Creating clarity and managing complexity through co-operation and communication

The case of Swedish icebreaker operations

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Abstract

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Sea transportation is vital for the global economy, and the amount of seaborne trade is expected to increase in the future. In some areas, icebreakers are necessary for maintaining open shipping lanes all-year round and ensuring safe navigation. Vessels operating in ice are exposed to harsh environmental factors such as severe weather and heavy ice, and when external forces become too strong vessels will depend on icebreaker assistance. However, successful icebreaker operations require the icebreaker to operate in close vicinity to the assisted vessel to break the ice, which in turn increases the risk of collision.

There are many factors which make icebreaker operations complex. The aim of this thesis is to use work organization, operational safety, and interpersonal communication as three lenses to describe and analyse the complexity of icebreaker operations, and its implications for practice. To thoroughly investigate this complexity, data are drawn from numerous sources; semi-structured interviews, a questionnaire, and a substantial amount of recorded authentic communication all provide complementary insights.

The results show that the icebreaker performs a multitude of tasks directly concerned with icebreaking, e.g. directing and physically assisting other vessels, but that these tasks indirectly rely on interpersonal interaction and communication. A number of conflicting constraints add to the complexity. For example, harsh winter conditions impede vessels' independent navigation in ice, while offering icebreaker crews opportunities to practice and maintain important skills. Furthermore, it was shown that language skills and communication play an important role in upholding the operational safety. However, closed-loop communication is not always used as intended, a deviation from intended communication protocol with potential to increase the risk of misunderstandings.

This thesis suggests that safety and efficiency of winter navigation can be enhanced by making better use of existing technology and data; by examining the past track of other vessels, e.g. via AIS, finding suitable ice tracks will be made easier. Another implication concerning communication is that training institutes should emphasize the logic behind standardized communication protocols rather than focusing on standard phrases, i.e. facilitating means for advanced English speakers to adapt their communication style. That way, novice and advanced speakers could find common ground.

Keywords:
maritime safety, organization, human factors, closed-loop communication, Standard Marine Communication Phrases, misunderstanding, other-initiated repair

Contents

List of publications

This thesis is based on the following publications, referred to by their Roman numerals:

I Boström, M. (2018). Breaking the ice: a work domain analysis of icebreaker operations. *Cognition, Technology & Work, 20*(3), 443-456. doi:10.1007/s10111-018-0482-2

II Boström, M., & Österman, C. (2017).[1] Improving the operational safety during icebreaker operations. *WMU Journal of Maritime Affairs, 16*(1), 73-88. doi:10.1007/s13437-016-0105-9

III Boström, M. (2020). Mind the Gap! A quantitative comparison between ship-to-ship communication and intended communication protocol. *Safety Science, 123*. doi:10.1016/j.ssci.2019.104567

IV Boström, M. (2020). Other-initiated repair as an indicator of critical communication in ship-to-ship interaction. *Submitted manuscript.*

[1] Distribution of work: As the main author of Paper II, Magnus Boström conceived and planned the study, as well as collected and analysed the data. He also drafted the manuscript, and Cecilia Österman assisted with revisions. Both authors contributed to the final version of the manuscript.

Preface

This thesis marks the end of a long journey. Condensing seven years of work in a few vigorous sentences is hard – but important. During my time as a PhD student I had the opportunity to participate in a course where we discussed, and practiced, pitching research ideas. How do you explain your research in less than four minutes, to someone who is not familiar with your research area? This could come in handy when socialising with a potential funder, having only a brief moment to catch their attention. Or as a young researcher, it could simply be reassuring to have a good answer when asked what your PhD is really about. After having a first go at my pitch, I went home and thought about how I would get the attention of others, and when we met a few weeks later, I was ready.

In my pocket I had a handful of LEGO® bricks. A few moments into my pitch, I started listing some factors that make icebreaking complex; and for each new thing I pulled out another LEGO brick, putting them all together. And when the model was assembled, I said: "My research isn't about these small individual LEGO bricks, it's about how they all come together." And there you have it. The research presented herein will cover topics such as organization of work, operational safety and communication, within the context of icebreakers. But they are not isolated factors; they are intricately intertwined within a complex system.

After having worked as a deck officer in the merchant fleet for some time, I stepped ashore 11 years ago and started teaching at Kalmar Maritime Academy. I have greatly enjoyed meeting and interacting with students over the years; it's a terrific way to never stop learning new things yourself. During the first years, my teaching mainly focused on courses with the collective purpose to prevent collisions at sea. Also, from the first day I took part and assisted in various types of ice navigation training courses: training of icebreaker officers, training for independent navigation for merchant vessels in ice, and specialized training in preparation for advanced arctic operations. My knowledge and interest about means of preventing collisions, applied to the complex situations found in icebreaker operations, sparked my research interest. However, over the years I have learnt to distance myself from the icebreaker; taking a step back, I have come to realise that the findings are likely applicable to other domains with similar complexity. Nonetheless, as an interesting object of study, the icebreakers will always hold a special place in my heart.

When the opportunity presented itself, I did not hesitate to dive headfirst into the PhD pond. Having the good fortune to embark on this journey was made possible by generous financial contributions from the Swedish Maritime Administration, the Swedish Transport Administration, and Stena Rederi AB. I would also like to thank Jan Snöberg for seeing the potential in me and finalizing the deal. I hope that I will be able to keep contributing to the maritime world in the future.

My warmest gratitude goes to my supervisors Jesper Andreasson, Carl Hult, and Cecilia Österman, in no particular order. Over the years, you have provided me with knowledge and advice, constructive criticism and challenges, and endless support. Knowing that you have always been on my side has made a tremendous difference. I also wish to thank my examiner Kjell Larson for valuable input and for keeping me on track with the formalities.

The making of this thesis would not have been possible without the support from experts from the field. Thank you, Kenneth Wahlberg, Göran Forss, Karl Herlin, and Jan Persson, all experienced icebreaker captains, for sharing your passion and know-how of matters such as icebreaker operations and icebreaker training. Their experience covers both the Baltic Sea and the polar regions. Also, thank you for welcoming me on board the icebreakers and providing the opportunity to take part in everyday work on board. My thanks and appreciation also go to many unnamed seafarers who have supplied me with a wealth of information. A few voices are heard through quotations, but all of you have contributed to deepening my knowledge and to making this work possible.

I would like to thank my colleagues at Kalmar Maritime Academy for their support during my time as a PhD student. Researchers, teachers, practitioners, and administrators have helped with all things great or small. It might not seem like much, but for someone absolutely focused on the specific task of finishing a PhD, even a small favour is greatly appreciated. Björn Mellström and Patrik Frick assisted me with putting together and setting up the recording device which was crucial for obtaining much of the data. To you, and many more colleagues – thank you!

Finally, and foremost, thank you Johanna for our innumerable and sometimes seemingly endless discussions about everything academic. Thank you for encouraging me, and sharing my frustration, my disappointments, and my joy over the years.

Magnus Boström
Kalmar
May 2020

1. Introduction

To say that the world, as we know it today, is dependent upon shipping is no understatement. About 90% of world trade is shipped by sea (ICS, 2019) and the amount of seaborne trade is expected to increase by almost a third during the period 2016-2030 (DNV GL, 2018). Shipping makes the world economy spin, while providing us with the amenities we have grown accustomed to. Some geographical areas, however, depend on icebreakers to facilitate all-year sea transportation. Without a suitable system for winter navigation, including a functioning icebreaker service, the logistics chain is compromised, affecting people, businesses and the economy. However, for ship crews, safety and the well-being of those on board take precedence over financial aspects, and that includes measures to avoid collisions.

As a general rule of thumb, to avoid a collision one must of course stay well clear of other ships, and to assist ship crews in doing so, the International Maritime Organization (IMO) has laid out a set of regulations governing collision avoidance at sea (IMO, 1972). Nonetheless, the distance between vessels naturally varies with geographical location; two vessels passing each other on the high seas do so at a much greater distance than two vessels in a congested area, such as the English Channel. However, while most vessels strive to stay clear of each other, icebreakers and merchant vessels receiving assistance through ice need to operate in close vicinity to each other (Buysse, 2007). The ice close to the vessel needs to be broken to release the grip of the ice, allowing the vessels to proceed. Still, there is a fine line between being close enough to free a vessel that is stuck and being too close and risk colliding. This, in turn, increases the risk of collision (House, Toomey, Lloyd, & Dickins, 2010). The reduced distance between vessels offers a very short time period to act if the operation does not advance according to plan. Essentially, icebreaker operations inherently have small error margins, adding to an already complex operation. What is more, the operation of assisting a vessel in ice is not performed solely by the icebreaker. Collaboration takes place within the bridge team of each vessel individually, but even more crucial is the co-operation between the two vessels. The icebreaker does not miraculously move the assisted vessel into safety; rather it offers advice on how the two can achieve the most, by joining forces.

This thesis focuses on the complexity of icebreaker operations and a number of broad concepts which govern their work: the *organization* of work and how prioritizations are made; the *safety* of operations and how improvements can enhance that safety; and the role *communication* plays in what is perhaps one of the world's most international work environments. By describing icebreaker operations in more general terms, one can easily observe similarities with other types of operations. For example, uncertainty, fluctuating intensity of work with high peaks, potential hazardous outcomes if something were to go wrong, human-machine interaction, and human-human interaction in intercultural settings are not unique to icebreaker operations, but can be observed in high reliability organizations such as aircraft carriers, nuclear power plants, and air traffic control systems, to mention just a few. The hope is that the findings and discussions put forward in this thesis will be of interest and contribute to domains beyond icebreakers and shipping.

1.1. Aim and research topics

The focus of this thesis is the complexity of Swedish icebreaker operations and how clarity can be created. More precisely, the aim is to use work organization, operational safety, and interpersonal communication as three lenses to describe and analyse the complexity of icebreaker operations, and its implications for practice. Complexity here derives from the interaction between multiple components, and the way they act when exposed to different influences. In this thesis, clarity should be understood as ways for people to better understand complexity, but also to include means that can be used to handle it.

Figure 1 shows how each paper for this thesis relates to the different topics.

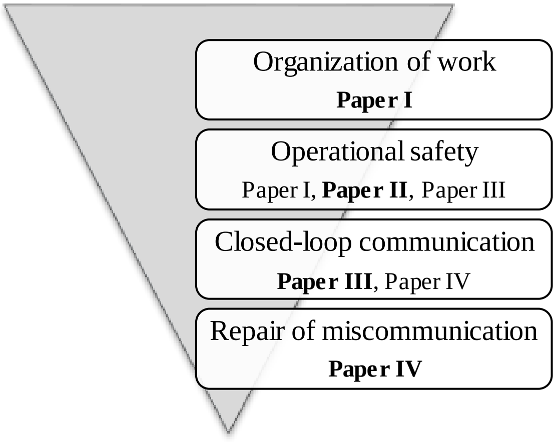

Figure 1. Relationship between the research topics and the papers.

The respective topic is primarily covered by the papers in bold. Still, some of the topics appear in several papers, indicating that there is an overlap and that complexity is manifested in the ways these topics relate to one another in the everyday life of icebreaker operations.

The terms *organization, safety,* and *communication* as general topics cover huge domains with numerous divisions and sub-areas, and the reader may relate to other commonly held understandings of these topics. However, an account of how this thesis relates to these topics is provided in Chapter 3.

The four papers included in this thesis progress from an overall concern regarding the organization of work, towards addressing the safety of icebreaker operations. Following that, the work then addresses one of several issues identified as crucial for safe and efficient performance of icebreakers: the issue of interpersonal communication, and in particular that of closed-loop communication (how information is acknowledged and repeated) and the repair of broken communication (how misunderstandings are handled). These issues were identified at an early stage of the project by mapping the work domain of the icebreaker. Finally, when examining the findings from the individual papers, a possibility emerges to discuss and analyse the complexity of icebreaker operations and how clarity in such an endeavour possibly can be understood.

1.1. Disposition of thesis

This introductory chapter has briefly accounted for the need for icebreakers, stated the aim of the thesis, and described the overall progression of the work. For an overview of the papers including their purpose, overall approach, and methods used, see Table 1.

Chapter 2 presents background material necessary to position the research. It introduces the reader to the shipping domain, briefly describing it from an international perspective, and then focuses on winter navigation and icebreaker operations in particular.

Chapter 3 provides an introduction to the topics of organization, safety, and communication, its relevance for icebreaker operations, and how they come together to create a complex system.

Chapter 4 outlines the methods used as well as how, and why, data were collected in the way they were. Furthermore, the data sample is described, as well as the ethical considerations that have guided the author throughout the work.

Chapter 5 presents the results along with a summary of the papers included in the thesis. Also, by highlighting findings from the individual papers it is showed that, when combined, various issues can converge to create complexity.

Chapter 6 offers a discussion of some aspects that have the potential to create clarity during complex icebreaker operations, and implications for practice.

Finally, Chapter 7 offers conclusions and suggestions for future research.

Table 1. An overview of the appended papers, summarizing purpose and research approach.

Paper	Purpose	Approach and methods
Paper I *Breaking the ice: a work domain analysis of icebreaker operations*	To identify the constraints on nautical officers on icebreakers during operations, and to distinguish any situations that further increase cognitive load.	Explorative study. Semi-structured group interview. Theoretical thematic (top-down) analysis of interview transcripts, including meaning condensation and categorization.
Paper II *Improving the operational safety during icebreaker operations*	To investigate what safety measures could be taken to improve the operational safety during icebreaking assistance in the Baltic Sea.	Explorative study. Semi-structured individual interviews with icebreaker officers. Questionnaire to officers on merchant vessels engaged in winter navigation. Content analysis of interview transcripts.
Paper III *Mind the Gap! A quantitative comparison between ship-to-ship communication and intended communication protocol.*	To describe verbal maritime communication in the context of icebreaker operations. This includes a quantification of what is being said, by whom it is being said, and what response it elicits.	Descriptive study. Analysis of authentic VHF communication. Categorization of message content according to IMO's message markers, and the elicited response. Quantification of response as a function of message type.
Paper IV *Other-initiated repair as an indicator of critical communication in ship-to-ship interaction*	To describe the use of other-initiated repair in maritime ship-to-ship communication. This includes a description of the practices used to signal misunderstanding, and the means used to rectify miscommunication.	Descriptive and analytic study. Analysis of authentic VHF communication. Conversation analysis.

2. An introduction to sea transportation

This chapter provides a background to any reader who is unfamiliar with sea transportation in general, and icebreakers in particular. It offers the reader an opportunity to reflect on the potential of transferability to other areas. Also, having a general understanding of icebreakers, which as study objects have a central role in this thesis, is important for positioning their work in a greater context. Icebreakers do not operate in a void; they make up one important piece of a large puzzle of shipping and knowing what the bordering pieces look like makes it easier to fit in the last piece. The chapter is initiated with a brief account of the transformation of life at sea to provide a context in which vessels operate.

