University of
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Assessment of Present and Planned Polar Research and Supply Vessels

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Abstract

Polar research vessels are currently being planned or build by many nations engaged in polar science. This includes for example the British newbuilding RRS *Sir David Attenborough* and Australia's RSV *Nuyina.* The study explores the field of Polar Research and Supply Vessels (PRSV) and investigates the possibilities of assessing their capabilities. An exploratory research approach is used to identifies sources of information and collects them into a database. Established models for performance assessment in the academic literature are presented. Links are drawn between those models, PSRV characteristics and the research field. An adapted model is created and applied on the data collected, providing the ability to assess capabilities of PRSV. The assessment is based on the four aspects size, icebreaking, logistic and science, each using several attributes from the database to provide a normalised score between 0 and 100. Data of five PRSV are used on this model and visualised in a radar diagram. Results show general applicability of the model and further development and refinement can result in a useful contribution for this focussed research field.

Keywords: Exploratory Study, Polar Research and Supply Vessels, Capability Assessment, Icebreaking, Science, Logistic

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List of Abbreviations

BAP	Buque Armada Peruana
BAS	British Antarctic Survey
BIMCO	Baltic and International Maritime Council
CCGS	Canadian Coast Guard Ship
DP/DPS	Dynamic Positioning
GT	Gross Tonnage
IACS	International Association of Classification Societies
IBRV	Ice-breaking Research Vessel
IHO	International Hydrographic Organisation
IMO	International Maritime Organisation
ISO	International Organization for Standardization
KPI	Key Performance Indicator
MBES	Multi-beam Echo Sounder
M/V	Motor Vessel
PI	Performance Indicator
PRSV	Polar Research and Supply Vessel
ROV	Remotely Operated Vehicle
RRS	Royal Research Ship
RSV	Research Vessel
RV	Research Vessel
SPI	Shipping Performance Index
TEU	Twenty Foot Equivalent Unit
UAV	Unmanned Aerial Vehicle
USCG	United States Coast Guard
USV	Unmanned Surface Vehicle

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1 Introduction

This Master Thesis in Maritime Commercial Management at the University of South-Eastern Norway was created out of contents of the programme's courses and the author's main interests and experiences. The research field incorporates topics from the study modules Ship Design, Ship Operations, Research Methods and Maritime Economics.

Currently a new generation of modern polar research vessels is launched, commissioned or planned by most nations that participate in polar exploration and science. Germany is planning the replacement of the RV *Polarstern* with the newbuilding *Polarstern 2* (BMBF, 2016), the United Kingdom is currently building the *Sir David Attenborough* which shall replace both, current and aging, polar support vessels RRS *James Clark Ross* and RRS *Ernest Shackleton* (British Antarctic Survey, 2017). South Korea and South Africa already finished building new vessels, named IBRV *Araon* and *S.A. Agulhas II* respectively (KOPRI, 2014; SANAP, 2012). Same applies to the new Norwegian vessel RV *Kronprins Haakon* which was delivered to Norway in the beginning of 2018 (Havforsknings Institutet, 2018). Other projects include a very ambitious and cost intensive project of Australia's new vessel, named RSV *Nuyina,* and the building of the world most powerful non-nuclear Icebreaker CCGS *John G. Diefenbaker* by Canada (Australian Antarctic Division, 2017b; CCG, 2018).

Despite this popularity the term 'Polar Research Vessel' is barely covered in the literature and similar notations are used interchangeably. The RV *Kronprins Haakon* is called 'Ice-going Research Vessel' as well as 'Polar Research Vessel' (Fincantieri S.p.A., 2017; Mikelborg, 2015). Australia's newbuilding is presented as 'Icebreaking Antarctic Supply and Research Vessel' (ASRV) (Knud E. Hansen A/S, 2017) and Germany's polar research flagship RV *Polarstern* is titled 'Polar Research and Supply Vessel' (Knust, 2017). For unification reasons and consistency during reading all types of vessels will be referred to as ‘Polar Research and Supply Vessel’ (PRSV) in this thesis.

The various notations indicate the vessel’s three main objectives: icebreaking, logistic supply and marine science and in some cases hint on their area of operations. It also presents the area of interest for a major part of this thesis. More information concerned with why these vessels exist and who their operators are, is presented in the next subsection.

1.1 Background

The Antarctic region is home to major scientific operations. Especially the ongoing climate change puts the Antarctic in the forefront of the research with ice sheets of more than 4 km thickness, a unique place to investigate the past climates of the earth and predict possible changes for the future (BAS, 2015). For this, logistic operations are needed where ice strengthened vessels break through the ice until they meet either their berth or shelf-ice where cargo is unloaded and transported to nearby stations.

Big project cargo like the German research station *Neumayer III* was designed and produced in Germany and then transported to the shelf-ice in the Antarctica by the polar research and supply vessel RV *Polarstern*, flagship of the German polar research. The combined weight of the station and building equipment was 3,500 tonnes (AWI, 2018). This ship does not only supply the Antarctic station with food, spares and equipment but also conducts research in the polar waters and cruises arctic waters in the Northern summer. It must cope with a multitude of tasks and is designed accordingly. (AWI, 2017)

This example shall highlight the dependency of many stations and scientific projects on maritime support using specialist vessels. The ability to support a particular station with a certain amount of supplies is a very important design criterion and might influence a final design of a newbuilding. Thus, the nations operating permanent stations on the Antarctic continent are set as starting point for this investigation. Figure 1 visualizes the identified actors on the world map.

