. The success experienced with in this field can come as a result of a stable and close relationship between major oil operators, employees and authorities. Very few of the current marine regulations are based on a risk-based approach, with the exception of the International Safety Management (ISM) code. The process of assessing and mitigating the risk the identified in the IMO Polar Code requires in depth knowledge in relevant fields, and the outcome of the assessment is never any better than the knowledge available during the process.

The IMO Polar Code requires additional equipment to be carried, e.g. equipment that enables survival on ice/land and equipment that enables a minimum of 5 days survival time. 5 days have been defined by IMO due to the lack of infrastructure and remoteness present in the polar region. This represents a challenge with regards to the capacity in the rescue craft, and downsizing, operating with a reduced number of passengers, can be a possible solution.

Currently there is no common understanding of the interpretation of the code. As a result, there are variations between flag states and classification societies on how to achieve compliance. For vessel operators/transportation providers the lack of consistency, predictability and transparency represent not only a practical challenge. It also induces an economic risk as downsizing, can be a result of the implementation of the IMO Polar Code. Downsizing or operating with a reduced number of passengers will greatly affect the profit of a marine operation.

3. SARex

An increased activity within the field of expedition cruises is experienced in the Arctic. This increase is expected to persist in the coming years. The tourist industry in areas like Svalbard is already preparing to meet the expected increase in visitors to the area (Brunvoll, 2015).

Much of the focus involves increasing the tourist activities and raising the revenue generated by the visitors. Few questions the safety and the risks involved in these types of activities. Limited understanding of the complex multi-discipline challenge of surviving in a rescue craft in a cold climate environment has troubled the marine industry since the first draft of the IMO Polar Code was released. Our goal has been to investigate and quantify survivability related to a major marine accident in the Arctic/Antarctic, and assess if our results are in line with the global societal expectations and the 5 day requirement as stated in the IMO Polar Code.

To increase the understanding related to the complex multi-discipline challenge of surviving in a rescue craft in an Arctic environment full-scale experiments have been conducted. The project has been called SARex (Solberg et al., 2016)and the objective has been to increase the level of maritime safety through quantification of survivability in relation to Safety Of Lives At Sea (SOLAS) approved equipment. The full-scale experiments have been conducted utilizing the Coast Guard vessel KV Svalbard in close cooperation with regulators (Norwegian Maritime Authority, Petroleum Safety Authority, ABS and DNV GL), equipment manufacturers (Norsafe and Viking-Life), in addition to experts within their respective fields (e.g. medical personnel and risk expert).

To fully grasp the concept of survival at sea, following an abandoning ship incident, there is a need for improved understanding of the mechanisms involved. An increased understanding of the mechanism involved, in combination with a functional based rule set, enables sub-suppliers to design their safety systems in a sustainable manner, incorporating not only the functionality required to supply adequate survival, but also at the same time take into account the economic demands enforced by the industry.

The results from our experiments have been communicated to the relevant major stakeholders in the global marine industry, including the Norwegian Government, maritime administrations, IMO, vessel operators/transportation providers and equipment suppliers.

4. The path of regulatory development

Much of the current regulatory regime enforced by IMO (International Maritime Organization, 2017) has been developed as a result of a retroactive processes preceding a major accident, e.g. the Titanic accident triggered the development of the SOLAS convention.

It is however important to note that the implementation processes taking place in IMO requires extensive time and consensus among the member states. As almost every country in the world is a member state of IMO. Considerable divergence among cultures, financial situation and involvement is experienced among the different members. As a result, common consensus among the member states can at times be hard to obtain. It is at times experienced that political agendas overrule scientific facts in the voting processes.

As there are many stakeholders and agendas, regulatory development can be regarded as a process of causation, where the process focus on predictable aspects of an uncertain future. We humans have limited control of the future. We retrieve knowledge to handle uncertainties. Both the regulatory goal and the regulatory development path can be unclear, just like economic decision-making. The regulatory development process has strong analogies with the theories described in Saras D. Sarasvathy "*Causation and Effectuation: Toward a theoretical shift from economic inevitability to entrepreneurial contingency*" (Sarasvathy, 2001).

Traditionally full scale experiments or "reduced full scale" experiments, e.g. towing tank experiments, have been utilized in design processes. In cases where the problem is complex and cross-disciplined, where all the individual mechanisms and interactions between the mechanisms have not been properly understood a holistic or "black box" approach can be utilized.

5. Stakeholders

Working with regulatory development within the marine industry on an international level require an in-depth understanding of both the evident and at times hidden agendas of the different stakeholders. The main stakeholders affecting work related to marine safety can be summarized as follows:

- *IMO* – The International Maritime Organization is a special agency under the UN. It has currently 172 member states, usually represented by their maritime administration. IMO is organized through 5 committees, each with several sub-committees. The work associated with life saving appliances is anchored in the legal instrument, the SOLAS Convention, which is administered by the Maritime Safety Committee (MSC).

  Many of the decisions made in IMO are based on finding common denominators and reaching a consensus among the member states. This process is time consuming and often involves taking into account political and national interests.
- *National interests* – In Norway the marine industry is governed by the "Norwegian Ministry of Trade, Industry and Fisheries" and the national interests are administered by Norwegian Maritime Authority (Sjøfartsdirektoratet, 2017). The Norwegian Maritime Authority (NMA) is not only administering and enforcing our national requirements, but is also administering our maritime registers (NIS/NOR registers). The vessels registered in our national registers are to comply with our maritime regulations. In most cases, the vessel owners are companies registered in Norway. Due to the income generated by the taxes imposed on the vessel owners, the individual nations strive to have commercially competitive regulations, both within the maritime regime and the taxation scheme.
- *Petroleum Safety Authority (PSA)* – The responsibility of the Petroleum Safety Authority (Petroleum Safety Authority, 2017) is to ensure an adequate safety level on offshore installations on the Norwegian Shelf. It is administered by the "Ministry of Labor and Social Affairs". PSA is only concerned with our national interest and no international consensus is required with regards to regulatory development/ implementation. PSA has no formal legal connection to the maritime industry (ships/vessels registered under NIS/NOR or any other maritime administrations), unless they are drilling on the Norwegian Shelf. They will however enforce requirements on offshore drilling operators, including their sub-suppliers like offshore supply vessels. Traditionally the requirements enforced by the PSA have been more conservative than the ones enforced by the NMA, addressing weaknesses in maritime regulatory regime.
- *Classification societies* – Classification societies are interpreting the regulations defined by the costal administrations. In some cases, they act on behalf of the costal administrations. Other times they act as objective third parties. It is however important to note that having vessels registered in a classification society generates income for the society. This mechanism forces

the societies to compete against each other in an aggressive marked. As a result, the societies have to balance the need for conservative interpretation of the regulations with the cost implied on vessel owner/operator to keep a fleet registered under their rules.

- *Vessel owners/operators* - The vessel owners/ operators have to cover the cost associated with the regulatory requirements. The owners/operators also have to pay insurance, which again is only valid if the vessel complies with the flag state requirements, typically enforced by class. In general, you are regarded as a responsible owner/operator if you operate in compliance with the flag/port state requirements.
- *Equipment producers* – the equipment producers provide the vessel owners/operators with equipment that enables them regulatory compliance. The safety equipment is usually evaluated on regulatory compliance, price, capacity, weight and volume, where regulatory compliance has to be in place, and where price is the key most important parameter determining the sales volume.
- *Ship officers/crew* – The training of the vessel crew is defined in the IMO STCW convention and their interest are safeguarded through unions, e.g.
- Norwegian Seafarers' Union (Norsk Sjømannsforbund, 2017). The unions enforce strong interest in the safety of the officers/crew, and have representatives present in IMO.
- *Passengers* – The safety of passengers is safeguarded by no individual organization. Usually their safety is the responsibility of the cruise operator/transportation provider. Their motivation of safeguarding their passengers is the risk of economic implications caused by an incident/accident. It is however important to note that the cruise operator/transportation provider main motivation is to generate a profit, which involves keeping the cost at a minimum level. To stay commercially competitive, they are often forced to keep the cost related to safety equipment at a minimum, but still within the levels defined by the regulatory regime.