2.1. The transformation of life at sea

Traditionally, life at sea has been viewed as a very special way of living and working. At times, there has been a romanticized view of an adventurous seafarer travelling the world, being cut off from the rest of the world during long ocean passages. Working at sea was not a job, it was a way of living. Another view has been represented by Goffman's (1961) concept of *total institutions*, institutions in which its members are more or less cut off from the outside world, and where work and living arrangements come together with no clear divide between the two. In that context, seafarers were placed in the same category as inmates, mental patients, and army recruits. Many seafarers were given one last chance to get their act together by signing on a vessel and going to sea. Aubert and Arner (1958) mention several ways the total institution helped shape and consolidate the organization on board. Traditionally, the officers and crew had separate living quarters, and the location of cabins has always symbolized the distinction in rank, even today. Also, separate mess-rooms (dining areas) and day-rooms (common living-rooms) constituted the norm for a long time. These practices isolated mainly the captain and senior officers, reinforcing the hierarchical structure. Furthermore, since the seafarers not only had to work together, but also spend their free time in each other's company, what happened within one area had ramifications in the other. This meant that authority relations on board influenced everyday life to a much larger degree than it did on land. However, both these views, the adventurous seafarer and the total institution, are in constant change. Today, working at sea is regarded more or less as a regular job. Due to economic reasons, ships are rarely allowed to stay in port for a prolonged time, limiting the seafarers' opportunities to explore the world. Modern communication technologies provide reliable and affordable means to communicate with anyone outside of the ship, making it easier to maintain fruitful relationships while at sea. Also, in parts of the world fleet, the hierarchical structures have been weakened, reducing the tension between groups on board. Nonetheless, some aspects, which differentiate shipping from many other lines of work, remain the same.

For example, a ship at sea is subjected to varying weather conditions. There is no way to simply suspend the work and go home if the conditions become too severe. Further, the ship and crew need to be prepared and equipped for handling both common occurrences and uncommon mishaps. The people on board need to be fixers. They need to be able to adapt to a variable environment and uncertainties stemming from not knowing exactly how the operation will unfold. On the high seas with perhaps a week's sailing distance to any major port, there is no stopping and waiting for assistance from land. This makes the ship a community within the community which, during periods of time has to be self-sustainable, caring for the well-being of the crew, the cargo, and the safe operation of the ship. At the same time, there is a lot at stake if something were to go wrong at sea: the lives of passengers and crew, the possible loss of cargo and ship worth great amounts of money, and the potential environmental hazard caused by an oil spill or a foundered ship (Chai, Weng, & De-qi, 2017). These high stakes are representative of any type of ship operation. Nonetheless, winter navigation, or icebreaker operations where an icebreaker assists a merchant vessel through ice, has one aggravating circumstance – the closeness between the vessels.

2.2. Shipping in the Baltic Sea

Shipping is an important component of international trade, and a vital drive for the global economy (Grzelakowski, 2009). Furthermore, shipping companies operate in a highly global market, and it is not uncommon for a ship to be engaged in worldwide operations far from the country in which it is registered (Mansell, 2009). The nations that supply most seafarers are China, the Philippines, Indonesia, the Russian Federation, and Ukraine. In total, there are approximately 1,650,000 seafarers, including both officers and ratings, with a current shortage of around 16,500 officers worldwide (ICS, 2019).

It is not uncommon for a vessel crew to be a mix of several nationalities. This, in combination with the presumptive large area of operation for a vessel, requires a common working language to be used both on board internally, as well as externally in contact with, for example, other vessels, shipping companies, charterers, and port authorities. The International Convention for the Safety of Life at Sea (SOLAS), first adopted in 1914 and amended several times, is a crucial international treaty concerning the safety of merchant vessels. Chapter V regulation 14.4 of SOLAS (IMO, 1974), states that:

> English shall be used on the bridge as the working language for bridge-to-bridge and bridge-to-shore safety communications as well as for communications on board between the pilot and bridge watchkeeping personnel**, unless those directly involved in the communication speak a common language other than English.
>
> **The IMO Standard Marine Communications Phrases (SMCPs) (MSC/Circ.794), as amended, may be used in this respect.

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) dictates the minimum competence required for certified seafarers, including standards for language proficiency. Still, varying language skills pose challenges, and it has been argued that one of the main barriers for Chinese seafarers to compete on the global maritime labour market is English deficiencies (Fan, Fei, Schriever, & Fan, 2017).

Together, these challenges constitute a melting pot of diversity. Globally operated ships can be regulated from one part of the world via its flag state, while operated from another part of the world where its headquarters is located. Officers might be drawn from one part of the world, while ratings are provided by a manning company in another region. Hence, a vessel operating in the Baltic Sea might have little in common with the icebreaker and its crew, who provide assistance through the ice, towards the vessel's destination. Training and experience, mother tongue and language proficiency, and cultural background are merely a few aspects that may vary; for some seafarers, it might be the first time they experience winter navigation and a voyage through ice.

Shipping is responsible for about 90 % of all import and export of goods to and from Sweden and Finland, which is the focused area for this study (Ministry of Transport and Communications, 2014; Trafikverket, 2015). Both these countries, bordering the Baltic Sea and Bay of Bothnia, have long coastal areas, which regularly experience harsh winter conditions. The degree of winter difficulty is classified as mild, normal, or severe, mainly based on the maximum extension of sea ice (SMA, 2019a). During a normal winter, the maximum extent of sea ice is often reached in mid-March, covering the Bay of Bothnia, the Sea of Bothnia, and the Sea of Åland (SMHI, 2018). Figure 2 illustrates the yearly maximum ice extension and severity of winters since 1900, with the horizontal lines indicating the cut-off points between mild, normal, and severe ice winters (SMA, 2019a).

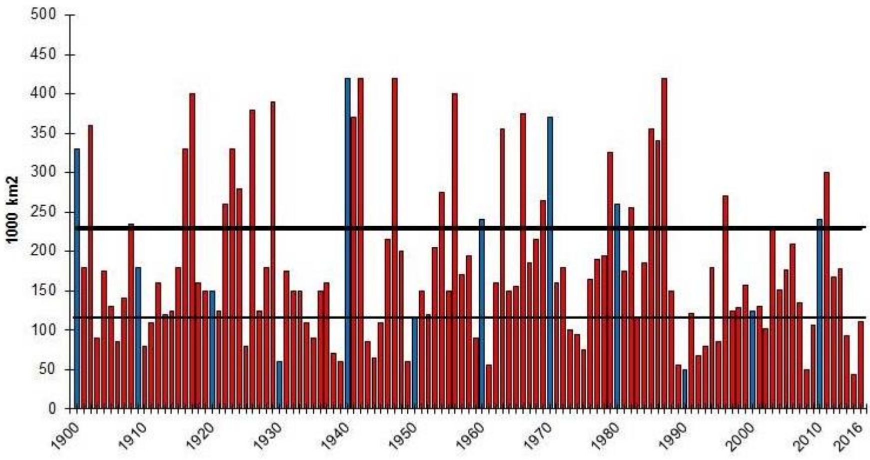

Figure 2. Maximum yearly ice extension in the Baltic region 1900–2016.

Even during mild winters, Sweden's five icebreakers are busy assisting merchant vessels. According to the Swedish Ice-breaking Service Ordinance (SFS 2000:1149), the responsibility of the Swedish state icebreakers to assist vessels stretches from open water into areas sheltered from drift ice; the areas close to shore and in port are managed locally, often by ice-strengthened tug boats provided by municipalities and port authorities (SMA, 2002). Maintaining shipping lanes open all-year round is crucial for the national economy in general, and for industries in northern Sweden in particular. The development and modernization of the economy of northern Sweden has been enabled partly by efforts to facilitate shipping during periods of ice (Eriksson, 2006).

2.3. Icebreaking in the Baltic Sea

Most vessels around the world operate in ice-free waters. When encountered, sea ice can be a challenge to sea transportation. Apart from the polar regions, vessels may also encounter ice in the Barents Sea, the Beaufort Sea, on the Great Lakes, and along the Northeast Passage (north of Russia), just to mention some areas where vessels depend on icebreakers to maintain shipping lanes open (House et al., 2010). When ice conditions are severe in the Baltic Sea, Swedish and Finnish icebreakers jointly assist merchant vessels to ensure safe navigation. Compared to shipping in open water, a vessel proceeding in ice is exposed to a number of fundamentally precautious aspects, e.g. severe weather conditions, including low temperatures and ice crushing pressure on the hull (Kujala & Arughadhoss, 2012), and icing, the accumulation of ice on the superstructure of the vessel, which impacts the stability negatively (Snider, 2012). To mitigate and manage these risks associated with winter navigation, access to the Baltic Sea is generally controlled by the use of traffic restrictions, ice class regulations, and icebreaker assistance (Jalonen, Riska, & Hänninen, 2005). Traffic restrictions and ice class regulations put regulatory demands on vessels wishing to traffic the Baltic Sea during winter time to improve the efficiency of vessel traffic (SMA, 2019b). The traffic restrictions, which are primarily set according to the extent of ice cover and severity of ice conditions, dictate the minimum ice class and deadweight required for a vessel to traffic a particular area; the ice class regulations (TSFS 2011:96) set requirements regarding vessels' hull strength and effect of propulsion machinery, while deadweight refers to a vessel's carrying capacity. Only vessels that comply with the ice class rules currently in force by the traffic regulations can rely on icebreaker assistance when needed. Different geographical areas, or ports, can have different traffic regulations, and the regulations follow the severity of the winter. Usually, there is a peak in traffic restrictions, both regarding ice class and deadweight, in February and March, with higher demands on vessels trafficking the most northern ports (SMA, 2019b). This general principle of the winter navigation system ensures that vessels that are too weak are not admitted to areas with winter conditions. On the other hand, this also guarantees that there is a sufficiently large icebreaker fleet available to the admitted vessels (Jalonen et al., 2005). Consequently, the traffic regulations are used to regulate the amount of traffic and the capabilities of the vessels, thus adjusting the system to the present conditions, allowing for an optimization of icebreaker resources.

A vessel bound for a Swedish or Finnish port subject to traffic restrictions is expected to report its ship name and nationality, destination, estimated time of arrival and speed via Very High Frequency (VHF) radio. This is needed for the icebreaker service to minimize delays and optimize icebreaker resources (SMA, 2019b). The progress of the vessel is then monitored by an icebreaker, which might also provide the vessel with updated information about the ice conditions.

Winter navigation operations can be classified into ship independent navigation and icebreaker assistance (Valdez Banda, Goerlandt, Kuzmin, Kujala, & Montewka, 2016). Independent navigation starts when a vessel enters ice covered waters and continues as long as there is no on-site assistance (Valdez Banda et al., 2016), but can include indirect assistance via way points, i.e. the most favourable route provided by an icebreaker or Vessel Traffic Service (VTS) (Boström & Österman, 2017). A vessel that is no longer able to proceed with independent navigation through the ice will receive icebreaker assistance. There are four main types of operations: escorting of a single vessel (Figure 3), escorting several vessels in a convoy (Figure 4), cutting loose a vessel which is beset in ice (Figure 5), and towing of a vessel (Figure 6) (Buysse, 2007; Valdez Banda et al., 2016).

Figure 3. Icebreaker escorting a single vessel.

Figure 4. Icebreaker escorting several vessels in a convoy.

Figure 5. Icebreaker cutting loose a vessel. Note the cracks in the ice forming as the icebreaker passes, thus releasing the pressure from the ice.

Figure 6. Icebreaker performing closed-coupled towing.

To determine what type of assistance is suitable for every situation is at the discretion of the icebreaker. The chosen mode will only be used as long as it is deemed necessary, and there may be a constant shift between modes. For example, a vessel stuck in the ice may need to be cut loose. After that, the same vessel may be escorted as a single vessel. Upon reaching another vessel unable to navigate independently, the second vessel may be requested to join and form a convoy. If conditions deteriorate, vessels may get stuck again, requiring the icebreaker to stop and break them loose. If conditions improve, the icebreaker may decide to leave the vessels, letting them proceed independently. This means that the work of the icebreaker is highly dynamic.

As can been seen in Figures 3-6, all types of on-site icebreaker assistance require the icebreaker and the vessel receiving assistance to operate in close vicinity to each other. The exact distance varies due to the pressure exerted by the ice, caused by wind and currents. With high ice pressure, vessels get beset more easily. Furthermore, with high ice pressure, the open channel behind the icebreaker also “closes” more quickly, as the channel is compressed by the pressure. This means that, for an icebreaker to successfully escort another vessel, the distance between the two needs to be reduced, and this in turn increases the risk of collision (House et al., 2010).

3. Organization, safety, and communication

This chapter provides a brief introduction to the three pillars upon which this thesis rests: organization of work, operational safety, and interpersonal communication. Specifically, this chapter describes the meanings that I attribute to these concepts.

3.1. Organization of work

A Work Domain Analysis (WDA) is used in Paper I to describe what the icebreaker "does", e.g. its purpose, main functions and the resources needed. A central concept within a WDA is its constraints, factors that limit the operator's freedom. A constraint can be seen as something that shapes the work of the operator within a system, and that is the rationale for conducting a WDA as part of this research project; identifying constraints within icebreaker operations is a way to direct research focus towards possible areas of improvement. Therefore, the WDA in Paper I illustrates how the subsequent papers relate to each other.

3.1.1. Work domain analysis

A system becomes complex through the interaction of the components and when the system is deployed within a certain context, or as Dekker (2015, p. 50) puts it: "complexity is a feature of the system, not the components inside of it". A complex system includes a large number of diverse components, and features an unanticipated variability within the system. Hence, it needs to be resilient, i.e. be able to adjust to sustain operation under unexpected conditions (Saurin & Gonzalez, 2013). Furthermore, complex systems are often distributed in different locations and social interactions are essential. They often have potentially hazardous outcomes, while at the same time include elements of uncertainties and disturbances (Vicente, 1999). To analyse complex systems the Cognitive Work Analysis (CWA) framework can be used. This framework has been used to describe transport domains, such as railroad (Salmon et al., 2015), road transportation (Birrell, Young, Jenkins, & Stanton, 2012), operation of motorcycles (Regan, Lintern, Hutchinson, & Turetschek, 2015), and submarines (Stanton & Bessell, 2014), as well as domains within the military (Naikar, Treadwell, & Brady, 2014) and healthcare sector (Dhukaram & Baber, 2015; Effken, Brewer, Logue, Gephart, & Verran, 2011).

A CWA includes one or several separate analyses, of which the first is usually a WDA (Stanton et al., 2013). A WDA serves "to represent the constraints implicit on the domain in which the activity of a system is conducted" (Birrell et al., 2012, p. 431); in other words, it describes the playing field and how that affects the system toward achieving its goal. The reason for choosing a WDA (from the CWA framework) is its focus on constraints and the way they limit the system performance; within a complex system characterized by variability and uncertainty, it is easier to define the boundaries rather than prescribe procedures. A WDA can be illustrated with an Abstraction Hierarchy (AH), which outlines the characteristics of the domain and its constraints on a number of levels. These levels have different foci and degree of detail; at the top the overall purpose of the system is described, at the bottom the necessary resources on which the system is dependent are listed, and in between the main functions of the system are shown (Rasmussen, 1985; Vicente, 1999). Figure 7 shows the AH of an icebreaker (Boström, 2018).

The content of the AH is discussed in detail in Boström (2018). Here, it is introduced in order to explain how the AH can be used or understood. At first glance, the AH can seem difficult to interpret, with its myriad of connecting lines. The complexity of the system is illustrated by the connecting lines, indicating interaction between system components. The level of detail in an AH never wholly represents reality. It will always be possible to further break down the functions and resources in smaller fractions. As a result, a high level of detail will make the AH difficult to follow. The lines between two entries are known as means-ends links, i.e. they illustrate the "means that can be used to achieve an end" (Naikar, 2005, p. 251) and as such they illustrate a why-how relationship; from any point in the AH, following a line up the hierarchy answers the question *why* that node exists, and following a line down shows *how* that node is realised or which resources are needed. For example, communication is needed for performing the functions directing and assisting, and is dependent on communication equipment, IB-plot/IB-net (a computer-based communication system), and information from other actors, to successfully perform those functions.