6. Societal perspectives

In the marine industry the decision processes is seldom "black and white", and it involves many considerations that interact on the different stakeholders in different ways. This is influenced by culture, economic robustness, global politics and facts. As described in "Technologies of Humility" (Jasanoff, 2007) science only offers part of the picture. It is important to understand that reaching consensus with regards to regulatory development and regulatory interpretation is as much a balancing act, incorporating political, economical and cultural aspects as well as objective scientific data.

There are 3 main stakeholders affecting the design of safety equipment for the maritime industry, the IMO requirements (enforced through the flag state and class rules), the equipment suppliers and the vessel operators. Each party has their own agenda and much of the challenges are associated with finding the right compromise between cost and functionality. The different agendas can be summarized as follows:

- Regulators – ensuring a safety-level that is globally considered acceptable, within the frames defined in IMO and giving their flag state register no commercial dis-advantage.
- Equipment suppliers – supplying equipment that is fulfilling regulatory requirements and at the same time is commercially attractive.
- Vessel operators – providing the safety as required by the regulators at the lowest possible cost.

As defined in Social Construction of Technology (SCOT) (Bijker, 1984) there is not just one way or one best way to design an artifact. Development of new technology or utilization of new combinations of existing technology could increase the safety levels considerably. This would reveal many unique opportunities with regards to development of new commercial products. However, the marked will not purchase these products unless they or their functionality is defined as a compulsory requirement in the governing regulations, or the products can be regarded as cost efficient solutions.

A result of the above mechanisms is that increased maritime safety is mainly accomplished through regulatory development and regulatory interpretation. This will later will be followed by development of new products. "Proof" that the current situation is not in line with the global societal expectations typically initiates regulatory development. This "proof" can be obtained through a major accident, and traditionally the marine regulations are retroactive and major regulator changes has emerged in the wake of major accidents.

"Proof" can also emerge because of scientific documentation. Through the SARex exercises, we have investigated the survivability to be expected if a real accident occurred in an Arctic/Antarctic region. The survivability figures obtained does not meet the global societal expectations or the 5 day requirement as defined by the IMO Polar Code.

As the maritime administrations are responsible for defining the acceptable risk levels associated with maritime activity. It is therefore important that the results from SARex have to be communicated to the maritime administrations, which further will communicate these finding to the international community through the IMO regime.

For the stakeholders represented as regulators, our results have to be incorporated in their organizations. The vessel operators/transportation providers are in general skeptical to findings that will induce additional costs that is to be carried by them. On the contrary to what many expect, the equipment manufacturers have very few opinions on the issue, as they only provide equipment according to regulatory requirements and have no responsibility beyond that with regards to the functionality or survivability provided by their equipment.

The international maritime industry is a complex structure with many stakeholders. Michael Gibson addresses this type issue in "Science new social contract with society" (Gibson, 1999) where he states that the price for increased complexity in society is a pervasive uncertainty. The same can be the case in the marine industry where ownership and responsibility can be hard to identify (NTB, 2017).

7. Responsible Research and Innovation Challenges

A responsible research and innovation approach (EPSRC's AREA framework for Responsible Research and Innovation, 2017) continuously seeks to:

- Anticipate – evaluate the impacts induced by the research activity
- Reflect – reflect on the implications of the results from the research activity
- Engage – opening up for relevant discussions in a broader audience
- Act – utilizing the above processes to influence the direction of the research process.

One way of fulfilling the above principles is that all societal actors are to cooperate and work together to align both expectations and results to societal needs. The SARex project has incorporated representatives from all major stakeholders within the maritime industry. This induces continuously discussions and dialog on the purpose, direction and implications of our findings.

The SARex project and its findings have also been present at several academic conferences, in addition to industry conferences. As the project has broad public interest, the results have also been communicated through media, in addition to several closed industry seminars.

Through our work on communication we have obtained dialog with multiple stakeholders that otherwise would have been difficult.

Among the maritime industry, in addition to all project participants, there is no disagreement on the importance of the issue of survivability on rescue crafts, and further knowledge is required. There is however conflict of interests among the different stakeholders. This is mainly due to the potential cost induced by our findings.

One of the main principles of the regulatory regime imposed by IMO is that there is to be no discrimination among the member states. From a vessel operator/transportation providers point of view this means that all competitors are to compete on "equal grounds". To our knowledge, there is currently no common consensus with regards to interpretation of the IMO Polar Code. If SARex can contribute to help the global marine industry reach a consensus that would be beneficial for all parties involved, despite the fact that there will be a higher cost associated with the solution. IMO processes are essential to reach this consensus. This takes time and a closure cannot be expected for several years.

There are currently no indications that disruptive effects will reduce the need for cold climate marine activities in the future. However, there might be some unforeseen and unpredicted societal effects of our work. There are many examples where societal impacts and effects have not been adequately considered in the early phases of the project (Hoven, 2013). Unforeseen impacts of our work remains speculations. If it turns out that survival along the lines defined in the IMO Polar Code (a minimum of 5 days) is not achievable within the limits of the industry, a combination the following effects are to be expected:

- IMO will have to reverse the implementation of the Polar Code. Reversing the implementation of the regulations is extremely difficult. It is a process that will take years and involve high-level political discussions in the IMO.
- Investment in the expedition cruise industry is dependent on predictability and transparency. As the Polar Code represents a possible high cost, and potentially a loss of income due to downsizing measures, investments can be regarded as a high risk venture.
- The nearest vessel in case of a cruise ship incident in the high north is most likely another cruise ship. With lower economic margins there is to be expected a reduced activity. Fewer vessels will again result in a longer response time. As a result, the passengers on expedition cruises to the high Arctic will expose themselves to an increased risk.
- The polar states will have to substantially increase their budgets set aside for Search & Rescue capacities to ensure a sustainable Arctic development.

The societal impacts and effects will most likely not reveal it selves until a major accident occurs, typically involving loss of life. Not only will the accident have to occur, but the accident will also have to be communicated to the public through the public media channels. Based on historical events it is a paradox that lives have to be lost before a major effort is put into regulatory development trying to safeguard lives.

8. Concluding remarks

Closure of the challenge related to survival in rescue crafts is achieved when the global marine industry reaches a consensus and perceives the problem as solved. This process will be influenced by not only the objective facts generated by academia, but also political and economic agendas. Science can only indicate that a potential disaster can occur and the effect of the different mechanisms at play.

It is evident that an increasing part of the marine industry is moving its operation into polar regions. Limited activity has been observed with regards to development of infrastructure in the relevant areas. This includes communication, SAR, and oil spill preparedness. This lack of infrastructure put a larger strain and responsibility on the industry which has to mitigate this lack of infrastructure. The costs associated with these mitigation-measures have to be covered by the industry.

As the global maritime industry is a complex and competitive industry where almost every party has a separate agenda. It is highly important that we, as a scientific institution, stay clear of commercial economic opportunities related to this work. Our credibility within the maritime sector is dependent maintaining the status as an objective third-party. The moment we, as a scientific institution, contribute in driving a political process in a direction where our motivation can be linked to our own economic gain; industry, regulators, governments and the IMO will question our credibility. This will terminate our role as a leading knowledge provider for the maritime sector.

References

9. Bibliography

Bijker, W. (1984). Social Construction of Technology. In *Social Construction of Facts and Artifacts.* Sage Publications.