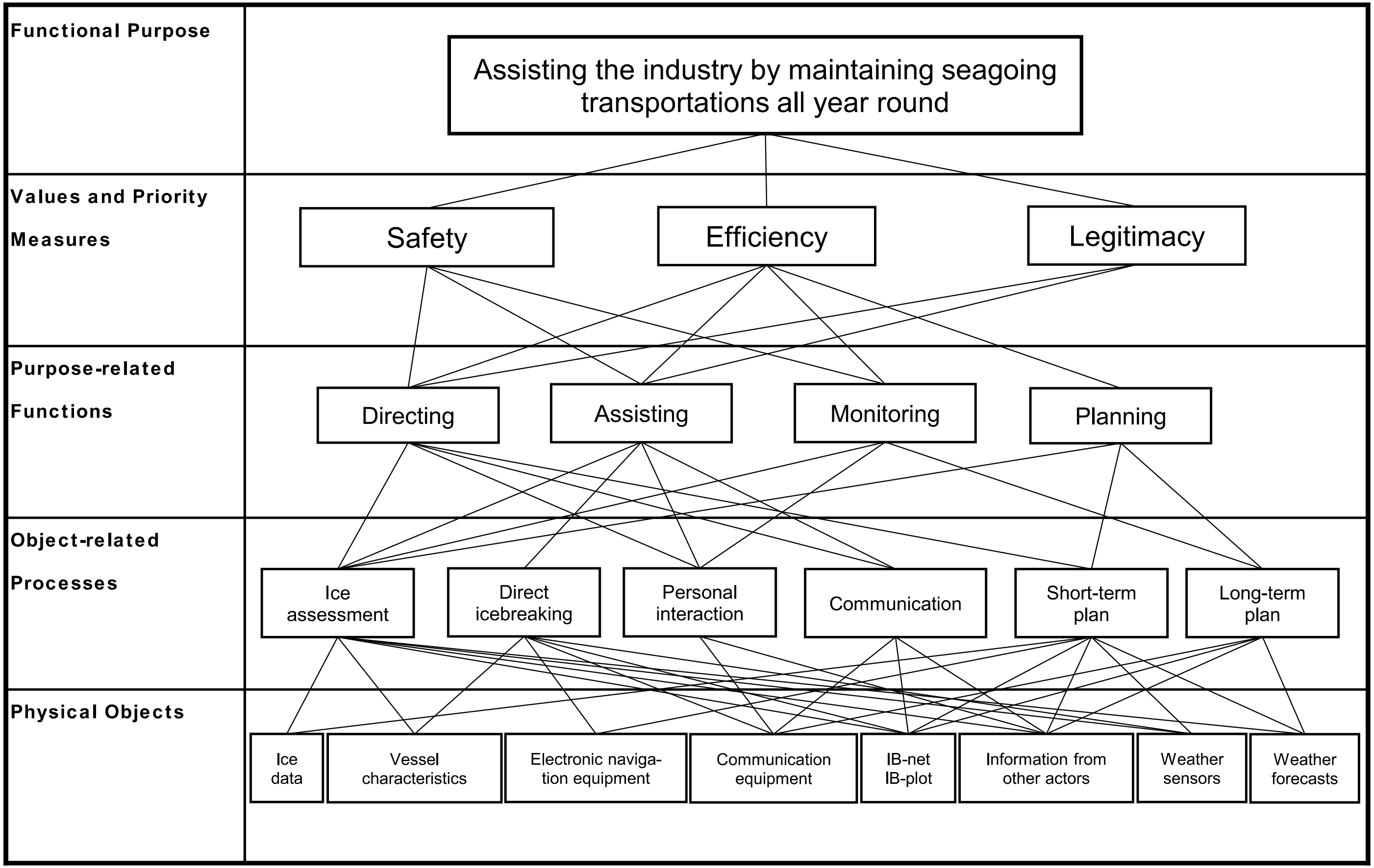

Figure 7. Abstraction Hierarchy illustrating the work of an icebreaker.

Moving up and down the AH is useful when considering what effect a constraint can have on the overall system. If a certain value and priority measure needs to be improved, the functions below should be the area of interest, as well as the subsequent processes and physical objects. Also, ensuring that a process runs smoothly by counteracting a constraint will lead to positive outcomes higher up in the AH, like ripples on water.

The number of means-ends links between functions can also inform us about the importance of a particular function or object. The loss of a resource on which many functions depend, i.e. one with many links to processes or functions higher up in the hierarchy, will thus have a significant effect on the system as a whole. Consequently, efforts have to be made to increase redundancy of those resources or functions.

3.1.2. Icebreaking as collaborative work

Successful icebreaker operations require a well-functioning teamwork both on board each vessel and perhaps even more important, between vessels. This has been emphasized by practitioners and researchers alike; for example, Jalonen et al. (2005) list good communication and mutual understanding as important elements. Similar results were found in one of the studies in this thesis; personal interaction and communication were two of several processes necessary to perform icebreaker operations (Boström, 2018).

Work on board is simultaneously carried out at several locations, e.g. in the engine room, galley, on deck, and on the bridge. On the latter, the master is ultimately responsible for the safety of the crew and vessel, and that adequate watchkeeping arrangements are in place to ensure a safe navigational watch. The officer on watch (OOW) acts on behalf of the master and is responsible at all times for the safe navigation of the ship and for complying with the collision regulations (IMO, 1978; TSFS 2012:67). The length of the watch depends on the number of navigational officers on board; common arrangements include a four-hour shift followed by eight hours of rest (with three OOWs) or a six-hour shift followed by six hours of rest (with two OOWs). In addition to the OOW, there must be a lookout present on the bridge. In daylight, it is possible for the OOW to be the sole lookout, provided the situation has been carefully assessed, taking into account for example the state of weather and traffic density. Under all other conditions, a separate lookout needs to be present on the bridge, a position ordinarily held by a deck rating. The master can decide other watchkeeping arrangements for other conditions, e.g. dense fog (IMO, 1978; TSFS 2012:67). Furthermore, at the discretion of the OOW, further reinforcements can be requested. The same regulations govern the composition of the bridge team of Swedish icebreakers, with one addition. During icebreaker operations, there are always two navigational officers present on the bridge; one is in charge of the watch and the other assists as appropriate (SMA, 2002).

A designated lookout on the watch should not undertake any duties that could interfere with the task of keeping a proper lookout (IMO, 1978; TSFS 2012:67). This means that the OOW performs all other tasks related to the safe navigation of the ship, including external communication. Normally, marine radios, including the VHF, have speakers; consequently, everyone on the bridge can hear what is being said and assist with interpretation. However, it should be noted that a navigational officer and a deck rating perform different tasks, and their positions require different training and certification (IMO, 1978). For example, a deck rating has no formal training in navigation and radio communication. Still, even without formal qualifications, any person can be of assistance when it comes to issues of hearing and interpretation, especially in a foreign language.

Both international (IMO, 1978) and national (TSFS 2012:67) legislation highlight the cooperative nature of watchkeeping. It falls on the OOW to give appropriate instructions and information to all watchkeeping personnel to ensure the keeping of a safe watch. Furthermore, the presence of a pilot on board does not relieve the OOW or master of their duties, and a close co-operation between the regular bridge team and the pilot is required.

Within the more general domain of maritime operations, teamwork has been identified as an area of concern. Miscommunication, and lack of communication, as well as coordination, have often been noted to reflect issues of poor bridge procedures and absence of teamwork (Mansson, Lutzhoft, & Brooks, 2017). The lack of communication was also mentioned by Brödje, Lundh, Jenvald, and Dahlman (2013), who showed that operators in a VTS sometimes refrained from communicating with pilots or officers about issues that they believed were already known. This was a display of trust. Furthermore, Bruno and Lützhöft (2010) found that communication and trust are closely related; they also recommended that deviations from communication protocols may be suitable at times, and that adapting the communication to the context can enhance trust between ship and shore stations. Finally, Costa, Lundh, and MacKinnon (2018) also discussed trust between VTS operators and ships. When vessels deviated from the practice of repeating and confirming messages, VTS operators sometimes let it pass, even though they were aware of the hazards associated with that practice.

Correspondingly, the medical domain shares some features of icebreaker operations; for example, there is little room for error, mistakes may have severe consequences, and co-operation is necessary for successful operations. There, communication plays a vital part. Researchers have shown positive effects of closed-loop communication, i.e. acknowledging information by repetition (El-Shafy et al., 2018; Schuenemeyer et al., 2017) as well as negative effects of open-loop communication, i.e. acknowledging information without repetition (Parush et al., 2011). When it comes to teamwork, Rydenfält, Borell, and Erlingsdottir (2019) concluded that there is a variation in the way doctors understand the concept. Still, one of the most commonly mentioned factors necessary for good teamwork was good communication skills.

Even though there is limited research on teamwork within icebreaking, research within other areas suggests that communication is an important element of collaboration or teamwork. But to say that people at sea just need to communicate for collaboration to work is a simplification. There needs to be suitable means for communication, as well as a common language.

3.2. Operational safety

Maritime safety management has largely been concerned with what can go wrong, and how safe outcomes can be prescribed by, for example, standard operating procedures. However, since icebreaker operations are characterized by variability and uncertainty, operators need to be able to adapt as necessary since there is not just one way to assist vessels in ice.

The way safety is presented in this section, represents my standpoint on safety management of complex systems. I argue that there is no silver bullet or universal solution when facing countless variables. Instead, by helping the operator by clearly framing the boundaries, e.g. through training, and by creating an organization built on competence, trust, and fairness (Grote, 2015), a sound basis is provided for the operator to facilitate appropriate decision making within a complex system.

3.2.1. Safety management of icebreaker operations

Traditionally, maritime safety management has been concerned with learning from accidents. As an example regarding icebreaker operations, Valdez Banda et al. (2016) identified ship-to-ship collisions as the most common accident during winter navigation. This type of accident accounted for half of the accidents in ship independent navigation, and around 95% of the accidents during icebreaker operations. Franck and Holm Roos (2013) reached a similar conclusion. They examined all accidents involving Swedish icebreakers, reported to the Swedish Maritime Administration and the Swedish Transport Agency. This amounted to 19 cases between 1985 and 2012. Of these, all accidents occurred during icebreaker assistance, and the main contributing factor was the difficulty posed by assessing the ice conditions, i.e. how tough the ice was. In a majority of these cases, the short distance between the vessels contributed to the collision, and in some situations the collision was further aggravated by the high speed maintained by the vessels to avoid becoming beset by the ice. While Franck and Holm Roos (2013) studied records of accidents, Boström (2018) interviewed icebreaker crews, who also stated that ice assessment was a vital, yet cognitively challenging task. The unpredictability of the ice as well as its changeability is an aggravating circumstance that requires the icebreaker to constantly adjust the distance to the assisted vessel (Boström

& Österman, 2017). Furthermore, Franck and Holm Roos (2013) highlighted the necessary trade-off between keeping a safe distance and successfully managing the ice. The safe way would be to simply increase the distance between the vessels, giving the assisted vessel time to stop if the icebreaker suddenly got stuck. However, as the distance increases, so does the risk for the assisted vessel to get repeatedly beset.

The effects of accidents during winter navigation and icebreaker operations are multifactorial, and can potentially put human lives at risk, damage the environment, and cause costly operational disturbances (Chai et al., 2017; Karahalios, 2014). Damages to vessels can be divided into two categories. First, effects following ship independent navigation can be caused by, for example, severe weather and difficult circumstances, resulting in structural damages to the ship's hull and rudder (House et al., 2010). Second, effects following collisions between two or more vessels, e.g. when breaking loose a vessel that is beset in ice, or during convoy operations, can have varying consequences. Collisions in an ice channel can occur if the icebreaker comes to a sudden stop due to impenetrable ice and the assisted vessel is unable to reduce its speed in time. Due to their structural differences, such accidents often result in minor damage to the icebreaker (Figure 8), while the escorted vessel might become severely damaged (Figure 9).

Figure 8. Damage suffered by the icebreaker following a collision in ice channel.

Figure 9. Damage suffered by the assisted vessel following a collision in ice channel.

Jalonen et al. (2005) conducted an extensive risk analysis of winter navigation in the Baltic Sea. Their emphasis was on environmental factors such as ice strength, wind, and visibility. Similarly, Kujala and Arughadhoss (2012) studied the ice crushing pressure on a ship's hull, which also relates to the safety of winter navigation. However, in addition to external environmental factors, Jalonen et al. (2005) also acknowledged contributing risk factors stemming from technical, as well as human and organizational factors. Both experience of ice and communication were mentioned as important. Communication, in particular, was stated as a way to mitigate risks. In an escort situation, it might be necessary to deviate from rules concerning safe navigation; however, that can only be done if the communication is sufficient to establish a common understanding about the proposed deviation.

Another risk analysis of winter navigation was conducted by Valdez Banda, Goerlandt, Montewka, and Kujala (2015), who examined ice-related accident data, ice charts related to those accidents, as well as expert assessment. They showed that most accidents involved general cargo vessels or ro-pax vessels below 10,000 deadweight tons and occurred in consolidated ice of between 15 and 40 centimetres. However, the results indicated that the majority of accidents in ice were classified as less serious. Following these results, Goerlandt, Montewka, Zhang, and Kujala (2017) further analysed convoy operations by combining Automatic Identification System (AIS) data with ice hindsight data to accumulate knowledge concerning such operations. Distance between vessels and transit speed under different ice conditions were intended to support decision making, increasing wintertime maritime safety. Lately, the use of big data has spread to the field of winter navigation. Lensu and Goerlandt (2019) compiled a large data base with nine years' worth of AIS data combined with marine environmental data (ice data). Furthermore, they demonstrated a number of applications, e.g. calculating the reduction of speed due to increased ice thickness.

Valdez Banda et al. (2016) presented a risk management model for winter navigation operations, which also takes environmental effects into account. The authors argue that ship independent navigation and convoys are linked to a higher probability of oil spills. However, major oil spills (>15,000 tons) are possible, yet unlikely.

Solid information about ice type and thickness reduces the risk of getting stuck in tough ice and ending up in dangerous areas, but an optimized route also holds potential for reducing fuel consumption and travel time (Kotovirta, Jalonen, Axell, Riska, & Berglund, 2009). Based on available ice data, Kotovirta et al. (2009) presented a system for route optimization by integrating ice modelling with a ship transit model. It included an end-user system that has been validated by vessels in the Baltic Sea.

In summary, previous safety related research within the field of winter navigation has mainly employed a technical and/or environmental focus; operator centred research within winter navigation is sparse. At the same time, several researchers have indicated the importance and need for teamwork and co-operation for safe operations.