Brunvoll, R. (2015). *MASTERPLAN Svalbard mot 2025.* Sysselmannen Svalbard. Retrieved from http://www.sysselmannen.no/Documents/Svalbard_Miljovernfond_dok/Prosjekter/Rapporter/2015/14-%2020%20Masterplan%20Svalbard%20mot%202025.pdf

EPSRC's AREA framework for Responsible Research and Innovation. (2017). Retrieved from https://www.epsrc.ac.uk/research/framework/area/

Gibson, M. (1999, December). Science's new social contract with society. *Nature*, pp. 81-84.

Hoven, J. v. (2013). *Options for strengthening Responsible Research and Innovation.* Brussels: European Commission.

International Maritime Oranization. (2016). *POLAR Code, International Code for Ships Operating in Polar Waters.* London: IMO Publishing, ISBN 978-92-801-1628-1.

International Maritime Organization. (2017). Retrieved from http://www.imo.org/en/Pages/Default.aspx

Jasanoff, S. (2007). Technologies of Humilitiy. *Nature*, 33.

Norsk Sjømannsforbund. (2017). Retrieved from http://www.sjomannsforbundet.no/?gclid=CL2h8Yr989MCFZbJsgodigQKJA

NTB. (2017, Februar 23). *Dagbladet.* Retrieved from Aner ikke hvem som eier Jæren-havarert skip. Skipet har heller ikke godkjenning til å seile.: http://www.dagbladet.no/nyheter/aner-ikke-hvem-som-eier-jaeren-havarert-skip-skipet-har-heller-ikke-godkjenning-til-a-seile/67327657

Petroleum Safety Authority. (2017). Retrieved from http://www.ptil.no/?lang=en_US

Sarasvathy, S. D. (2001). Causation and Effectuation: Toward a theoretical shift from economic inevitability to entrepreneurial contingency". *Academy of Management Review*, 243-263.

Sjøfartsdirektoratet. (2017). Retrieved from Sjøfartsdirektoratet: https://www.sjofartsdir.no/

Solberg et al. (2016). *SARex Spitzbergen, Search and rescue exercise conducted north of Spitzbergen, Exercise Report.* Stavanger: University of Stavanger, ISSN 0806-7031/ISBN 978-82-7644-677-7. Retrieved from https://brage.bibsys.no/xmlui/handle/11250/2414815

Paper number 5

On exercises for search and rescue operation in the polar region

Paper number 6

Identification of key elements for compliance of the IMO Polar Code requirement of minimum 5 days survival time

Paper number 7

Findings from Two Arctic Search and Rescue Exercises North of Spitzbergen

Paper number 8

Survival in cold waters - learnings from participation in cold water exercises - a regulatory perspective related to the Norwegian offshore industry

Paper number 9

Thermodynamic optimization of liferaft designed for Polar regions

Paper number 10

Time to rescue for different paths to survival

Time to rescue for different paths to survival

Authors

Knut Espen Solberg, GMC Maritime, DNV GL, University of Stavanger

Keywords

Time to rescue, IMO Polar Code, Arctic, SAR, Rescue, Passenger vessel

Abstract

Time to rescue is a critical factor for surviving a marine incident. The IMO Polar Code (International Maritime Organization, 2019) utilizes a risk based approach and states that the vessel operators is to define the time to rescue and never use less than 5 days in their risk assessments. Based on experience from the classification society DNV GL, utilizing the minimum requirement of 5 days is the current industry standard when conducting risk assessments.

As the SAR resources is a national issue, there are no international requirements defining the adequacy of the resources in different areas. Each geographical area has to be evaluated on a case-to-case basis. It is, however, clear that the remoteness and lack of resources present within the IMO Polar Code area imposes a significant challenge.

The time required for rescue is highly dependent on the number of persons to be rescued, the number and type of evacuation platforms and the distance each evacuation platform has to travel. In addition, the metocean conditions play a significant role when determining the efficiency of the operation.

Introduction

Providing adequate SAR facilities dimensioned to handle the large passenger vessels in the Arctic is challenging from an economic, practical and logistical perspective. Large distances, lack of infrastructure and harsh metocean conditions represents risks that must be handled.

A substantial increase in the polar cruise tourism activity is expected, especially around Svalbard (Visit Svalbard/MIMIR AS, 2015). Several frameworks address the additional risks associated with this kind of activity (International Maritime Organization, 2019), (Norsk Polar Institutt, u.d.). However, few quantitative studies address one of the key elements essential for survival – the TTR (time to rescue). The time to rescue is mainly determined by the availability of SAR resources, which to a great extend is determined by geographical distances and political decisions and governmental funding.

This paper assesses the TTR (time to rescue) for different scenarios, utilizing different PTS (paths to survival) and investigates the factors influencing the outcome.

Definitions

There is no international consensus with regards to the interpretation and definition of many of the common used expressions relevant for the topic. In this paper the following definitions are utilized:

- Evacuation platform – means to evacuate the crew/passengers from the water, survival craft or shore to a place of safety/temporary place of safety.
- FRC – fast rescue craft/mob-boat.
- JRCC – joint rescue coordination center, coordination of the resources to be utilized in the SAR operation.
- Place of safety - a location where rescue operations are considered to terminate; where survivors' safety or life is no longer threatened; where their basic human needs (such as food, clothing, accommodation, and communications and medical needs) can be met; and from where transportation arrangements can be made for their next or final destination (International Maritime Organization, 2006).
- PTS/Path to survival – the crew/passengers of a vessel of distress will have different options with regards to maintaining survival until being rescued. The chosen combination of options is defined as a path to survival. The preferred paths will depend on elements like:
    - Condition of vessel
    - Available equipment
    - Metocean conditions
    - Number of people involved
    - Access to SAR resources
    - Governing procedures
    - Training
    - Personnel judgment

  An example of a PTS can be from a survival craft to FRC, further transportation by FRC to SAR-vessel.

- Rescue – the crew/passengers are considered to be rescued when they are placed in a place of safety or a temporary place of safety. The temporary place of safety will prohibit further escalation of the incident on an individual level, e.g. onboard a helicopter, at a temporary place of safety or onboard a SAR-vessel.

- SAR vessel – the a purposely built vessel with trained crew, including FRCs and helicopter support facilities, coming to aid the vessel of distress.
- Survival Craft – lifeboat or life raft.
- Temporary place of safety – a location where persons are protected from hazards to life and health and provided with basic humanitarian services such as shelter from the elements, warmth, first aid medical treatment, food, water and sanitation, where communications with the JRCC and a means of accounting for and identifying surviving persons are provided, and from which the survivors may be safely transferred to a place of safety (International Maritime Organization, 2006). Ideally this will be located close to a helicopter fuel depo to enable efficient refueling of the helicopter.
- Time to rescue(TTR)/time to recover – is the length of time beginning with the completion of the ship abandonment and ending when all persons have been recovered from survival craft into a place of safety or a temporary place of safety (International Maritime Organization, 2006).
- Vessel of distress – the vessel that is seeking help due to an unforeseen incident.

Model

Based on simple relationships between travel speed, distance, time, resources available, downtime (e.g. rest/maintenance) the TTR was calculated for different paths to survival. Most of the defined parameters are based on expert opinions, gathered from experienced SAR-operators. These values assume:

1. Adequate metocean conditions to conduct an efficient operation
2. Adequate number of trained personnel to conduct the operation in a safe manner
3. No technical breakdowns

Based on the above, the model can be regarded as a "best case".

The model has been generated utilizing the computer program Python 3.7.

The model has further been validated by comparing the results to real incidents, e.g. the helicopter operation carried out on Viking Sky, the rescue of the crew of Northguider and the SAR-operation carried out during the Maxim Gorkiy incident (Hovden, 2012).

Discrepancies between the model and a real scenario

Modeling of TTR involves handling a substantial amount of uncertainty. Every vessel that comes to rescue will have its own specific resources, including level of training and number of personnel.

The following discrepancies are to be expected between the model and a real scenario:

- Number of available evacuation platforms – the available number of helicopters and FRCs might be reduced during the operation due to technical failures, maintenance intervals and grounding incidents.
- Level of crew training will greatly affect the efficiency and risk involved in the operation.
- The ability to get personnel from the survival crafts onboard the evacuation platform will be affected by the sea state.
- The model does not consider any time spent for searching. With a controlled evacuation, and the IMO Polar Code requirement of equipment for communication between the survival

crafts, this should not represent a large challenge. It is however, to be recognized that this aspect represents an uncertainty if comparing the model with a real scenario.

- For operations that have an extended duration, the survival crafts are expected to be scattered over an extensive area. Transportation and coordination of the effects caused by the scattering effect is not considered in the model.
- The model considers a controlled evacuation and rescue effort. It does not consider a melee situation, picking up individual survivors from the sea.
- In a real situation a combination of survival paths is to be expected. The model only assesses each survival path individually.
- The resources mobilized to the scene of the accident will be a dynamic process. This will change throughout the operation and be affected by mechanisms like availability, access to well rested crew, technical breakdowns, maintenance intervals and duration of the operation.
- The model does not consider the effects of bad weather delaying or stopping the operation.

Due to the elements mentioned above, it is to be expected that in a real scenario the time to rescue is to be significantly longer than the absolute values identified by the model. However, the model gives an indication of the sensitivity associated with the different paths to survival.

Assumptions

There is a great variation of the different parameters. Based on best practice and practical experience from real-time operations, the following assumptions/average values have been chosen for the model:

- Transit speed of the SAR-vessel = 15 (knots) (ice free waters)
- Distance from SAR-vessel to survival craft when commencing FRC operations = 1 (nautical mile) (Prestøy, 2019)
- Distance from survival craft to temporary place of safety (e.g. shore/vessel of opportunity) = 4 (nautical miles)
- Time used for preparations before departure for the helicopter = 60 (minutes) (Requirement from the Governor of Svalbard (Olsen, 2019))
- Time used for preparations before departure for the SAR-vessel = 60 (minutes)
- Number of FRC's utilized in the operation/carried onboard the SAR vessel = 2
- Average speed of the FRCs = 15 (knots) (Johansen, 2019)
- Time utilized per person to embark from the survival craft to the FRC = 1.5 (min) (Johansen, 2019)
- Time per person utilized to embark off the FRC = 0.3 (min) (Johansen, 2019)
- Time utilized to lower and hoist the FRC = 3 (min) (Johansen, 2019)
- Time utilized to refuel the FRC = 15 (min) (Johansen, 2019)
- Refueling interval for the FRC = 60*4 (min) (Johansen, 2019)
- Number of passengers carried onboard the FRC (excluding FRC crew) = 10 (persons) (Johansen, 2019). This is based on the capacity of the MOB boats utilized by the Norwegian Coast Guard. According to SOLAS requirements (International Maritime Organization, 2004), the MOB boat is only required to carry 5 persons sitting, in addition to one person on a stretcher.
- Number of helicopters involved in the operation = 2

- Speed of helicopter (AS332L1 Super Puma) = 120 (knots) (Hagen, 2019)
- Average time utilized to hoist 2 persons simultaneously = 2.5 (min) (Hagen, 2019)
- Time utilized for each person to depart from the helicopter, including landing procedures = 0.5 (min)
- Time utilized for refueling of helicopter = 10 (min) (Hagen, 2019)
- Refueling interval of helicopter = 4 (hours) (Hagen, 2019)
- Time utilized for helicopter critical maintenance/daily check = 30 (min) (Hagen, 2019)
- Critical maintenance interval = 24 (hours) (Hagen, 2019)
- Number of passengers onboard the helicopter (excluding helicopter crew) = 15 persons
- Time for maintenance and refueling is executed when the FRC or helicopter is at the SAR-vessel, at the temporary place of safety or at the helicopter base.
- Additional helicopter crews are brought into the operation to ensure proper rest time.
- The time required from a distress call is initiated until it is received by the JRCC is not considered as it is expected to be relatively short.
- All equipment has an up to dated maintenance schedule and no major maintenance intervals (putting the helicopter out of service) are occurring during the rescue operation.
- The temporary place of safety has unlimited capacity to handle survivors.

Paths to survival

Surviving a marine incident is a result of a combination of measures. The combination of measures is defined as a PTS (path to survival). An example of a path to survival is PTS3. The survivors are initially located inside a survival craft. From the survival craft, they are evacuated on to a FRC, and further onto a SAR-vessel.

The model assesses the following paths to survival (Table 1).

Table 1 . Paths to survival considered in this document

Path to Survival	**Evacuation From**	**Means Loading**	**Platform**	**Evacuated To**	**Means unloading**
PTS1	Vessel of distress/ survival craft	Hoist	Helicopter	Shore/nearby vessel of opportunity	Walk
PTS2	Survival craft	Hoist	Helicopter	Helicopter base	Walk
PTS3	Survival craft	Hoist & crawl	Helicopter & FRC	SAR-vessel	Walk
PTS4	Survival craft	Crawl	FRC	SAR-vessel	Walk
PTS5	Shore	Walk	Helicopter & FRC	SAR-vessel	Walk
PTS6	Vessel of distress/ shore	Walk	FRC	SAR-vessel	Walk

PTS3 and PTS5 assume that the helicopter immediately will start to transport survivors to the SAR vessel as it is transiting to the scene of the accident. In PTS3 and PTS4 the FRC operation (transporting survivors from the survival crafts to the SAR-vessel) is not commenced until the SAR-vessel is located less than 1 nautical mile from the scene of the accident.

Results

The model has been run to assess different paths to survival for three scenarios.

Scenario 1 – small passenger vessel operating a in a remote region

The scenario assesses relatively a small passenger vessel carrying up to 600 passengers, at a distance of 200 nautical miles from the nearest helicopter base and 200 nautical miles from the nearest SAR-vessel. This can be representative for the expedition cruise vessels operating in remote regions.

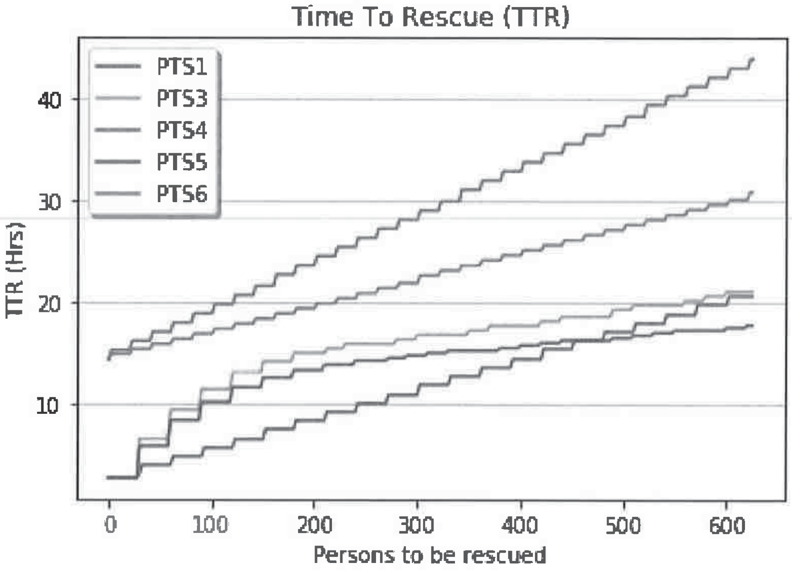


Figure 1 Time to rescue for small passenger vessel operating in a remote region.

PTS2 has been left out of the plot as it would have taken more than 80 hours to complete the task. This path of survival proved however to be efficient for a lower number of passengers, involving only 1 or 2 flights.