3.2.2. From reactivity to proactivity

Traditionally, maritime safety has been concerned with identifying and rectifying underlying causes of accidents. The logic behind this approach is the *causality credo*, the belief that accidents are caused by mechanisms, or a series of events, that once they have been identified can be eliminated and prevented (Schröder-Hinrichs, Hollnagel, & Baldauf, 2012). In other words, adverse outcomes are the result of something going wrong, and by treating or eliminating the causes, future accidents will be avoided (Hollnagel, 2014a). Solutions within this approach are mainly placed on designing errors out of the systems and to some extent replacing humans with increased automation. This way of addressing safety issues is attributed as Safety I (Hollnagel, 2014b). Consequently, maritime safety has largely been reactive, utilising legislation, quantitative risk mitigation, automatization, and training of operators to manage increasingly complex systems (Schröder-Hinrichs, Hollnagel, Baldauf, Hofmann, & Kataria, 2013). This reactive approach has a significant drawback. Due to the limited number of serious outcomes there is a lack of information regarding the overall safety of the system.

In contrast to managing the causes of accidents, with what Hollnagel (2014b) labelled a Safety II-perspective, the focus is shifted towards successful, or at least acceptable performances. Here, emphasis is placed on what constitutes normal operations and how safety can be promoted to reach such operational standards. Weick (1987, p. 118) noted that "reliability is both dynamic and invisible, and this creates problems". It is dynamic in the sense that people and systems vary in their everyday performance, thus functional resonance may occur. Therefore, safety can be seen as a dynamic non-event (Weick, 2011) that is continuously re-accomplished when the system successfully adjusts to the contextual demands of the environment and situation. People are generally unaware of how many mistakes they could have made but did not. These non-events are constant, meaning that there is nothing to pay attention to. An operator who observes no abnormalities might conclude that by simply continuing the same way, nothing will continue to happen. However, such a conclusion would be deceptive, assuming that dynamic inputs would create stable outcomes (Weick, 1987).

To meet dynamic and unpredictable conditions, rather than fighting deviations from a predefined procedure, "the focus should be on the control of behaviour by *making the boundaries explicit and known* and by giving opportunities to develop *coping skills at boundaries*" (Rasmussen, 1997, p. 191). Similarly, Dekker (2019, p. 412) stresses that giving people "freedom within a frame" is the only viable approach for a complex system to remain adaptive in a dynamic world. However, when faced with uncertainty, a natural response might be to bury one's head in the sand. But instead, Grote (2015) argues that strategies for managing uncertainty should be a natural part of risk management. *Reducing*, *maintaining* or *increasing* uncertainty are three options which could be considered, each founded on different conceptions of risk control. For complex icebreaker operations, a suitable approach would be to maintain uncertainty, achieved by striking a balance between flexibility and stability, delegating control, and through empowerment of the actors. To achieve this, it is important to establish flexible rules (Grote, 2015; Grote, Weichbrodt, Günter, Zala-Mezö, & Künzle, 2009). Three types of rules are distinguished, depending on the amount of guidance they provide: *goal rules* define the goal without specifying how it should be reached; *process rules* provide guidance for how the goal is to be reached, sometimes providing several options; and *action rules* prescribe a desired procedure. By using goal and process rules, the operator can be strengthened in his or her decision making, and safety can be supported since "both sufficient openness and guidance for adaptive action is provided" (Grote, 2015, p. 75). However, flexibility should not be used to allow rules to be violated, nor should it be an excuse for ill-specified rules.

In summary, contemporary safety management in complex situations should be based on empowerment rather than control, giving the operators freedom within a frame. As argued by Dekker (2019), in a changing world, the only way for a system to remain adaptive is if uncertainties are met with fewer regulations and more freedom. The everyday operations all take place within the boundary of a system's constraints. As long as one stays within this boundary, the operator has a large degree of freedom to act in response to varying and uncertain conditions, and still remain within what can be described as normal operations.

3.3. Communication

This section describes the basis of maritime communication, linking common models of communication with the technical properties of the VHF radio and practices at sea, which is in focus in Papers III and IV. Furthermore, this section provides a brief introduction to theories governing interpersonal communication, and ship-to-ship communication.

3.3.1. Models of communication

Definitions of communication often take the Latin root *communicare* as a vantage point, meaning *to share* or *to be in relation with* (Cobley & Schulz, 2013). Common definitions of communication include the exchange of information, and Martin and Nakayama (2013) note that the defining feature of communication is meaning; communication is what happens when someone makes meaning of another person's words or actions. Schramm (1971, p. 13) uses the term very broadly and simply defines communication as "the sharing of an orientation toward a set of informational signs". Schramm (1971) emphasizes that information is anything that reduces the uncertainty or the number of interpretations of a situation; facts, opinions and emotions, as well as latent meanings and silent language, are all information that is used to influence others, who in turn comprehend the information in their own way. Consequently, the relationship between people is central to Schramm's view.

Interpersonal communication is often described using sport or game metaphors. Griffin, Ledbetter, and Sparks (2015) compare communication to bowling, ping-pong and charades. These metaphors are useful to introduce the reader to a number of common models of communication.

The bowling metaphor implies that communication is exclusively performed by one person. The bowler is the sender, who delivers the message by throwing the ball down the lane, and as long as the ball is well aimed, it will strike the passive pins, just as a perfectly delivered message is thought to be received by a passive listener. This metaphor assumes that the target listeners are static, waiting to be swept off their feet just like bowling pins (Griffin et al., 2015). Several early models of communication stem from mass communication in the form of propaganda during World War I. In the early days of mass communication, the media was seen as a powerful source, and a common idea was to view the audience as a passive, sitting target, and as long as the communicator could hit that target, it would be affected. This has been called the Bullet Theory (Schramm, 1971) or Hypodermic Needle model (Eadie & Goret, 2013), the latter suggesting that the audience could be injected with a message. Such models of communication are linear and can be exemplified by the Shannon-Weaver model of communication (Figure 10).

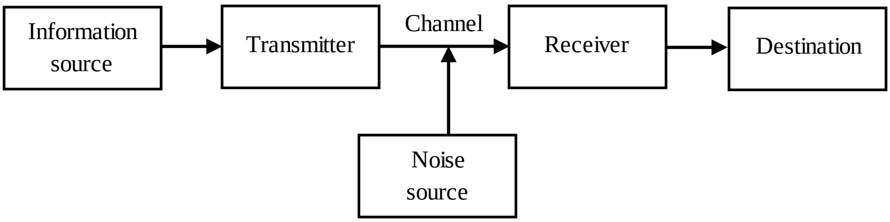

Figure 10. Shannon-Weaver model of communication.

In the Shannon-Weaver model (Shannon, 1948), an information source, i.e. the sender, initiates the process by formulating a message. The message is converted by the transmitter, and delivered through the appropriate channel to the receiver, where the message is converted back to its original form and delivered to the recipient at the destination. The channel, or medium, is the infrastructure that gets the message from the transmitter to the receiver. During this transfer, the signal might get distorted by external noise sources. The noise was central to Shannon and Weaver, who defined information as “the reduction of uncertainty” and noise as “pure uncertainty” (Eadie & Goret, 2013, p. 24). Consequently, they were concerned with the acceptable amount of noise that could be tolerated before a message would be transmitted inaccurately. The Shannon-Weaver model is, through its simplicity, a good starting point for understanding communication systems. At the time when it was first introduced, it was revolutionary because it showed how noise interfered and distorted messages. However, people are different and unpredictable, and communication theories that only emphasize the sender are rarely realistic. Furthermore, there are major disadvantages that make such models insufficient for explaining maritime communication. Most importantly, the linear models do not include means for feedback. In response to the shortcomings of linear models, several circular models emerged.

In contrast to the bowling metaphor, the ping-pong metaphor shows communication to have more than one player. One player puts the conversational ball in play, and from that moment two players take turns playing the ball, just like they would send and receive a message (Griffin et al., 2015). One such model was put forward by Wilbur Schramm and Charles Osgood (Schramm, 1971).

In critique to the linear models, Schramm (1954, p. 8) wrote:

> In fact, it is misleading to think of the communication process as starting somewhere and ending somewhere. It is really endless. We are switchboard centers handling and rerouting the great endless current of information.

In the Osgood-Schramm model each person alternates as sender and receiver (Figure 11), which offers a feedback mechanism that was missing in earlier linear models.

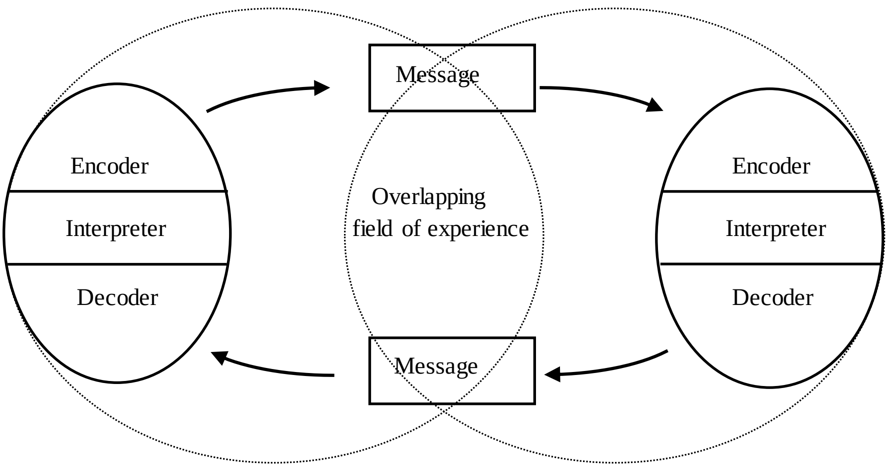

Figure 11. Osgood-Schramm model with overlapping fields of experience.

Within this circular communication sequence, each person has three roles. The person wanting to send a message first has to encode it, i.e. think of what one wants to say and then craft an appropriate message. The encoded message is then transmitted to the receiver which in turn has to decode it. This is done by putting together speech, images or any other type of information that has been transmitted. It is at this stage that the receiver of a message might mishear or misread the information, e.g. if speech is cluttered by background noise. This will in turn interfere with the subsequent interpretation of the message, which is the final step in each sequence. People might interpret the same message differently, so here there is a risk of misinterpretation. However, no matter whether the message is interpreted as intended or not, the roles then shift, and the receiver can go about encoding his or her own message to send back to the original sender, thus continuing the circular sequence.

The encoding, decoding and interpretation of a message is shaped by one's beliefs, values and previous experiences. To successfully communicate, two people need to have at least some degree of overlapping fields of experience (Schramm, 1971). Field of experience (or commonality) incorporates what is mutually understood between the sender and the receiver, and if there is no overlap they will have a hard time understanding each other. Nonetheless, after a while, you might get to know your ping-pong opponent and adjust to his or her style. Similarly, the more you talk to the same person, the better a conversation partner you become, one could argue.

Another scholar who stressed the interpretative nature of communication was Stuart Hall (1980). Before a message can be transmitted, it needs to be produced, and this encoding process takes place in a specific context, shaped by, for example, knowledge-in-use within that field, professional ideologies, and assumptions about the receiver. The message is then transmitted as a sort of *meaningful discourse*. At the receiving end, before the output can have an effect, the discourse needs to be decoded, and just as with encoding, this process is also influenced by current practices and assumptions. Hall (1980) also emphasized that there might be a discrepancy between the outgoing (encoded) and incoming (decoded) messages. Furthermore, distortions or misunderstandings are caused by this "*lack of equivalence* between the two sides in the communicative exchange" (Hall, 1980, p. 166), a concept that corresponds to Schramm's overlapping (or non-overlapping) fields of experience.

Finally, the charades metaphor differs from the previous two because it is a mutual game that, just like communication, can be characterized as a transaction. It is an ongoing process where both parties send, receive, and adapt their messages, both verbal and non-verbal, to create a shared mental image. Initially the images might diverge, but just as with charades, the joint efforts of successful communication will increase the overlap between the two images.

Compared to the charades metaphor, Griffin et al. (2015) argue that the ping-pong metaphor has two faults. First, interpersonal interaction, often in the form of face-to-face communication, involves multiple simultaneous messages, instead of a single repetitive back and forth motion as in ping-pong. Essentially, there is no clear divide between the speaker and the listener; both verbal and non-verbal messages are continuously sent and interpreted. Second, the metaphor is misleading since in the case of successful communication, unlike a competitive game, everybody wins.

Even though Griffin et al. (2015) consider the charades metaphor best suited for describing interpersonal communication, and I agree that to be the case for everyday face-to-face communication, there are a number of reasons that make me favour the ping-pong metaphor to describe ship-to-ship communication. To start, many marine radio channels used for communication between vessels are half-duplex channels, meaning that they broadcast and receive messages on the same frequency. As a result only one person can talk at a time; the listener has to remain silent and all parties must adhere to proper turn-taking (Sidnell, 2010). Another condition that contradicts the charades metaphor is that the participants are not co-located and therefore lack non-verbal cues. Last, most communication between vessels at sea is brief and seldom reoccurring. That makes getting to know your conversational partner difficult; most of the time, encountering a new vessel means starting from scratch.

Consequently, I argue that the Osgood-Schramm model (Figure 11) is well suited to depict maritime communication. It clearly shows the circular nature of the VHF radio with its sharp distinction between speaker and listener, with rotating roles. Furthermore, the fact that a message is not merely transmitted, but also encoded, decoded and interpreted, fits well with the international characteristics of shipping. With the multitude of nationalities on board the world fleet and the possibility for a vessel to operate almost anywhere in the world, VHF communication is likely to be conducted between people with different first languages and cultural backgrounds. Thus, interpretation will depend on various factors, some of them beyond the control of the sender of a message. Similarly, the field of experience also puts emphasis on the interpretative nature of communication. However, the concept contains a wide array of factors, such as attitudes, beliefs and values, as well as previous experiences. In the specific context of icebreaker operations, the latter is crucial. Previous experience of winter navigation and icebreaker operations are important for safe and efficient operations in ice, and that experience will vary greatly between vessels and seafarers (Boström & Österman, 2017). An experience gap between people is likely to limit the overlapping field of experience, hampering the interpretation of messages. To summarize, the Osgood-Schramm model of communication satisfactorily illustrates the complexity of interpersonal communication at sea, with its circular motion and clear boundary between speaker and listener caused by the technical limitation of the VHF, which only permits one speaker at a time.

3.3.2. Communication within the maritime domain

Today the main language spoken at sea is English, but that has not always been the case. During the 16th and 17th centuries, the Dutch language dominated the maritime domain, due to the Dutch domination as a seafaring nation. But with a shift of power in the maritime domain, from the Dutch to the British Empire, English slowly became the *lingua franca* during the 18th century. Still, many English maritime words originate from Dutch, e.g. iceberg (ijsberg) and buoy (boei) (Molt, 2006). However, it was not until 1973 that the IMO Maritime Safety Committee agreed that “where language difficulties arise, a common language should be used for navigational purposes and that language should be English” (IMO, 2001, p. 3). Having introduced a formal language requirement, it was also deemed necessary to standardize the language into a maritime version of English. To facilitate this standardization, in 1977 IMO adopted the Standard Marine Navigational Vocabulary (SMNV). However, this effort was not enough, and a more comprehensive version of the SMNV was needed, one that covered more safety related verbal communication. This resulted in the Standard Marine Communication Phrases (SMCP), adopted and implemented in 2001, which in addition to designating English as the key language, also included specific phrases meant to improve communication among and between multilingual crews and others involved in the safety of shipping (IMO, 2001; Katarzynska, 2009).