The plot (Figure 1) reveals that it will take about 14 hours until the first marine resource is available at the scene of the accident and can start the rescue by FRCs. However, for PTS3 and PTS5 the helicopters can start to move survivors from the scene of the accident to the approaching SAR-vessel/temporary place of safety immediately upon being deployed, and the FRCs will be involved in the operation as the SAR-vessel arrives at the scene on the incident.

For vessels in Scenario 1 involving 600 people, there is a relatively marginal difference between PTS1, PTS3 and PTS5. They all have in common that the helicopters are deployed to the scene of the incident, and that one starts the evacuation by helicopter immediately upon arrival. In PTS1 the survivors are shipped to the shore/nearby vessel of opportunity while in PTS3 and PTS5 they are shipped back to the approaching SAR-vessel. The effect of FRCs contributing to the operation is not critical for vessels carrying less than 500 people due to the relatively long response time associated with the marine resources. The helicopter will be the critical asset and have completed most of the evacuation before the SAR-vessel arrives.

For vessels carrying less than about 500 persons, utilizing the helicopter for evacuation of personnel from the survival crafts to an onshore safe heaven/vessel of opportunity (PTS1) is the preferred solution.

Scenario 2 - a larger passenger vessel operating in vicinity of infrastructure and a SAR-vessel

The second scenario is based on a passenger vessel carrying up to 3000 passengers, operating in closer vicinity to infrastructure, 50 nautical miles from a helicopter base and 50 nautical miles from a SAR vessel.

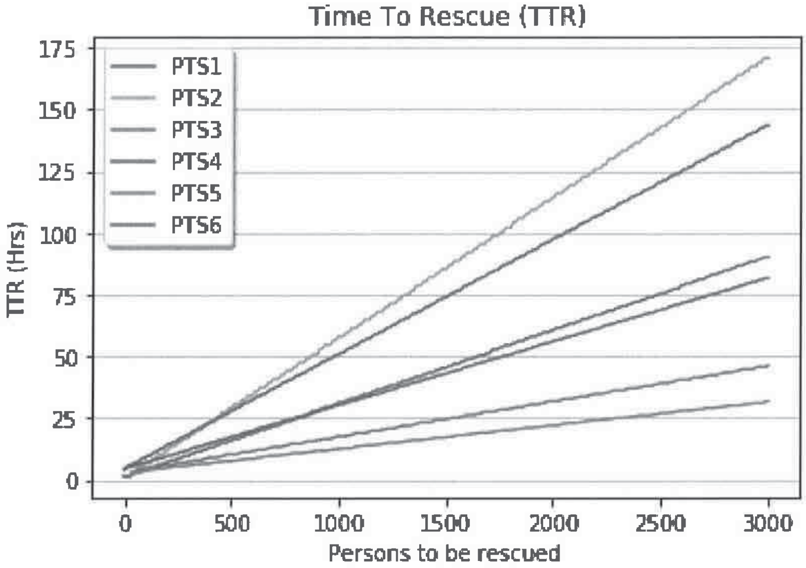


Figure 2 Time to rescue for a larger passenger vessel operating in vicinity of infrastructure and a SAR-vessel

It is evident (Figure 2) that there is little time required to get the SAR resources in position. The effectiveness of the FRC operation compared with a helicopter hoisting operation out-weights the reduced travelling time of the helicopter. The most efficient means of rescue is the utilization of FRCs in combination with helicopters (PTS3 and PTS5). It is also evident that avoiding hoisting, enabling the personnel to "walk", onto the evacuation platforms increases efficiency substantially, reducing the TTR with about 33%, from 46 to 31 hours. This would require the survivors to evacuate to land by themselves. In a real scenario, a temporary place of safety should be established at the same location.

Scenario 3 - a larger passenger vessel operating in a remote region

Scenario 3 is based on a relatively large cruise vessel (up to 3000 persons onboard) operating in a remote region, 200 nautical miles from a helicopter base and 200 nautical miles away from the nearest SAR-vessel.

The plot (Figure 3) for PTS2, flying the survivors directly back to the helicopter base is removed from the plot as it would take more than 400 hours and is not regarded as a feasible option.

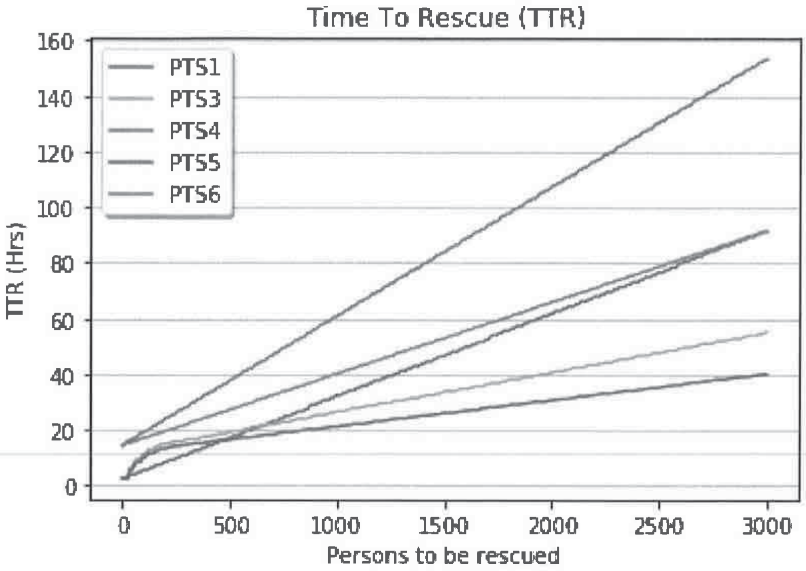


Figure 3 Time to rescue for a larger passenger vessel operating in a remote region

Due to the long response time for the SAR-vessel it is evident that with the exception of PTS1, establishing and flying the survivors to a safe haven/vessel of opportunity near the scene of the incident, the operation will not reach its full effectiveness until about 14 hours into the operation. The helicopter is an important asset, but the FRCs play an important role for the larger part of the operation.

Discussion of model results

Scenario 1

In Scenario 1 it is evident that PTS1, freighting the survivors by helicopter to a temporary place of safety established on shore/vessel of opportunity, is efficient, especially when the number of survivors is relatively low (e.g. below about 500 persons). This will require establishment of a safe haven, in addition to a fuel depo near the scene of the accident. The time utilized for the operation is greatly affected by the distance from the survival crafts to the temporary place of safety and fuel depo (Figure 4).

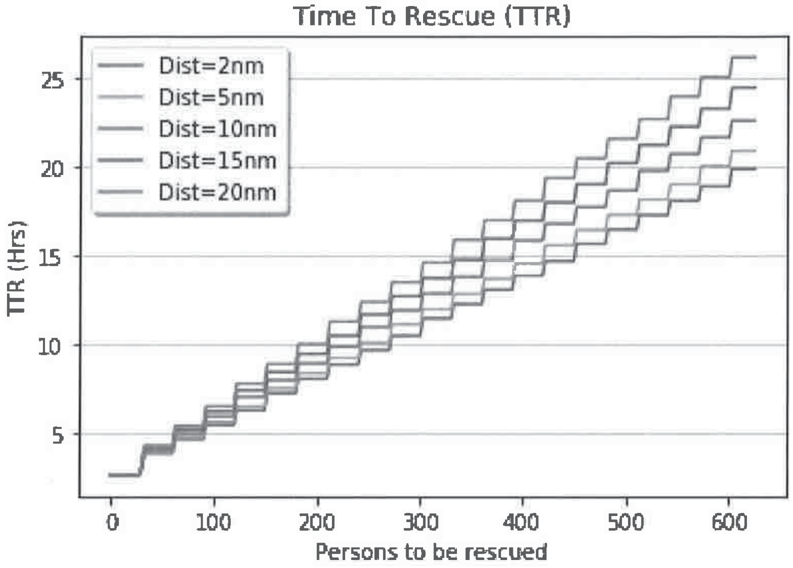


Figure 4 Time to rescue for different distances from scene of the incident to safe heaven.

Increasing the distance from the incident to the temporary place of safety from 2 nautical miles to 20 nautical miles will result in an increased flying time per round trip for the helicopter. Based on the plot above (Figure 4) it is evident that the increase in distance (from 2 nautical miles to 20 nautical miles) will reduce the efficiency of the operation by about 20%. However, the potential waiting time associated with multiple helicopter operations taking place in a limited airspace simultaneously, will reduce the efficiency for short distances.

A more robust and realistic approach would be to focus on PTS3, as utilizing this approach, the helicopter will have access to required helicopter support systems at each drop off of survivors at the SAR-vessel. Utilization of this methodology was seen in the Maxim Gorkiy incident (Hovden, 2012).

This is especially true when the number of survivors approach 600 or above, as the efficiency of PTS1 and PTS3 converges around this point.

Introducing a marine asset to the operation will also contribute to increase redundancy and handle the scattering effect caused by the survival crafts.

Shipping survivors directly back to the helicopter hub will not be a feasible option unless the number of survivors is relatively low, involving only a few helicopter flights. This will also reduce the need for establishment of an onshore safety haven. An example of this was seen during the evacuation of the crew of the fishing vessel Northguider (Hagen, 2019).

Scenario 2

In Scenario 2 it is evident that PTS3 and PTS5 provide the lowest TTR. These paths to survival enable a simultaneous operation of 2 FRCs and 2 helicopters.

The lowest evacuation time observed is PTS5 where all the survivors are located on shore. In a real scenario, it would be advisable to establish a safe haven at this location (if possible), and at a later stage evacuate them in a controlled manner.

It is worth noting that even at these distances, very close to onshore infrastructure, PTS1 came out about average. This option does not take into account that FRC and smaller local vessels of opportunity could be utilized for evacuating personnel onto the shore. Few SAR-vessels have the capacity to handle 3000 survivors, and additional accommodation resources must be brought into the scene of the accident, either as other vessels, or by establishing an onshore safe haven.

Based on the findings above it is evident that an onshore temporary place of safety would be an asset also for incidents that took place in close vicinity of onshore infrastructure.

Scenario 3

In Scenario 3, marine resources are essential for the operation and they reduce the TTR by more than 50% compared to only utilizing helicopters. It is also clear that the time utilized by the marine resource to reach the scene of the accident only represents a small portion of the total time required for the rescue operation.

An operation that is to have a duration of several days will need to supply its own support functions. This includes additional personnel, FRC fuel, helicopter fuel, technical personnel and food. Establishing the logistics required for an efficient operation will require substantial efforts and time. Parallel to the first responders rushing to the scene of the accident, a logistics support system should be initiated and mobilized.

Common denominators for all scenarios

It is evident that for all scenarios the TTR is expected to be in the range of days, not hours.

It is further apparent that 3 different key factors highly influence the TTR; the number of persons to be rescued, the number of evacuation platforms available and the distance to be travelled by the individual evacuation platforms.

The **number of persons** to be rescued represents a major driver when determining the TTR.

When the resources are at the scene of the incident, the **number of evacuation platforms,** e.g. number of FRCs and helicopters available, is critical in determining the time to rescue. Each individual platform provides rescue capacities as long as they can operate in parallel. The cumulative capacity of the evacuation platforms highly affects the total speed of the evacuation, which further defines the total time required for the rescue operation. Utilizing a substantial number of evacuation platforms in parallel will, however, demand a high capacity reception facility to handle the high and steady influx of survivors.

The **distance travelled by the evacuation platforms** is determined by the distance from the survival crafts to the temporary place of safety established on shore/vessel of opportunity/SAR-vessel. As this distance has to be travelled twice (back and forth) when picking up the survivors it will highly influence the TTR. It is of uttermost importance that the SAR-vessel maneuvers close to the survival crafts and that the temporary place of safety is established in close vicinity of the scene of the incident. The location of the helicopter fuel depos also plays a significant role when assessing the efficiency of the helicopters.

When evacuating a vessel in distress, involving an extensive number of rescue platforms will reduce the TTR up to a certain point. Beyond that, it will only increase the robustness of the operation. It is also important to consider the capacity of the reception facilities. The capacity to of the reception facilities and the capacity of the evacuation has to be harmonized for an efficient operation. During the Viking Sky incident, the onshore casualty reception facility was manned with about 100 volunteers from the Red Cross in addition to professional health workers, providing first aid and psychological support (Verdens Gang, 2019).

During the Viking Sky incident 397 persons were evacuated in about 16 hours, giving an average time of 2,4 minutes per person. Five helicopters were involved in the operation, and the helicopters were refueled at the same time as they were dropping off the survivors. However, only one helicopter was able to conduct hoisting operations at the vessel at any time due to issues caused by turbulence (NRK, Viking Sky fekk trobbel - dette har skjedd, 2019), (NRK, Cruiseskip i trøbbel utanfor Møre og Romsdal, 2019), (Verdens Gang, 2019). The indications of reduced efficiency during utilization of several helicopters together is also addressed in the guidelines defined by "Norsk Olje og Gass". They state that an efficiency of 50% is to be expected for the second helicopter arriving at the scene of the accident (Norsk olje og gass, 2015).

It is evident that the distance from the nearest helicopter base/SAR-vessel influences the TTR. In scenario 3 the lowest TTR was about 40 hours utilizing a combination of helicopters, FRCs and a SAR-vessel. Out of this time the SAR-vessel utilizes about 13 hours and the helicopters utilizes about 1,6 hours to get to the scene of the incident. This represents respectively about 30% and 2,5% of the total TTR. From a cost/benefit perspective, the recommended focus should be on increasing the rate of survivor evacuation by increasing the number of evacuation platforms, not only focusing on reducing the response time.

In PTS 5 and PTS6 the survivors have been able to reach shore by their own means. If the location is suitable, it would most likely be advisable to establish a temporary place of safety at this location instead of moving the survivors.

During the Maxim Gorkiy incident about 325 people were rescued in about 3,5 hours (Hovden, 2012). This means an average of 0.65 minute per person. This achievement was achieved utilizing multiple helicopters landing and refueling onboard KV Senja, in addition to survivors directly climbing/being onto the aft deck of the SAR-vessel. The large discrepancy between the evacuation speed (time utilized per person) in the Maxim Gorkiy scenario compared with the evacuation time in the Viking Sky or Northguider scenario is mainly due to survivors evacuating directly from the survival crafts onto the aft deck of KV Senja from the life boats by walking/climbing. This reduced the need for FRC/hoisting operations which are time consuming.

To be able to conduct this operation calm seas was a necessity. Despite the extraordinary good conditions, there were incidents where helicopters almost slide off the helideck and lifeboats obtained considerable damage under the stern/side of KV Senja, due to the rolling motion of the vessel.

Conduction of part of the operation was beyond normal regulatory directives, but a chosen option due to the limited time available.

This incident proves the importance of multiple evacuation platforms being utilized simultaneously. It also indicates the increase in speed when of having a system that enables the survivors to "walk" off the evacuation platform instead of being hoisted/lifted.

Model uncertainty

The model represents a best-case scenario with 100% operational efficiency. The uncertainties associated with the result increase for operations of longer duration. This is due to the effect of several mechanism, e.g. human fatigue caused by prolonged working hours, fatigue due to continuums repetitive operations (e.g. operator of FRC winches will have conducted several hundred hoists during a relatively short time frame), stretching of maintenance intervals for essential equipment, additional resources being introduced to the operation and variable metocean conditions.

The model assumes twin hoisting (hoisting 2 survivors simultaneously). It is experienced that when the helicopter approaches its full carrying capacity, it is preferred to conduct single hoist operations due to the challenge of the stowage of the survivors inside the helicopter.