The main purpose of the SMCP is to provide a precise, simple and unambiguous way to communicate between vessels (ship-to-ship), between vessels and costal stations (ship-to-shore) and on board vessels (intra-ship). There are a number of main features of the SMCP: a simplified grammar, a glossary with technical and nautical terms, and standard phrases covering many situations and conditions at sea (IMO, 2001). Furthermore, depending on nationality, most individuals already have a certain level of English before learning SMCP, and the SMCP is meant to bridge the gap between these different levels. A person speaking at an advanced level will not be understood by a person with very basic English skills. Or language difficulties might arise during communication between a native and non-native English speaker, as illustrated by Clare (2017, p. 168):

> On the European side communication was no problem. We were all Finnish; they were all Dutch; we all spoke English. But when you get to the UK they can't understand anything we are saying and they are using all these strange words.

With this in mind, it is not only important for seafarers with limited English skills to master the SMCP. It is equally important for those with a good command of the English language to know the SMCP and somewhat simplify the language used. By doing so, two individuals can meet at a mutual level, increasing the chances of the communication being successful (Trenkner, 2010).

The adoption of the SMCP by IMO was meant to improve the communication among and between multilingual crews at sea. However, Sampson and Zhao (2003) suggested that simply introducing an improved Maritime English with technical vocabulary, i.e. a *top-down approach*, is not enough to improve the language skills among crew members. The authors suggested a *bottom-up approach* instead, where crew members need basic general English skills prior to setting foot on a multilingual vessel. That will enable them to engage in conversation to a larger extent, something that is crucial for further developing one's language skills.

Diversity among crews might also have implications for wellbeing and safety on board. Pauksztat (2019) studied the effects on informal relations, i.e. friendship, based on crew members' English proficiency as well as first language. The findings indicated that proficiency in English increased the chances of people discussing problems, which in turn made them make suggestions and point out problems. Having the same first language resulted in a similar outcome; however, that was mediated through a friendship relation formed by a shared first language. To facilitate informal discussions, Pauksztat (2019) also suggests that the shared language proficiency on board cannot be limited to a technical vocabulary and selected phrases, a more comprehensive language training is necessary.

In addition to having means to communicate clearly, it is also necessary to have a way of knowing whether a message has been received as intended. Therefore, the SMCP states that when responding to a question, it is not sufficient to provide a yes/no answer, it also has to be followed by the appropriate phrase in full. The same applies when confirming an instruction or a piece of advice (IMO, 2001). This concept of repeating and confirming a message is known as closed-loop communication and has a central role in Paper III. Closed-loop communication is a mechanism for providing feedback on messages. It can be defined as a three-step process where "a message is sent by a team member, another team member provides feedback regarding the received message, and the originating team member then verifies that the *intended* message was received" (Flin, O'Connor, & Crichton, 2008, p. 105). In other words, it is a circular way to confirm or test one's interpretation of a message. Closed-loop communication is commonly used, for example, within the maritime traffic monitoring system (Brödje et al., 2013), but also within other safety critical domains, such as healthcare (El-Shafy et al., 2018; Schuenemeyer et al., 2017) and aviation (Barshi & Farris, 2016). Furthermore, Froholdt (2016) describes the function of the readback, the repetition of a message exactly as received. However, both Brödje et al. (2013) and Froholdt (2016) state that these practices are not always followed as stipulated in the SMCP. A deviation from recommended communication practices is also noted by Pritchard and Kalogjera (2000) in their study of authentic maritime communication. Consequently, both Pritchard and Kalogjera (2000) and Bocanegra-Valle (2011) stress the need to further investigate this gap of compliance.

The role of verbal communication in ship-to-ship and ship-to-shore communication has been debated. The MARCOM Project (1999, p. 137) examined maritime ship-to-shore communication and concluded that increased use of automatic data-transmission was expected to have a number of positive effects. One of these would be to "do away with the need for most verbal communication". However, in contrast to the MARCOM Project (1999), which advocated less communication, Froholdt (2016, p. 488) concluded that such a development would be unlikely since "spoken interaction is used to create a joint understanding of institutional practices". Even when automated information systems are used, verbal communication offers means to verify and coordinate the exchange of information.

Finally, it should be noted that the choice of communication channel makes a difference. Using an open, unencrypted communication channel such as a marine VHF instead of, for example, a mobile phone has one unsurpassed positive effect; since anyone can listen in on the conversation, other people who are not directly involved in the present operation can remain "in the loop". VTS operators use the possibility to overhear other vessels as a means to verify that the traffic situation is under control (Costa et al., 2018). Similarly, the advantage of overhearing is one reason why IMO stresses that English should be used (2001). This also means that when action or information is needed from someone other than the two primary interlocutors, it can be provided hastily.

3.4. Concluding remarks on organization, safety, and communication

This chapter has provided the reader with the basics of the three pillars on which this thesis rests: organization of work, operational safety, and interpersonal communication. The organization of work on board the icebreakers, which is manifested through the analysis of the work domain and illustrated in the abstraction hierarchy, is central in this thesis since it defines the "playing field", or the rules that the system has to follow (Birrell et al., 2012). Within any domain, there are numerous factors that limit the overall conduct of a system. However, by identifying these constraints and finding ways to counteract them, the system performance can be increased (Goldratt, 1988). The work domain analysis also links the constraints together, showing how parts of the system interact.

The theories presented in this chapter can all be seen as individual pieces of knowledge about a defined topic. However, according to Dekker (2015), it is the *interaction* between system components that gives rise to a complex behaviour, and consequently, it is first when the system is viewed in its entirety that we really can observe the complexity. For example, when operators who already face variable and unpredictable conditions within their system also are required to interact within a distributed team, complexity is increased. While some individuals interact with ease, others might find it complex due to the interpretive nature of communication, influenced by the speaker's field of experience (Schramm, 1971). And when an operator faced with an unpredictable new problem is bound by rigid action rules and not given the right means or support to make proper decisions (Grote, 2015), that is an organizational aspect which adds to the complexity.

The icebreaker's work has been described in terms of *uncertainty*, *variability*, and *adaptability*, terms that embody a proactive mind-set. Still, even if the overall purpose and goal of a system is made known, the question is how the actors can be assisted in reaching that goal. It is suggested that making the boundaries explicit to the operators, providing sufficient freedom to act within their given frame is a suitable solution (Dekker, 2019; Rasmussen, 1997). Such flexibility should be realized through education and training, awareness, and support from supervisors and fellow team members (Grote, 2015).

The papers appended to this thesis address the topics of organization, safety, and communication respectively. Given the intertwined nature of the topics presented, I prefer not to give precedence to any one of them over the other. That is also the reason why they are characterized as three lenses in the introductory chapter; they offer different views which together form a whole. Or, as stated in the preface; each contributing factor is only one LEGO brick, but put together, you get something that is bigger than the parts. You get complexity.

4. Methods and material

This chapter provides an overview of the methods and material used in the thesis. First, a summary of the methods used for data collection and analysis will be offered. Then, the ethical considerations made throughout the research work will be described, followed by a discussion about trustworthiness and transferability. Hopefully, the latter will guide the reader in deciding if, and how, the findings can be applicable to other domains. Finally, the research limitations of this thesis are described.

4.1. Methods for data collection and analysis

This section presents an overview of the methods used in this thesis. For a detailed account, the reader is referred to the individual papers. For the initial stage of this PhD project in which the organization of work was studied (Paper I), a group of subject matter experts was purposively recruited. The transcript from a group interview was analysed using a thematic analysis with a top-down approach (Braun & Clarke, 2006). Subsequently, the data were coded, structured into themes, and used as a basis when constructing the abstraction hierarchy.

As for the study about operational safety of icebreaker operations (Paper II), two sets of groups (officers on icebreakers and merchant vessels respectively) were used to elicit rich data on potential safety concerns based on the respondents' knowledge and experience. The data for this study were collected by performing individual interviews with icebreaker officers, to get insights about how they perceive their situation with regard to icebreaker operations, co-operation and communication between vessels. The interviews were transcribed, coded, and structured into themes using content analysis (Krippendorff, 2004). In addition, a questionnaire was used to obtain corresponding data from officers on board merchant vessels. The interviews and questionnaire covered the same topics.

A substantial part of this research has dealt with communication, from both a quantitative and qualitative standpoint. To be able to study communication, a large set of authentic VHF communication was recorded on board an icebreaker. The data were initially transcribed into a *clean verbatim* transcript, i.e. a word-for-word transcript but without filler words and indication of pauses, and used as a basis in the studies described in Papers III and IV. What followed in Paper III was a coding process in which the message content was classified in accordance to SMCP's message markers (IMO, 2001). Furthermore, the different practices of replying to a previous message were coded, to allow a quantitative description of the use of closed-loop communication.

For the study presented in Paper IV, the same transcript was used to identify sequences of other-initiated repair (Kendrick, 2015), i.e. when people signal problematic talk. Subsequently, Conversation Analysis was used "to locate and describe the practices of human conduct" (Sidnell, 2010, p. 28). For this to be possible, the sequences were transcribed in more detail to show not only *what* was being said, but also *how* it was being said. The data were finally coded and categorized according to type of repair and repair solution (Dingemanse et al., 2015).

Communication as a theme appeared in several studies, and could therefore be observed from a number of different perspectives:

- The need for communication for successful icebreaker operations (language as needed) was studied in Paper I.
- The perceived image of how the communication works (language as imagined) was studied in Paper II.
- The recorded version of the communication (language as it is) was studied in Papers III and IV.
- The mandated way of speaking, i.e. the SMCP, was used as a yardstick (language as stipulated) in contrast to the collected data.

One reason for combining interviews and recorded communication has to do with research reactivity. Reactivity occurs when the study subject is affected, either by the set-up of the study itself, e.g. in an artificial or controlled environment, or by the presence of the researcher, e.g. during observation. Since peoples' behaviour changes as a result of the measurement process, it is therefore difficult to distinguish between typical, real behaviour and behaviour induced by the measurement (Marrelli, 2007). Furthermore, when interacting with others, both in research situations and everyday life, people present themselves differently depending on the situation (Goffman, 1959), and consequently, the relationship between researcher and the field is an aspect that has to be taken into account. Webb, Campbell, Schwartz, and Sechrest (1966) were pioneers in nonreactive research in social science, and creators of the term *unobtrusive measures*. Contrived observations, such as using hidden recording equipment, is one way to reduce reactivity. The recording equipment on board the icebreaker was not hidden, the equipment was located in plain sight. It is possible that the crew members altered their behaviour at first. However, the effect of this may erode over time (Webb et al., 1966).

Another reason for combining interviews and recordings was to approach the complexity of icebreaker operations from different standpoints. Relying solely on recordings would not provide the full picture, since “the data, like so many simple observational data, don’t offer the ‘why’, but simply establish a relationship” (Webb et al., 1966, p. 127). The interviews added insights which could not have been derived exclusively from the recordings.

4.2. Data sample

The data presented in this thesis are collected from different sources, and the means used for data collection have been governed by the respective purpose of each study. These are described in more detail in the individual papers. However, the following provides a brief overview of the complete data set along with a quantification of the data in Table 2.

Table 2. The data sets used in this thesis.

Paper	Type of data	Amount
Paper I	Focused group interview with four experts	2.5 hrs
Paper II	Seven individual interviews (30–45 min each) 22 individual questionnaires	4 hrs
Paper III	Authentic ship-to-ship communication	2,825 loops
Paper IV	Authentic ship-to-ship communication	8,366 turns

The study presented in Paper I was based on a group interview with four experienced icebreaker officers. They all held onboard positions within the nautical department of a Swedish icebreaker, and had different ranks: two 2nd officers, one chief officer, and one master. This was deemed valuable to provide perspectives stemming from different experiences on the basis of their positions. The purpose of the interview was to gain insights into how the respondents, from their individual positions, perceived the roles of the icebreaker and the resources required to fulfil those roles. The interactive nature of a group interview fuelled the conversation.

The study in Paper II sought to gain views from officers on both icebreakers and merchant vessels receiving icebreaker assistance, on topics related to safety during icebreaker operations. Icebreaker officers were reached in person; the link to the merchant vessels was established through local ship agents (contact persons) along the coast of northern Sweden. Since the time a vessel spends in port is relatively short, and the number of vessels calling at ports in that area is relatively small, a questionnaire was used to receive their views over a period of time.

Finally, the studies in Papers III and IV were based on recorded ship-to-ship communication. A total of 40 days of communication was recorded, including all verbal icebreaker related communication between one icebreaker and the vessels receiving assistance from that icebreaker. Since the amount of talk is unevenly distributed over time, depending on the amount of traffic and ice conditions, it is difficult to estimate the amount of talk in hours. Instead, turns and loops are used. One turn is the talk produced by one part of a conversation, until the turn is handed over and the other part initiates the next turn. In VHF communication, this is done when the current speaker releases the "press-to-talk" button; then the next speaker can press and talk, thus initiating the next turn. One loop, on the other hand, consists of a message, a response, and a confirmation, i.e. three turns distributed between two individuals. These two ways of quantifying the data reflect the character of the respective paper; Paper III sought to study the use of closed-loop communication, while paper IV identified trouble turns to study the use of repair. However, the recorded communication is the same, it is only the quantification that differs.

Many issues surfaced in more than one data set. For example, safety concerns and communication practices were raised in the data obtained for the first two papers. The same issues could then be observed in the recorded material. These data sets supplement each other well.

4.3. Ethics

Ethical considerations have been made through different stages of research. First, it should be noted that even though this thesis has been almost entirely funded by external sources, the funders have not in any way influenced the orientation of the research, decided the means for data collection or study participants, or influenced the way that findings were derived or presented.

When interviews were used, these were conducted in accordance with good research practice (Swedish Research Council, 2017). The participants were informed about the study aim, their participation, and how the data would be utilized. The voluntary nature of the interviews was stressed, as well as the fact that participation could be ended at any time without having to provide an explanation.

Careful deliberations were also made prior to recording communication on board the icebreaker. First, all nautical crew members were informed about the purpose of the data collection, and provided an informed consent. This information was provided in written form, so that it could be reviewed at any time. Furthermore, means were provided so that the recording could be temporarily disabled, allowing anyone who desired to opt out from participating without leaving any record showing who had done so. However, no one objected to being recorded. The crews on board the merchant vessels with which the icebreaker communicated were not informed about the study or the recording of conversations. This was deemed unfeasible. Having the icebreaker crew brief their forthcoming conversational partners about the study would have required extensive work. From a research perspective, it is an obtrusive measure likely to make the participants self-conscious, resulting in abnormal conversations. But more important, it would have hampered the natural interaction, possibly resulting in safety complications. Furthermore, the communication was conducted on an open radio channel, allowing anyone to listen on the conversations. Finally, the nature of the communication was expected to be strictly work related, and not cover any sensitive topics, which in retrospect also proved to be true.

After being retrieved from the icebreaker, the recordings, which were stored on an external hard drive, were kept and handled in a safe manner. They were not left unattended and no unauthorized personnel had access to them. When not used for transcribing, the hard drive was stored in a fire-proof safe.

Lastly, the population of Swedish icebreakers and their crews is relatively small. Therefore, measures have been taken to ensure anonymity. Vessel names, geographical locations, and similar data of individual character have been omitted or altered from the transcript when presented. Only the main author listened to the actual recordings; supervisors and peers read the de-identified transcript. Furthermore, the researcher is not familiar with the study subjects, and is consequently not in a position to attribute a specific person to any individual recording. This would have been different if the researcher had been present on the bridge.