If the survivors are in a physical state that requires single hoisting, e.g. being on a stretcher (e.g. due to serious injuries or hypothermia), the efficiency of the helicopter operation is reduced by more than 50%, further increasing the TTR substantially. Stowage of survivors on stretchers inside the helicopter is also highly time consuming. It is of very high importance that the survivors are in a physical state that enables an efficient hoist and stowage.

The efficiency of a SAR operation is highly dependent on numerous unknown variables. Based on experience from SAR-helicopter operators (Hagen, 2019), the efficiency in a hoisting operation is reduced when rolling motion is encountered on the vessel/survival crafts the survivors are to be hoisted from. The rolling motion is related to a variety of parameters like vessel size, vessel heading, vessel metacentric height, sea state and wave periods. This study assumes 100% efficiency in the rescue operation. Due to factors like bad weather, lack of/improper communication/logistical challenges etc., the operational efficiency can be reduced significantly. In a real scenario, this could result in a substantial increase in the TTR, and this study is to be regarded as a best case.

Robustness of the operation

The model is based on 100% functionality of all technical equipment. Malfunction and technical breakdowns are to be expected for an operation that is to have a duration of several days. Due to lack of infrastructure, reduced availability of critical spare parts and technical competence the operation can be significantly delayed when comparing a real SAR operation, the model results.

To reduce the likelihood of the above-mentioned mechanism, it is important to evaluate different aspects of the robustness of the operations, Table 2.

Table 2 Robustness of the different paths to survival.

Survival Path	**Robustness weather**	**Robustness technical**	**Robustness human element**
PTS1	High	Low	Medium
PTS2	High	Low	Low
PTS3	Medium	Medium	Medium
PTS4	Low	High	High
PTS5	High	Medium	High
PTS6	High	High	High

PTS6 assumes that the survivors have been able to reach a protected location onshore. With the exception of PTS6 it is clear that none of the PTS's are clearly favorable. It is however clear that mobilizing many assets to the scene of the accident is of high importance to increase the robustness of the operation.

The weather limitations associated with FRC operations will also affect the robustness of the operation. According to JRCC Bodø, personnel transfer by FRC is not advisable in seas above 1 meter unless the FRC operators have special training and the survivors are fit (Prestøy, 2019). For most of the offshore sector in the North Sea the wave height limitations for a specially trained crew is defined to be a significant wave height of 4,5 meters (Preventor, J. E. Vinnem, 2012).

If the survivors seek a sheltered location or the shore, the probability of efficient FRC operations would significantly increase.

The effect of having a SAR-vessel at the scene of the accident increases both the robustness from a technical and a human element perspective. The vessel would provide valuable assets like helicopter logistic support, food, water, medical facilities and improved abilities for communication.

Human Resources required in an efficient SAR operation

When dimensioning a SAR-system it is important to consider the human resources involved in the operation. For an operation that is to be conducted on a continuous basis for several days it is important to follow standard operation procedures to prevent development of fatigue and reduce the likelihood of failures.

Bellow (Table 3) is an example of the human resources involved in transportation and reception of survivors from survival crafts. This does not take into account the resources needed for staffing of SAR-vessel operations, first aid treatment or accommodation of the survivors.

Table 3 Human resources required for a multiday SAR operation.

Operation	**Minimum number of persons conducting operational tasks**	**Minimum number of persons allocated to the operation on a continuous basis (3 shifts)**
FRC operation		
FRC crew	3	9
Crane operators	2	6
Reception facilities (only registration)	2	6
Total FRC operation	**7**	**21**
Helicopter operation		
Pilots	2	6
Winch operator	1	3
Mechanic	1	3
Vessel HKO + 2 NAVKIS	3	9
FDO (Flight Deck Officer)	1	3
FDA (Flight Deck Assistant)	1	3
FDM (Flight Deck Crew)	4	12
Mechanic preparing heli-fuel	1	3
Reception facilities (only registration, no medical treatment)	2	6
Total Helicopter operation	**16**	**48**

Total all transportation operations		**69**

The table indicates what would ideally be required for a multiday SAR operation. The figure does only take into account the evacuation processes and does not address the personnel required for e.g. casualty treatment or organizing logistics. Much of the above-mentioned personnel would not be available as the first responders rush to the scene of the accident. Mobilization and transportation of additional required personnel to the scene of the incident should be initiated in the early phases of the operation.

It is also worth considering mobilization of the human resources required for the survivor reception facilities, including the staffing of safe havens. In the Viking Sky incident there were about 100 persons involved in the reception and premedical treatment of the survivors (Verdens Gang, 2019).

Utilization of twin vessel operation/vessels of convenience

In parts of the industry twin vessel operations are observed, where two vessels operate in close vicinity of each other. Utilization of this practice can increase safety as one of the vessels can represent a safe haven. However, for this to be feasible one is dependent on safe transportation of passengers between the survival crafts and the vessel. This will require special training and extensive experience in FRC operations, unless there is a calm sea.

Survivors could be lifted by helicopter on to the vessel, but due to the lack of helicopter support facilities, e.g. ability to re-fuel the helicopter, this operation would be aborted after a limited duration as e.g. a Super Puma helicopter only has a fuel capacity for about 4 hours and 20 minutes.

Due to the vulnerability associated with FRC operations and the sea state, and the lack of helicopter support facilities, twin vessel operation/vessels of convenience is not to be regarded as a substitute for purposely built and trained SAR resources, as they only can provide parts the services required for a robust and efficient SAR operation.

Conclusions

Despite the uncertainty associated with the model, there are several learning points identified. Increasing the number of evacuation platforms greatly affects the TTR. Utilization of FRCs and helicopters simultaneously proved to be the beneficial for all 3 scenarios. However, this requires access to helicopter support functions (e.g. ability to refuel) and the reception facilities to be dimensioned to handle a large influx of survivors.

For incidents taking place in remote areas (far from infrastructure and SAR-vessels), the time required for the SAR-vessel to arrive at site affects the rate of rescue. The following generalization can be made for the most efficient path to survival:

- Less than 40 survivors – PTS2, utilizing helicopters, freighting the survivors directly back to the helicopter base.
- 50 to about 600 survivors – PTS1, utilizing helicopters, establishing a temporary place of safety on shore while waiting for arrival of SAR-vessels as long as helicopter fuel is available in the vicinity.
- More than about 600 survivors – PTS3, utilizing a combination of all evacuation platforms available.

In all cases the survivors would benefit from seeking sheltered waters/the shore to increase the efficiency of the rescue operation.

It is also evident that access to helicopter fuel/support facilities is essential for prolonged operations involving helicopters. All paths to survival, except PTS2, require this in the vicinity of the scene of the incident. The issue of access to helicopter support facilities was also essential for the successful outcome of the Maxim-Gorkiy incident (Hovden, 2012). Shore-based depos located in vicinity of the scene of the accident, available before any SAR-vessels arrive, utilized in combination with SAR-vessels with helicopter facilities is regarded as the most beneficial approach.

Recommendations

The general learning points can be divided into 2 different categories; *vessel operator recommendations* and *SAR operator recommendations*.

Vessel operator recommendations

From the perspective of a vessel operator, the following issues are to be considered:

- For vessels containing more than a couple of hundred persons, the time to rescue is expected to be days, not hours for most areas of the Arctic/Antarctic.
- The number of persons onboard is a key parameter when estimating TTR. As a result, it is to be expected a longer TTR for a large passenger vessel than for a smaller vessel.
- The availability of SAR-resources is critical when determining TTR, and it is to be recognized that prolonged helicopter operations are not a viable option for a large part of the Arctic/Antarctic due to lack of support infrastructure, e.g. helicopter fuel.
- Rescue by marine resources will require relatively calm waters (wave height below 1 meter is recommended by JRCC Bodø) (Prestøy, 2019).
- The survivors should try to avoid spreading over a large geographical area (reduce the scattering effect) and seek sheltered waters or preferably evacuate to onshore. This will increase the probability for efficient evacuation operations, reduce the probability for conducting helicopter hoisting operations, reduce the TTR and increase the probability of survival
- Having a companion vessel (twin vessel operation) can increase safety. This will require special training and purposely built equipment to enable efficient ship to ship transfer of personnel. This is only a viable option in calm waters.
- Installation of helicopter support facilities onboard passenger vessels/vessel of convenience can substantially increase both the efficiency and the duration of helicopter operations.

SAR operator recommendations

From the perspective of a SAR operator, the following issues are to be considered:

- Dispatching a combination of purposely built and trained marine SAR-resources to the scene of the accident to provide a safe heaven, helicopter support facilities and enabling of FRC operations are essential to reduce the TTR and increase the robustness of the operation.
- Mobilization of additional resources (including personnel) is critical for logistics and support of an extended operation that is to last for several days.
- Maximize of the number of evacuation platforms available at the scene of the incident will in most cases reduce the TTR.

- The reception facilities must be dimensioned for the capacities provided by the cumulative capacity provided by the evacuation platforms.
- For many scenarios involving a substantial number of passengers, an on shore temporary place of safety is a critical asset. Equipment and personnel should be readily available at the helicopter base and pre-established helicopter fuel depos should be available in the geographical area of interest.
- Contingency plans addressing mobilization and transportation of additional essential SAR-personnel to the scene of the accident should be prepared as an efficient operation of an extended duration will most likely involve more than 100 SAR personnel at the scene of the accident.
- It is important to consider the safety, food and water required to support the SAR-resources brought to the scene of the accident.
- Helicopter fuel depos – the depos should be located at short distances from each other to reduce the time utilized for transportation. The depos should enable helicopter operations for a duration equivalent to the time required for SAR-vessel to reach the area.

Concluding remarks

In the risk assessment required by the IMO Polar Code, a majority of the vessel operators aim for the minimum time to rescue requirement of "minimum 5 days" (International Maritime Organization, 2019).

Being rescued within the timeframe defined will require an enormous functional SAR-system in place, in addition to favorable metocean conditions. This is especially valid for larger vessels carrying more than a couple of hundred persons. Within the IMO Polar Code area, the SAR-resources are sparse and far apart. When conducting the risk assessment as defined in the "Polar Water Operation Manual", it is important to consider the elements described in this manual to ensure the time defined as "time to rescue" is valid for the area of operation.

It is also of importance that the governmental agencies responsible for the SAR facilities is actively communicating the availability and functionality of the SAR system within geographical areas. This information is essential input for the marine industry to enable defining a realistic time to rescue.

Epilog

Deficiencies in a vessels SOLAS equipment (International Maritime Organization, 2004) will cause incompliance with the governing rules and regulations. Such a vessel would be detained and prohibited from leaving port as the functionality of the safety equipment would be regarded as not adequate to provide the functionality required for survival in the event of an incident involving the vessel.

Bad weather will also reduce the functionality of the safety equipment. A relatively high significant wave height will prohibit launching of the lifeboats/life rafts and evacuation of the vessel in distress would not be possible.

A vessel with compliant SOLAS equipment would not be restricted from leaving port, despite a valid weather forecast defining conditions where the functionality of the safety equipment is severely reduced. In this event, the vessel operators purposely put the vessel in a position where they should know that the safety is compromised.

This paradox imposed on the marine industry is relatively recent. In previous times the vessels traveled slowly, and the weather predictions were unreliable or unavailable. In more recent times the accuracy and availability of weather forecasts has improved significantly, and most vessels can avoid bad weather, if prioritized.

For vessels operating on the high seas, avoidance of bad weather is at times difficult. However, most cruise/passenger vessels operate in in coastal waters for a larger part of the time. Avoidance of situations where the functionality of the safety equipment is significantly reduced is perfectly possible with todays technology. This will require prioritizing safety and a willingness to bear the cost associated with the implications of the mitigation measures.

Slogans like "Never compromise on safety" is frequently observed in the marine industry. However, as the industry accepts the risks associated with lack of functionality of safety equipment associated with bad weather, safety is compromised every day, in all parts of the world. Operating with risk acceptance criteria's that compromise on safety is not necessarily a bad thing – a human life has a price. It is, however, important that this fact is accepted and communicated to relevant parties; including the passenger who puts his/her life in the hands of the vessel operator.

Bibliography

Hagen, S. (2019, 05 02). SAR Chief Pilot, Luftransport AS, Longyearbyen. (K. E. Solberg, Interviewer)

Hovden, S. T. (2012). *Redningsdåden.* Sandnes: Commentum Forlag AS.

International Maritime Organization. (2004). *SOLAS - International Convention for the Safety of Life at Sea.* London: International Maritime Organization. Retrieved from http://library.arcticportal.org/1696/1/SOLAS_consolidated_edition2004.pdf

International Maritime Organization. (2006). *IMO COMSAR 10 .* London: International Maritime Organization.

International Maritime Organization, I. (2019). *Shipping in polar waters*. Retrieved from http://www.imo.org/en/mediacentre/hottopics/polar/pages/default.aspx

Johansen, G. (2019, 05 03). University of Tromsø/Former Second in Command, KV Svalbard. (K. E. Solberg, Interviewer)

Norsk olje og gass. (2015). *Anbefalte retningslinjer for Etablering av områdeberedskap, Rev 3.* Stavanger: Norsk Olje og Gass.

Norsk Polar Institutt. (n.d.). *Cruise Handbook*. Retrieved from http://cruise-handbook.npolar.no/en/kongsfjorden/fjortende-julibukta.html

NRK. (2019). *Cruiseskip i trøbbel utanfor Møre og Romsdal*. Retrieved from https://www.nrk.no/mr/cruiseskip-i-trobbel-utanfor-more-og-romsdal-1.14487336

NRK. (2019). *Viking Sky fekk trobbel - dette har skjedd*. Retrieved from https://www.nrk.no/mr/viking-sky-fekk-trobbel-_-dette-har-skjedd-1.14487961

Olsen, E. (2019, 06 24). Police Chief Inspector. (K. E. Solberg, Interviewer)

Prestøy, R. (2019, May 03). Rescue Coordinator, Joint Rescue Coordination Center, Bodø. (K. E. Solberg, Interviewer)

Preventor, J. E. Vinnem. (2012). *Retningslinjer for områdeberedskap - Underlagsrapport, forutsetninger og faglige vurderinger.* Bryne, Norway: Norsk Olje og Gass.

Solberg K. E., Gudmestad O. T. (2018). *SARex3: Evacuation to shore, survival and rescue.* Stavanger: University of Stavanger.

Solberg, K. E., Gudmestad, O. T., Kvamme, B. O. (2016). *SARex Spitzbergen : Search and rescue exercise conducted off North Spitzbergen : Exercise report.* Stavanger: Stavanger University.

Solberg, K.E., Gudmestad, O. T., Skjærseth, E. (2017). *SARex2 : Surviving a maritime incident in cold climate conditions.* Stavanger: University of Stavanger. Retrieved from https://uis.brage.unit.no/uis-xmlui/handle/11250/2468805

Verdens Gang. (2019). *Cruisskipet Viking Sky med motorstans - dramatisk evakuering.* Retrieved from https://www.vg.no/nyheter/innenriks/i/1nOlqB/cruiseskipet-viking-sky-med-motorstans-dramatisk-evakuering

Verdens Gang. (2019). *Viking Sky evakuering.* Retrieved from https://www.vg.no/spesial/2019/viking-sky-evakuering/?utm_source=vgfront&utm_content=row-1

Visit Svalbard/MIMIR AS. (2015). *Visit Svalbard/Masterplan.* Retrieved from Visit Svalbard: https://www.visitsvalbard.com/dbimgs/Masterplan%20Destinasjon%20Svalbard%20mot%202025.pdf