4.4. Trustworthiness

The trustworthiness of research needs to have a central role in the design of any research project, and in the dissemination of its results. Traditionally, trustworthiness has been discussed in terms of internal and external validity, reliability, and objectivity. While these concepts have proved useful within some aspects of quantitative research fields, some researchers within, for example, social sciences have rejected these frameworks, arguing for other standards for judging the quality of research (Trochim, 2020). Based on the seminal work by Lincoln and Guba (1985) I will here describe the criteria commonly used within qualitative research traditions and how they have guided the work presented in this thesis. The four principles proposed by Lincoln and Guba (1985) for assessing trustworthiness of naturalistic inquiries are credibility, transferability, dependability, and confirmability.

Credibility refers to whether the results of the research are believable from the viewpoint of the study subjects. There are several ways to establish credibility. One is through triangulation, e.g. by using multiple and different sources (Lincoln & Guba, 1985). Here, credibility has been sought by combining data from interviews, questionnaires, and observations (voice recordings), all of which deal with similar topics, or rather, contribute to an overarching ambition to understand complexity. Furthermore, credibility can also be increased by choosing participants with various experiences; this is the reason why purposive recruitment through expert sampling (Etikan, Musa, & Alkassim, 2016) was used for the interviews in Papers I and II. Finally, at times, member checks have been used to establish credible findings. This is the practice of testing interpretations and conclusions with members of the stake holding groups. For example, after conducting a group interview, a subject matter expert was asked to reflect on conclusions derived from the interview. That offered additional insights and credibility from someone who is an insider, but still did not partake in the actual interview.

Transferability refers to whether the results can be transferred to other contexts, settings, or times. However, to be able to state confidently that a finding can be transferred, one must have knowledge of both the sending and receiving contexts. Consequently, Lincoln and Guba (1985, p. 298) stress that "if there is to be transferability, the burden of proof lies less with the original investigator than with the person seeking to make an application elsewhere". Nonetheless, efforts can be made to facilitate transferability. Since transferability depends on the degree of similarities between the contexts, the researcher can provide a thick description of the original context. Here, this is done by providing a description of the study object, i.e. the icebreaker, as well as accounting for the domain in which it operates, and the risks associated with its work. Still, it should be borne in mind that this description does not offer an index on transferability, it only offers a database for others to make transferability estimations (Lincoln & Guba, 1985). Nonetheless, there is potential for conceptual transferability to complex systems in other domains, e.g. health care, traffic management, and the process industry. By employing the approach of studying complexity through the same, or similar lenses, a heightened awareness of the interconnectedness of system elements contributes to increased knowledge of the complexity and its implications within that particular system.

Dependability refers to the need to take into account the ever-changing context surrounding the research; that is, to describe the changes affecting the research and the ways the chosen approach was adjusted to meet those changes

(Trochim, 2020). However, Guba (1981, p. 81) argued that validity is a direct function of reliability; “reliability is thus not so much essential in its own right as it is a precondition for validity”, and consequently, demonstrating a study’s credibility also implies its dependability. Nonetheless, Elo et al. (2014) stress the importance of documenting principles and criteria for selecting study participants and documenting their main characteristics, which has been done above as well as in the papers. Another technique is to use overlapping methods, i.e. triangulation (Lincoln & Guba, 1985; Webb et al., 1966).

Confirmability refers to the extent to which the results would be confirmed by others. It deals with objectivity, and the means researchers use to distance themselves from the data or object of research. One way to do this is to account for the procedures for checking and rechecking the data. Another way is to have someone else critically examine the accuracy of the results (Trochim, 2020). As already mentioned, the interview data used in Paper I was reported back to a person other than the interviewees, to verify its accuracy. Also, the process of coding the verbal communication used in Papers III and IV contained several steps of checking and rechecking the data and codes used. For example, after a quarter of the data had been coded, the result and coding process were evaluated together with peers not involved in the actual coding. After adjusting the procedure, the data were once again coded in their entirety.

4.5. Research limitations

The majority of data presented in this thesis is derived from Swedish icebreakers. When data have been sought from merchant vessels, there has been no desire to approach vessels with a particular flag; the data are, however, collected from vessels operating in the Baltic Sea and receiving assistance from Swedish state icebreakers. Consequently, the findings are of a Swedish nature, in the way that they reflect practices common in Baltic Sea icebreaking. Nonetheless, there is no reason to believe that the findings presented in this thesis would be substantially different if an icebreaker from another part of the world were to be studied, since training requirements for seafarers adhere to international standards. Furthermore, since the introduction of the International Code for Ships Operating in Polar Waters (aka the Polar Code) which entered into force on 1 January 2017, the operation and manning (including training) of vessels operating in polar waters is standardized (IMO, 2014).

Another limitation stems from the decision to keep the thesis focused around the people and practices involved in icebreaker operations. Throughout the thesis it is acknowledged that technical aspects of icebreaking are vital for safe and efficient operations, and in some situations technical limitations affect practices. Nonetheless, there is a clear human-centred focus in the thesis. Therefore, technical aspects of icebreaker operations and maritime communication have received little, or no, attention. For example, when it comes to communication, factors such as maximal transmitter and receiver range, unwanted radio noise, and incorrect handling will definitely affect communication; still, those, and other technical aspects, are beyond the scope of this thesis. However, there is no contradiction between these two foci, and both likely have great importance for successful operations.

Here, it is also appropriate to mention researcher positionality. As a researcher, it is important to position oneself in relation to the context of the study. Having previously worked as a deck officer within the merchant marine, as well as spending almost two months on board various icebreakers prior to this research project, I position myself as an insider, being familiar with the trade. This position comes with both advantages and complications (Chavez, 2008). An insider usually gains easy access to the field of study, is able to apply a nuanced perspective for observation, has sound knowledge of the field, and is likely to notice unusual or unfamiliar situations. However, there is also the risk of being biased in selecting participants, adhering to selective reporting, and missing patterns due to familiarity with the field. Awareness of these biases is a good start. However, a number of concrete measures were taken during the research process. For example, before interviews the researcher's prior understanding was mentioned to the respondents, who in turn were urged to be as exhaustive as possible to minimize the risk of implied understandings between researcher and respondent. Nonetheless, being familiar with the field also made it possible to pick up ideas that likely would have passed unnoticed to an outsider. These ideas could then be further elaborated during the interviews. Furthermore, during the analysis, seminars where the data were presented and discussed were used to mitigate the risk of selective identification of patterns. Similarly, although more informal, dialogue with peers with varying knowledge of shipping and icebreakers, as well as with experts from the field, was used to exchange ideas about findings and conclusions and to discuss their relevance.

5. Results and summary of the papers

This chapter contains a summary of the four papers, including their results. Furthermore, in a concluding section, results from the papers are drawn together to present a picture that extends beyond the sum of its parts. By presenting the results as a whole, issues may appear that otherwise could go unnoticed if one were only to examine one piece at a time. Holism and synthesis are important aspects when trying to understand the complexity of a system (Dekker, 2015), and a shift in view between the parts and the system as a whole will provide insights and warrant further discussion.

5.1. Breaking the ice: a work domain analysis of icebreaker operations (Paper I)

Aim

The aim of this study is to identify the constraints on nautical officers on icebreakers during operations, and to distinguish any situations that further increase cognitive load. With regard to icebreaker operations, identifying constraints and subsequently addressing them has potential to increase efficiency, but more importantly decrease risks for human lives at sea.

Background

This paper describes the icebreaker and its work from a socio-technical standpoint. Icebreaker operations are complex and characterized by uncertain and changing conditions. The more obvious variations stem from weather and ice conditions, with fluctuating winds causing varying ice pressure, and an ice thickness that is often difficult to predict beforehand. However, there are also uncertainties and dissimilarities due to geographical location, e.g. various areas have different general ice characteristics causing the ice to behave in certain ways. Also, personal skills, e.g. language proficiency or previous experience from winter navigation, vary between individuals. Taken together, this means that there is not one, or even a few, standard conditions. While this can be challenging, the icebreaker crew has considerable freedom to adapt their actions to each unique situation. Nonetheless, for successful and safe operations, there are constraints to which the crew members have to conform. In this study, a constraint is defined as "anything that limits a system from achieving higher performance versus its goals" (Goldratt, 1988, p. 453). Even though a constraint limits the behavioural freedom of a person, it can be used to increase performance. After identifying a constraint, active measures can be taken to counteract the negative effects posed by it, thus increasing the overall performance of the system.

Method

A Work Domain Analysis (WDA) was performed based on a semi-structured group interview with four nautical icebreaker officers. The respondents all had sound knowledge of icebreaker operations and held different ranks on board. The latter was considered important to get a rich description of their work, as views may vary with rank and experience.

Results

The multitude of tasks carried out on board an icebreaker and its inherent constraints are illustrated with an abstraction hierarchy (AH). The tasks and constraints are modelled into levels, with the icebreaker's overall purpose at the top, various functions in the mid-levels, and finally the bottom level with objects or resources upon which the icebreaker is dependent. The complete AH can be found in section 2.2.1, as well as in Paper 1.

The tasks performed by the icebreaker can broadly be grouped into two sets of activities. The first set includes tasks strongly associated with actual icebreaking, such as determining the most appropriate action based on present ice conditions, and how to manoeuvre the icebreaker in close proximity to other vessels; these tasks can be viewed as the *essence* of icebreaker operations, activities that differentiate icebreaking from most other shipping activities. These activities rely largely on technical attributes, such as a fully operational icebreaker, and the availability of accurate weather forecasts, including ice data. These resources also have the potential to constrain operations. For example, availability and accuracy of weather or ice forecasts are crucial for safe and efficient operations.

The second set of tasks are not icebreaker specific. On the contrary, they include tasks related to co-operation, such as personal interaction and communication. These tasks emphasize that assisting a merchant vessel through heavy ice is not an endeavour singly performed by the icebreaker. The icebreaker crew are dependent on the crew on board the assisted vessel, pilots and shore-based personnel. The diversity of ships trafficking the Baltic Sea adds complexity to the situation; varying language skills and knowledge of ice constrains icebreaker operations.

Finally, there are a number of situations that increase the cognitive load for icebreaker officers. These can be divided into the following categories: external factors such as weather, wind, ice conditions and darkness; geographical factors; technical malfunctions; and human interaction.

Conclusions
This study identified a number of conflicting constraints, that is, a factor which has both positive and negative effects for the participants. The most prominent one concerns the severity of the winter season. A long and harsh winter unquestionably poses challenges for both the merchant fleet and the icebreakers. Nonetheless, a short winter season with moderate ice conditions makes practising and maintaining icebreaker competencies troublesome. Also, harsh winters make it easier to legitimize the presence, and cost, of the icebreakers.

The WDA is a suitable mean of identifying constraints and, therefore, future research needs. This paper emphasizes the need to further examine the non-technical issues of maritime communication. Since communication is a vital part of shipping in general, as well as many other domains, the results of in-depth communication studies will have numerous beneficiaries beyond the sphere of icebreaking.

5.2. Improving operational safety during icebreaker operations (Paper II)

Aim
The aim of this study is to investigate what safety measures could be taken to improve the operational safety during icebreaker assistance in the Baltic Sea.

Background
Compared to shipping in open water, navigation in ice adds a number of precautious aspects. Vessels will be subjected to low temperatures, severe weather, ice pressure and icing, and this applies to both icebreakers and other merchant vessels. Well suited merchant vessels may be able to operate independently in ice, while others have to rely on icebreaker assistance to reach their destination. Consequently, icebreakers are necessary for keeping shipping lanes in northern Sweden open all-year round. Operating together with an icebreaker, however, is subject to one additional hazard. To assist a vessel that is stuck in ice, the icebreaker needs to pass close by; by breaking the ice next to the beset vessel, the pressure exerted by the ice is reduced and the vessel can hopefully proceed. The distance between the vessels can be as little as ten metres or less. It is not the short distance itself that is problematic, but the small error margin. If something unexpected were to occur, there is not much time to react and come up with an alternative solution. This, in turn, increases the risk

of collision and poses a threat to the safety of human lives, vessels, and the environment.

Method

Qualitative data were collected in two ways. Individual semi-structured interviews were conducted with seven icebreaker officers and a questionnaire was distributed to a number of vessels calling at ports in northern Sweden; a total of 22 questionnaires were returned. Both the interviews and questionnaires covered the same themes; apart from personal information and vessel specific information, major themes included convoy operations, communication and language use, and safety during icebreaker operations. Content analysis was used to observe patterns in the data.

Results

The safety concerns as well as suggestions for improvements during icebreaker operations could be broadly categorized into three groups.

First, technical developments offer great possibilities for improved safety. By tracking the progress of other vessels' voyages, valuable information can be gained about the most favourable route through the ice. The data and technology exist, but a more widespread use would favour safety and efficiency. Also, such technology would mitigate the constraint posed by difficult ice assessment, identified in Paper I. For example, tracking a vessel's speed in ice through its AIS data can give valuable advice about the route chosen, which could be used to inform other vessels. This way of obtaining a vessel's speed also mitigates the constraint of language difficulties, since no interaction is needed.

Second, training and experience play a vital role in icebreaker operations, and the lack thereof is a concern for personnel on both icebreakers and assisted vessels. The results show two critical areas: training and/or experience of ice navigation, and adequate language skills. It is also important to make a distinction between training and experience and point out that there is not an absolute relationship between the two. A person can be experienced without having acquired any formal training, while training on its own cannot replace experience.

Third, requirements could possibly improve safety. Other domains within shipping have required specific certificates of competence for a long time, and with the introduction and recent implementation of the Polar Code, operations in some (but not all) ice covered areas now require approved training and certification. While the results clearly show that icebreaker officers are confident that such a requirement would guarantee a lowest level of competence, not all respondents were sure that the associated costs for training would match the safety gain.

Conclusions

This study focused on the views of Swedish icebreaker officers. In addition, views of a number of officers on merchant vessels were acquired, and these represented a more diverse group of nationalities. Still, it is assumed that the findings would also be applicable to Finnish icebreaker operations; there is a close co-operation between Sweden and Finland regarding icebreaker services, and the prerequisites are largely the same.

Among other things, the study concluded that language plays an important role. One suggestion raised was that by increasing the awareness of, for example, the Standard Marine Communication Phrases, better communication could be facilitated, leading to safer operations. The study also showed training and experience to be crucial for the safety of icebreaker operations. That finding may not come as a surprise, but it emphasizes the necessity of mandatory training and certification for onboard personnel, which since the publication of this paper has become a reality with the Polar Code entering into force. However, the Baltic Sea is exempt from that code.

5.3. Mind the Gap! A quantitative comparison between ship-to-ship communication and intended communication protocol (Paper III)

Aim

The aim of this study is to describe verbal maritime communication in the context of icebreaker operations. This includes a quantification of what is being said, by whom it is being said, and what response it elicits; in other words, to what extent closed-loop communication is, or is not, used in this specific context.

Background

This paper examines the language use between an icebreaker and the vessels under assistance, and compares it to the Standard Marine Communication Phrases (SMCP). SMCP, which was adopted by IMO in 2001, aims to increase the safety of navigation, standardize the language use, and assist maritime training institutes in meeting language requirements. The SMCP can roughly be divided into two parts. One part provides a large variety of phrases appropriate for situations requiring both external and onboard communication. There are pre-designed messages for routine situations, e.g. embarking and disembarking of pilot, exchanging traffic information with VTS operator, and onboard briefing of other crew members, and emergency situations, e.g. fire, grounding and piracy. Use of these phrases “should be made as often as possible in preference to other wording of similar meaning; as a minimum requirement, users should adhere as closely as possible to them in relevant situations” (IMO, 2001, p. 11). In addition to the phrases, the other part provides general guidelines that shape the language use and optimize the communicative performance, e.g. to avoid synonyms and contracted forms (“do not” instead of “don’t”), and to use the NATO phonetic alphabet for spelling of letters (Alpha, Bravo, Charlie etc.). All taken together, SMCP is intended to bridge the gap between native and novice English speakers by providing a simplified grammar and set phrases.

Another recommended feature is closed-loop communication, which is a feedback mechanism for verbal messages. Flin et al. (2008, p. 105) define it as a “three-step sequence whereby a message is sent by a team member, another team member provides feedback regarding the received message and the originating team member then verifies that the intended message was received”. However, research from other maritime areas (e.g. VTS) indicates that closed-loop communication is not always used.

Method

The material used in this study consists of verbal communication between an icebreaker and the merchant vessels under icebreaker assistance. A recording device recorded 40 days of authentic VHF communication; the recorded channel was used only for assistance related communication. In total, the data amounted to 2,825 communication loops (i.e. a message, a response, and a confirmation). Furthermore, the data were coded according to SMCP’s message markers to show the types of messages (e.g. instruction, intention, or question) and the extent to which each message was repeated, and whether the correctness of the repetition was confirmed; basically, this resulted in a quantification of the usage of closed-loop communication.

Results

Since the icebreaker and the assisted vessels have different roles during icebreaker operation, there is no surprise that they initiate communication at varying degrees and that the proportion of message types differ. The icebreaker, with its leading role, initiates over 70% of all the communication, i.e. is the one who initially calls the other party. Regarding the type of message, both vessels offer *information* and ask *questions*, but only the icebreaker gives *instructions*. Information messages deal with the exchange of factual information, and questions obtain specific information in an interrogative manner. Instructions from the icebreaker are often explicit, e.g. “Please go full ahead”. However, more important are the findings about closed-loop communication. The extent to which closed-loop communication is used varies with the type of message. Instructions and questions are repeated at a relatively high rate, while messages containing general information or intentions far more often receive a yes or no answer, i.e. not a repetition. Furthermore, a full closed loop, where the correctness of the repeated message is confirmed, was only observed in about 16.4% of the messages initiated by the icebreaker and 14% of the messages initiated by the assisted vessels.

Conclusions

Not using closed-loop communication as a feedback loop risks diluting the meaning of the message, since the sender of a message cannot be certain about to what extent a message has been received. However, the results clearly show a differentiation regarding messages with a descriptive (longer) nature. There seems to be a relationship between the length of a message and the use of closed-loop communication; simple instructions are often repeated correctly, while compound messages containing several message types only get partly repeated. The overall results confirm previous findings from other studies indicating a discrepancy between how people should talk and actually do talk.

5.4. Other-initiated repair as an indicator of critical communication in ship-to-ship interaction (Paper IV)

Aim

The aim of this study is to describe the use of other-initiated repair in maritime ship-to-ship communication. This includes a quantification of other-initiated repair, a description of the specific practices used to initiate repair, as well as the ways miscommunication is rectified. The paper finally discusses implications for practice within maritime discourse.

Background

This paper describes the use of other-initiated repair (OIR) during ship-to-ship communication, and how that is used by interlocutors to display misunderstandings. Also, the means used to rectify miscommunication are described as well as the implications this practice has on maritime communication. Marine radio communication shares many features with a regular telephone call, most prominently in that the call is technically mediated with speakers in different locations, ruling out the use of body language. However, a fundamental difference is that many VHF channels are half-duplex channels where simultaneous talk is impossible. This shapes, or hampers, the communication since listeners cannot signal their lack of understanding by interrupting the speaker or by inserting questions.

The concept of conversation repair was first described by Schegloff, Jefferson, and Sacks in the late 1970s. Different types of repair are differentiated by two dimensions: i) who initiates a repair, i.e. identifies a misunderstanding, and ii) who repairs it, i.e. resolves the misunderstanding. Each dimension is performed by either the first speaker ("self"), or by the receiver of the message ("other"). Even though there is a preference for self-initiated self-repair due to its speediness (Schegloff, Jefferson, & Sacks, 1977), e.g. when a speaker stumbles over a word and immediately corrects him or herself, this paper studies other-initiated repair. Other-initiated repair occurs when the listener displays an uncertainty, for example expressed as "Huh?" or as a request for clarification as in "You met who?" The study of other-initiated repair is useful since it offers a view of what the recipient of a message finds problematic.

Method

This study is based on the same data material as Paper III, i.e. a large data set of recorded verbal communication. A recording device recorded 40 days of authentic VHF communication between one icebreaker and the vessels receiving icebreaker assistance. In total, the data amounted to 8,366 individual turns of talk. In the subsequent analysis, turns that included an other-initiated repair were identified. These were then categorized according to type of repair initiation (open request, restricted request, and restricted offer) and repair solution (e.g. repetition or rephrase).

Results

Based on an extensive set of recorded VHF communication, the use of other-initiated repair was described and quantified. Three main types of other-initiated repair were identified: *open request*, in which the receiver indicates a misunderstanding and requests an explanation but without offering a clue about what was misunderstood ("Can you please repeat?"); *restricted request*, in which the receiver requests a clarification of a specific part of the message ("Please repeat, what do you want me to send?"); and *restricted offer*, in which the receiver tests his or her understanding of a message by providing a repetition which in turn can be confirmed by the first speaker ("You are leaving at noon, is that correct?"). In all, 85 other-initiated repairs were identified, which is approximately one in every 100 turns of talk. An open request was used in approximately half of the repair situations, which is a considerably higher frequency than in naturally occurring conversations. Also, there seems to be a preference for slightly longer phrases instead of brief utterances like "Huh?" or "What?" A possible reason for this might be that ship-to-ship communication is technically mediated; with background noise and no way to produce simultaneous talk, brief utterances can easily go unnoticed.

The most common way to rectify miscommunication is for the speaker to repeat the message, either as a full or a partial repeat. An open request is likely to receive a full repeat since there is no way for the speaker to know what part of the message was problematic; with a restricted request, a partial repeat does often suffice, since the receiver has signalled more specifically what the problem concerns.

Conclusions
Since many VHF radio channels use the same frequency for transmitting and receiving signals, simultaneous talk is not possible. This, in turn, causes a slowness in the system since speakers have to wait for their turn. Furthermore, since receivers have no way to signal understanding while listening, e.g. by nodding or interrupting, longer messages often become problematic. Being aware of this implication, speakers can split complex messages, delivering them over several turns, and wait for a confirmatory response in-between the turns. In other words, the risk of miscommunication can be reduced by delivering shorter messages and by using closed-loop communication.

5.5. Complexity of icebreaker operations

When looking at the papers presented above as a whole, it is clear that the topics of organization, safety, and communication cannot be separated easily. The fact that they are interrelated is of course hardly surprising. Nonetheless, it shows the complexity of icebreaker operations; changes within one area will likely have effects in others. Organizational factors shape our understanding of safety and preconditions for safe operations; interaction and communication are essential components necessary for safety, efficiency and legitimacy; depending on the situation, communication can be either a constraint causing intercultural disharmony, or a way to create clarity in situations requiring adaptability. These are some of the links between the topics.

The complexity of icebreaker operations stems from several reasons. First, there is a large amount of uncertainty involved. Paper I shows an array of factors which constrain the icebreaker. For example, the crew of the icebreaker continuously have to judge the potential impact of not knowing the exact ice thickness. However, many uncertainties come from the need to interact with people outside of the icebreaker. The level of experience of other people involved, and whether or not their instructions will be correctly understood and followed are two examples. The fact that there exists an interdependency between the icebreaker and the assisted vessel, and that neither one of them really "knows" the other, is challenging. Furthermore, deviating from the recommended use of closed-loop communication, as demonstrated in Paper III, adds to the complexity. These, and other uncertainties, require a great deal of adaptability from the people involved to stay within the boundary of what can be considered normal operations. What is more, Paper I makes it clear that the icebreaker's main purpose is to assist merchant vessels through the ice; consequently, the icebreaker depends on its "clients" as justification for their existence. Still, the results also show that the icebreaker has to take other parties with sometimes diverse needs into consideration, e.g. pilots and local residents in the archipelago. This raises questions about the relationship between the icebreaker, the assisted vessels, and these other parties, e.g. how the relationship is characterized and manifested.

Another reason for the high level of complexity derives from an inherent slowness of the system, noticeable in at least two ways. First, a vessel is a dynamic system in that the effectiveness of actions, e.g. vessel manoeuvres, cannot be observed immediately. Second, due to technical limitations, many VHF radio channels only facilitate one speaker at a time, making simultaneous talk impossible. In Paper IV, several implications for both speakers and listeners were identified as a result of this. Both of these examples of slowness require the operator to plan well ahead and allow ample time, an additional dimension which adds to the complexity of the system.

One of the many tasks carried out by the nautical icebreaker officers, assisting merchant vessels through ice, further illustrates the complexity of operation. The following quote from an icebreaker officer describes what it is like to manoeuvre an icebreaker in ice (Boström, 2018, p. 450):

> It is like a feeling inside your body, like balance. Some have that feeling and improve upon it, others can mechanically train up to a certain level, like a sequence that you repeat and learn to recognize. Other people have the feeling that the vessel is an extension of the body's motion sensors and feel and observe how the vessel moves before the instrumentation indicates any rate of turn. Both can be super skilful on the bridge, but there is still an important difference.

This quote illustrates that icebreaking is a task that cannot easily be reduced to a definite set of instructions covering every situation. The variability of the environment and the uncertainty posed by for example other actors as described before, would make it impossible to use action rules to control the system as that would limit the actor's freedom to handle unexpected situations (Grote, 2015); increasing or at least maintaining the uncertainty by applying less strict process rules could be a viable way, i.e. providing options for guidance while still allowing considerable leeway. Furthermore, the quote also indicates that some operators acquire a "feeling" for manoeuvring the icebreaker, while others may rely more on instrumentation, i.e. technology, for taking appropriate actions. Nonetheless, it was shown in Paper I that "getting a feeling" of the ice, i.e. learning to assess the ice, takes time and practice. At the same time, in Paper II, technological solutions emerged as a potential way to increase safety. Taken together, this raises questions about whether technology could be used to mitigate the complexity posed by a variable and uncertain environment, but also how competence in icebreaker operations is maintained and developed at an individual and organizational level.

The role of communication is clearly crucial in a complex system which relies heavily on interpersonal communication. Through all four papers, communication has a clear presence: the need to communicate with multiple actors with varying backgrounds, language skills and experience of icebreaker operations; the notion that communication can be both a constraining factor and a means towards increased safety; the fact that international communication protocols are not used to the extent they were intended to be; and the complexity posed by not being able to talk simultaneously through the VHF.

If people lack a common frame of reference for how they should communicate at sea, or if that frame is not being used, they are likely to fall back on how they talk in everyday life. This means that there is a risk of problematic talk caused by an unsuccessful match in the way two people communicate, with an increased level of uncertainty or ambiguity within their talk. This warrants further discussion about how operators could address issues regarding problematic talk and how that could influence future maritime English education.

As shown in this section, by looking at the complexity of icebreaker operations and merging four papers into a whole, several discussion points emerge. These have been introduced in this section and will be further discussed in the next chapter on complexity and clarity during icebreaking operations.

6. Discussion

This chapter discusses the points that emerged from the analysis of the presented work as a whole and how clarity can be created to manage the complexity of icebreaker operations. In the present context of icebreaker operations, creating clarity highlights ways for vessel crews to better understand and adapt to the challenges posed by variability and uncertainty within the system in which they operate.

6.1. Creating clarity by managing relationships and diverse needs

Complex systems are characterized by a high level of interaction between numerous system components, including social interaction (Cilliers, 1998; Vicente, 1999). Relationships make systems complex, yet have potential to create clarity if managed properly.

From the perspective of the assisted vessel, ice restricts the vessel's independent navigation, making them depend on icebreaker assistance. However, for the icebreaker crew, the opposite holds true. Long winter seasons provide ample time to practice and maintain necessary skills. This is especially important for junior icebreaker officers who depend on sufficient onboard training to receive the necessary qualifications. Consequently, the yearly variation of winter severity makes the retention of qualified personnel complex. Furthermore, within each season, the crew faces geographical complexity as well. The icebreakers cover several areas of operation, each requiring local knowledge, but also interaction with local actors such as pilots and shipping representatives. Mild winters, when less time is spent in southern areas, can potentially weaken those relationships. Also, since complexity is derived from interactions within a certain context (Dekker, 2015), moving from one context to another requires adaptability. The geographical variation can be solved on an organizational level by conscious planning, making sure that the icebreakers rotate between different areas, allowing the crew to maintain crucial relationships and local knowledge. The yearly variation is more difficult to address. The fact that icebreakers are crewed partly by seasonally employed personnel means that the workforce needed will likely be smaller during short winter seasons. Uncertainty about availability of work makes seasonal employment less attractive and risks worsening the retention of skilled icebreaker officers even further. One way of managing this uncertainty is to strengthen job security by providing additional work opportunities, for example in co-operation with other shipping companies (Boström, 2018). Thus, the complexity caused by seasonal variability would be less acute.

The icebreaker needs to cultivate relationships with several stakeholders. The most obvious direct stakeholder is the assisted vessel. The relationship between the icebreaker and the assisted vessels is characterized by a dual dependency. A vessel stuck in ice naturally depends on the icebreaker to get freed, and most vessels accept having to wait for assistance, even for an unspecified or long period of time. Likewise, the icebreaker depends on an ample amount of vessels to assist, to warrant their mere existence; without them, there is no need for icebreakers. This dependency is manifested in their talk. For example, the icebreaker generally refers to the assisted vessels as clients as a way of showing respect. Furthermore, the verbal communication showed, with only few exceptions, a polite tone between both parties. A mutual understanding of the challenges faced by the other party permeated the verbal exchanges, indicating acceptance for the variability and uncertainties that make icebreaker operations complex.

Finally, the icebreaker shows considerable care towards groups of people affected by the icebreaker's presence. Inhabitants in the archipelago depending on ice roads, and maritime pilots boarding vessels directly from the ice both depend on unbroken ice. Staying away from such areas, or when not possible at least reducing speed to minimize the risk of fractured ice, is common icebreaker practice. The vessel under assistance and the other stakeholders can be said to represent conflicting interests for the icebreaker; caring for one poses a constraint in relation to the other by reducing the icebreaker's freedom to act, thus increasing the complexity of the system. Still, the willingness to cater to diverse needs indicates an awareness of the various stakeholders, and that conscious considerations have been made about icebreaker operations as a whole.

In summary, icebreaker officers need to maintain area specific competence from diverse geographical areas, to be able to adapt to a large variety of external factors. If this is facilitated by a recurrent shift of the vessels' areas of responsibility, relationships with a vast number of actors are sustained as well. This offers a good basis for maintaining legitimacy of icebreaker operations, even in relation to actors who do not depend directly on icebreaker assistance.

6.2. Creating clarity by managing existing technology

Even though the work presented in this thesis at large has focused on people and their role in a complex system, technology and its implications on icebreaker operations have been touched upon in several ways. From the first exploratory phase, where the work of the icebreaker as a system was thoroughly described, it became clear that the icebreaker relied heavily on technology; the icebreaker vessel itself as a wonder of technological advancements, weather sensors and satellite images that pave the way for weather and ice forecasts, and the fact that ship-to-ship communication is technically mediated are just some examples that emerged in Paper I. However, the following will offer a discussion about how existing technology can be used to improve the safety and efficiency of icebreaker operations and mitigate verbal misunderstandings.

One of the central findings of Paper II dealt with how one can make better use of existing technology and data to find a suitable route through the ice. The rationale is simple; knowing where others have been and how they performed in that location offers vast knowledge when choosing the optimal route through the ice. And everything is already there, freely available. Ships communicate with each other via AIS, and they automatically share information with each other, both static data (*Who am I?*) and dynamic data (*Where am I and what am I doing right now?*). This is sent at intervals of a few seconds, depending on present situation. The data can be presented on a separate display or integrated visually on an electronic chart display, and the latter can prove extremely useful. That way, the historical track of other vessels can be observed. For a merchant vessel operating independently in ice, this can assist in finding an old ice track. Without this method, a vessel has to rely on radar observations (which require practice) and visual observations (which require practice and good visibility). Now, the exact route taken by previous vessels can be shown along with the speed with which they proceeded, indicating the degree of difficulty on that route. Of course, sea ice is not stationary and if a previous ice track is not found, that may be because it has drifted. Still, by accounting for winds and currents, a fair estimate can be made. For icebreakers, the same data can be used to monitor the progress of merchant vessels proceeding on their own. Finding the optimal route increases efficiency by saving time and fuel, reduces wear and tear from high ice pressure, and increases safety by lowering the risk of getting stuck and grounding a vessel due to drifting ice.

However, the idea of sharing information is not new. Porathe (2012) has previously identified the need for icebreakers to see their own and others' tracks. The problem, which still persists, is that not all manufacturers of electronic chart displays provide such a feature. Furthermore, Porathe, Lützhöft, and Praetorius (2012) showed that the transmission of intended routes can be beneficial in ship-to-ship route negotiations. Also, the idea of Sea Traffic

Management aims to make the maritime sector safer, more efficient and environmentally friendly by connecting ships, service providers and shipping companies, facilitating an efficient exchange of already available information (Lind, Hägg, Siwe, & Haraldson, 2016). It is the same driving force behind Sea Traffic Management and the utilization of others' routes in winter navigation; safety and efficiency will be enhanced by making use of already existing data. What is needed is for the data to be presented in a user-friendly application.

Another way that existing technology can be used is to mitigate verbal misunderstandings. But, before explaining how and when that can be done, I want to clearly state that replacing communication with technology should not be done altogether. As presented earlier, the role of verbal communication between vessels has been debated (Froholdt, 2016; MARCOM Project, 1999). Within the context of icebreaker operations, I agree with Froholdt (2016) in that it would be unlikely to do away with verbal interaction; that is, and will remain, an essential element of maritime operations in the future as well. In Paper I it was clearly shown that personal interaction and communication are two crucial elements necessary to maintain safe and efficient icebreaker operations, and similarly, Paper II listed improved communication and language skills as means to increase the operational safety. I believe that it is the complex nature of the operations and the unpredictability of environment and people that set a high demand for adaptability. To be able to adapt quickly and perform joint actions when there is little time to think, people need to quickly negotiate their ideas by means of verbal communication. This is foremost the case during direct icebreaker operations, where vessels operate in close vicinity to each other and a hesitation or misunderstanding can mean the difference between a close call and a collision. It should be noted, however, that the communication in those situations to a large extent is actually clear and precise. Paper III showed, among other things, that verbal instructions from the icebreaker were satisfactorily repeated at a relatively high frequency, compared to other message types (Boström, 2020). Nonetheless, in other situations, I would say that one could do with less verbal communication.

One illustrative example of when one should replace verbal communication with transmission of data is the exchange of numbers. During icebreaker operations, as well as other types of ship operations, locations of objects, e.g. a pilot boarding position, or a navigational route, i.e. a series of geographical positions, are often spoken verbally, e.g. "latitude five six degrees three nine decimal six minutes north, longitude zero one six degrees two one point seven minutes east". However, Paper IV showed that pronunciation and comprehension of spoken numbers are often troublesome. This was manifested as a request for a repetition of a previous message. There are numerous possibilities as to why people might fail to hear, understand, or simply not remember a series of numbers, e.g. ambient noise, an unfamiliar accent, lack of concentration, bad short-term memory, cognitive overload, not having pen and paper nearby etc. At one time, it took the icebreaker and the assisted vessel five minutes to agree on two sets of coordinates, repeating, checking and confirming several times until satisfied. At this point, the underlying reason is not important, but the solution is to transfer non-urgent communication to other means than spoken communication. For example, the efficiency improvements stemming from shared routes have already been mentioned; the same measure is expected to reduce misunderstandings or mitigate language problems (Boström & Österman, 2017). Even a more low-tech solution, such as transferring information via e-mail or the AIS, would allow the recipient to get the information in writing directly, without having to search for a pen.

In summary, with relatively small means, the safety and efficiency of icebreaker operations can be enhanced by making better use of available technologies and data. Manufacturers of navigation equipment should be informed about the benefits of integrating and displaying the AIS tracks of other vessels. An unanticipated benefit from sharing routes or data electronically could be a reduction of misunderstandings due to unintelligible pronunciation of non-urgent matters. However, to completely do away with verbal communication in complex situations is highly unlikely as long as there are people involved in the operations.

6.3. Creating clarity by managing ambiguity in communication

The IMO makes clear that ambiguous words and phrases should be avoided, mentioning, for example, the modal verbs *may*, *might*, *should* and *could*, as well as the word *can* which "describes either the possibility or the capability of doing something" (IMO, 2001, p. 17). Furthermore, IMO states that misunderstandings frequently occur, especially in VTS communication, sometimes resulting in accidents. However, it is unclear whether these accidents are caused by ambiguity or by other types of misunderstandings.

Issues concerning whether a statement or question should be seen as a direct or indirect speech act, i.e. interpreted literally or not, has been well studied. Clark (1996) states that speakers generally expect their intentions to be understood from their utterances as constructed in the current situation. For example, when asked a simple yes or no question like "Do you accept credit cards?", most people will, in addition to an affirmative answer, also state which cards (Clark, 1979). The point made by Clark (1979) is similar to that made by Dingemanse et al. (2015) about the principle of least collaborative effort; in conversations, people tend to assist each other by providing as much information as practicable, so as to minimize their joint work. Clark (1996) uses the expression "short circuiting" in describing the way people respond to questions, addressing potential follow-up questions in advance.

Similar situations occur during icebreaker operations. One example includes the use of the vessels' searchlight. During night time, the searchlight, an extremely luminous source that can be pointed in different directions, is used to identify cracks in the ice. If a searchlight on board the assisted vessel is incorrectly positioned, it could potentially blind the crew on board the icebreaker; consequently, from time to time the assisted vessel is asked to switch off their searchlight or lower it. During the 40 days that the communication was recorded there were 16 instances where the icebreaker asked the assisted vessel to either lower or switch off the searchlight. The only appropriate phrase in the SMCP would be "Switch on [or off] the bow/stern search light" which in fact is intended to be used during icebreaker assistance (IMO, 2001, p. 44). Out of 16 occasions, there were three times when the icebreaker posed a direct request (e.g. "Please lower your searchlight"), including one instance in which the proposed SMCP phrase was used. The remaining 13 questions were more ambiguous and included either "can" or "could" or were introduced with the phrase "Is it possible to…". Both these practices could be seen as a question by which the icebreaker asked about the vessels capability to perform the desired action, i.e. the wording was ambiguous. However, in all of the situations, the desired result was achieved; the context in which the conversations took place, i.e. a merchant vessel following closely behind an icebreaker, made it clear to the assisted vessel that the apparently ambiguous question was in fact a request.

Another cause of ambiguity is caused by inconsistency between sentence structure and intended meaning. An example from the context of icebreaker operation is the practice of disguising a question as a statement, such as "I will keep full ahead?" What indicates that this should be interpreted as a question is a rising intonation at the end. However, this subtle way of asking questions is unfortunate in radio communication; the absence of eye contact and visual cues makes the listener dependent on spoken communication, which in turn can be obstructed by a noisy environment and bad radio reception. This example illustrates the importance of formulating messages in a clear and simple way. There are recommended phrases and vocabulary proposed in the SMCP. However, and more importantly, the example shows an excellent area of use for a message marker, a spoken word that precedes a message to indicate the nature of that message (IMO, 2001). By adding the message marker *question* to the previous example, this could help clarify the intended meaning, and potentially counteract for vague messages. In other words, the structure of the communication could mitigate the effects of ambiguously formulated messages.

Both examples above, the possibility/request and question/statement, have the potential to cause confusion due to ambiguity and should therefore be avoided (IMO, 2001). Of course, reducing the level of ambiguity is desired; still, I suggest that the risk of misunderstandings caused by ambiguity should be downplayed. The communication is not an isolated event, it takes place in a greater context. Goss (1972) tested students' interpretation of vague and ambiguous nouns and found that the breadth of interpretations among respondents was significantly smaller when the word was included in a sentence, compared to alone, indicating the important role of context. Furthermore, communication is a cooperative activity and a speaker is not going to say something totally irrelevant (Wharton, 2013). A vessel approaching an anchorage area asking, "Can I drop my anchor?" is probably intending it to be received as a request; the alternative, that the vessel is asking about its own capability to anchor, is simply not plausible.

Throughout this section, I have offered numerous examples of communication that have been ambiguous in one way or another. When faced with verbal ambiguity, it should be kept in mind that the communication takes place in a certain context. Based on existing literature, it has been argued that contextual factors generally make people good at anticipating the communicative actions of their conversational partners, hence, they adapt. The adaptability of human communication described here can be seen as an example of a dynamic non-event. The system, or in this case the communicator, is often able to adapt to the changing environment caused by non-standard communication. The next section will offer a suggestion to how the focus of maritime English training can be shifted to better prepare seafarers for the challenges posed by ambiguity in ship-to-ship communication. In short, in addition to focusing on *what* is said, more attention needs to be payed to *how* it is said. This would be in line with the idea of giving people freedom within a frame: the speakers should be given considerable freedom in what they say, as long as staying within the frame of how it is delivered.

6.4. Implications for maritime English education and training

In short, the SMCP provides two things: a large number of specific phrases suitable for a broad range of situations requiring communication, and general guidelines aiming to optimize the communicative performance (Bocanegra-Valle, 2011; IMO, 2001). However, it can be argued that the sheer volume of the SMCP phrases provides a hurdle for people already possessing moderate to good English skills. Since SMCP is a simplified form of English, they would be required to *learn to speak simpler*, which could be difficult to encourage. If they instead were encouraged to use short and simple messages, and to apply closed-loop communication, I believe that the outcome would be different.

Following the discussion presented in the previous section, I suggest that the general and specific features of the SMCP (Bocanegra-Valle, 2011; IMO, 2001) need to be further emphasized in maritime education and training. Studying the standard phrases could be a suitable start for a novice seafarer with very basic general English skills, but for an intermediate or advanced English speaker it may be more valuable to learn the logic *behind* the phrases, instead of putting in time and effort memorizing words and phrases by heart. This would be in line with Rasmussen's (1997, p. 191) idea of making the boundaries explicit and known as a way to meet dynamic conditions. Also, it could be seen as a way to introduce flexible rules (Grote, 2015). Instead of stipulating exactly *what to say* (action rules), guidance about *how to say it* (process rules) could strengthen the operator and provide enough guidance to support an adaptive behaviour in response to uncertainty. Nevertheless, it must be stressed that I do not propose a removal of the standard phrases, nor that they should be deducted from maritime language syllabi. However, I argue that it is important to direct the students' attention to more aspects of the SMCP than just the standard phrases. Training institutes should also make sure that maritime English is well implemented in other parts of the training as well, so it is not a one-time occurrence. This, in turn, might require faculty members to refresh and uphold their maritime English skills. It is a delicate balancing act between the need for a standardized language where novice and advanced speaker meet halfway (Johnson, 1999), and to have a system for verbal communication that is easy enough so it is actually used. However, the lack of compliance between intended and actual use of communication protocols indicates that maritime English has yet to reach that equilibrium.

7. Conclusions

The overall aim of the research work presented in this thesis has been to use work organization, operational safety, and interpersonal communication as three lenses to describe and analyse the complexity of icebreaker operations, and its implications for practice. The complexity stems from a high degree of variability and uncertainty from environmental and personal factors, such as weather and ice conditions, as well as experience of winter navigation and language skills. In addition, the dynamic nature of ship manoeuvres requires operators to plan well ahead, since the effects of manoeuvres are not immediately evident.

Successful icebreaking not only requires skills and resources necessary to literally break the ice, e.g. a strong vessel, knowledge and experience of ice, and reliable forecasts. It is also necessary to break the ice figuratively, through co-operation and interaction, often facilitated by spoken communication. However, there is a gap between stipulated and actual communication practices. Communication protocols are not always used as intended and the adherence of closed-loop communication, i.e. whether a message is repeated and confirmed, varies greatly with type of message. This gap indicates that there are organizational issues regarding maritime language training and retention affecting practices. Hence, it is suggested that this needs to be addressed by maritime institutes by further emphasizing the discursive features of maritime English, i.e. the logic behind the SMCP. This could strengthen the adaptive behaviour of seafarers in response to non-standard communication.

Moreover, when two people fail to reach a common understanding during icebreaker operations, the most common way to signal misunderstanding is with the use of an open request, e.g. by saying “Please repeat”, which indicates that there is a problem, but not what that problem is about. This practice deviates from other types of natural conversations, where body language and inserted questions play an important role. This can be a result of the limitation of not being able to talk simultaneously; the listener cannot simply interrupt and ask for clarification at the time of the misunderstanding. An increased awareness of this limitation could prompt speakers to split complex messages over several turns, allowing for a confirmatory response in-between.

Using AIS data to better see where, and with what degree of success, other vessels have proceeded through ice is believed to have great potential for safety and efficiency of icebreaker operations. In terms of clarity, this could mitigate a lack of experience as a way to handle complexity.

Finally, it would be unfair to represent the success of a complex operation in a binary way, either as a perfectly executed operation or an accident. Rather, it can be argued that there exists a continuum between the two, a wide array of normal operations. Even though serious accidents involving icebreakers are infrequent, there could still be drawbacks from an unsuccessful operation even if there is no accident.

The following topics are suggested as future research:

- With the work domain of icebreaker operations thoroughly mapped, additional analyses from the CWA framework could be undertaken. For example, a worker competencies analysis, where the requirements of the domain reflect the competencies needed by workers in a complex system, could provide valuable information. Such an analysis could be used to suggest improvements of icebreaker training, to better meet the demands of the domain.
- The degree of previous experience of winter navigation or icebreaker operations has been suggested as an important factor for safe and efficient operations. Future research could investigate whether, or how, experience affects the operator's perception of safe operations and the resources necessary to perform complex tasks. This knowledge could offer guidance towards the design of training activities, for example to distinguish differentiated training needs for novices and advanced operators respectively.
- The use of closed-loop communication during emergency operations should be investigated. Since confirming a message takes longer than simply acknowledging with ok/yes/no, it is necessary to investigate whether there are situations in which time is so critical that it is advisable to deviate from the practice of closed-loop communication.
- A deeper understanding of the underlying reason for why people act and communicate as they do in the special context of icebreaker operations is required. Such information could be valuable in strengthening present communication protocols, or to suggest future amendments.

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