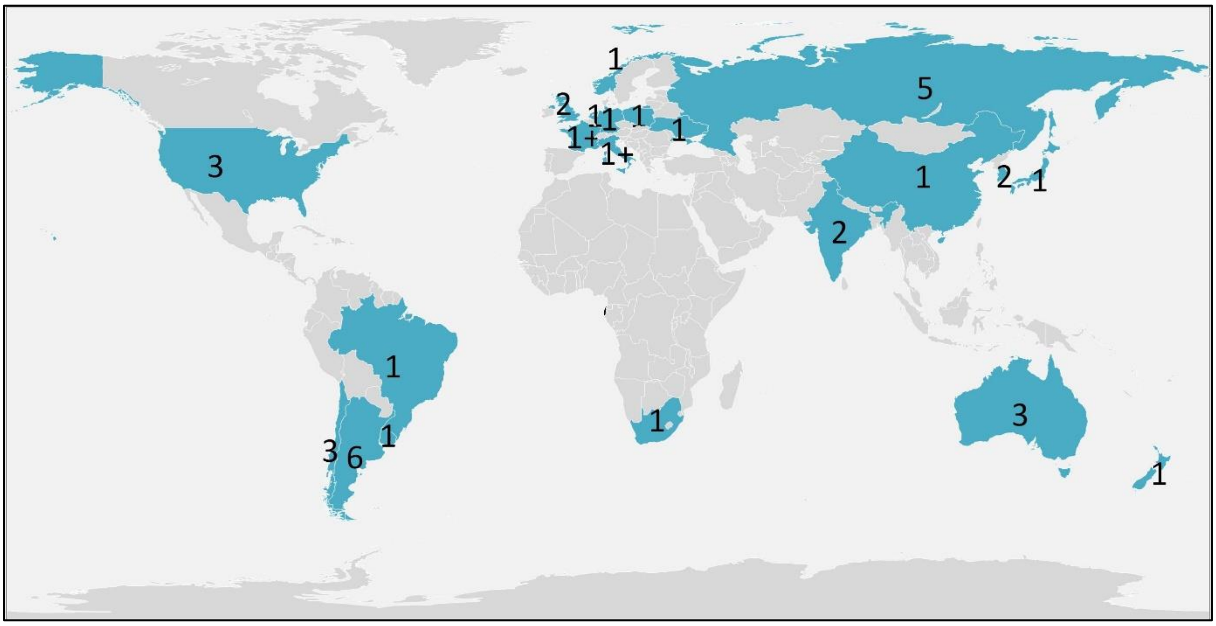

Figure 1. Countries maintaining year-round Antarctic bases (Numbers shown). Data from CIA (2018) and COMNAP (2017). Note. This only includes bases on the continent itself and doesn't count islands.

On top of that are the many newbuilding projects confronted with regulations that did not exist when the old vessels were built. Due to this current popularity and the lack of combined sources of information the author aims to create a base which can be used to assess capabilities of current and planned PRSV. This shall help to define this group of vessels and give insights on key characteristics.

Additionally, the author has a great interest in the field of PRSV. He took part on multiple research cruises aboard German research vessels where valuable insight into the way of working were gained. Furthermore, he was responsible for a cruise into the arctic pack ice for seabed mapping and geological sampling where close coordination of icebreaker and research vessel was required (Figure 2). Therefore, he acquired a broad general knowledge about scientific instruments and methods applied in this region. It happened on such cruises, where the multifaceted roles and requirements became apparent and sparked curiosity.

Figure 2: Finnish icebreaker Otso in the arctic drift ice belt. Note: Bow form, large bridge and helicopter, features very similar to that of PRSV. (Source: Author)

This interest in research cruises, icebreakers and operations in the Arctic combined with the news of newbuildings formed a natural basis for the further investigation of PRSV and their multidisciplinary field of operation.

1.2 Research Questions

This research is considering the present and planned PRSV and ways to assess their capabilities. This leads to following primary research question:

What are the capabilities of PRSV and how can they be assessed?

For better structure the following secondary research questions are formulated:

a) *What are characteristics of PRSV and how many vessels are there?*

b) *How are vessel performances assessed in the maritime industry?*

c) *How can the assessments be applied to modern PRSV?*

The aim for the primary research question is twofold. It shall identify key characteristics of the group of PRSV and use these to provide a basic model that frames the group based on chosen criteria. The research process shall also discover areas of interest and show areas for further investigation and later studies.

The secondary questions are formulated to guide the narrative of this thesis. They are treated in different parts of the thesis and are put into holistic perspective together with the primary research question.

The vessel characteristics are gathered by a literature survey utilising official vessel registers, building yard specifications and information from the operator’s and owner’s websites. Additional personal inquiries to respective ship operators and users might add additional information. The resulting research field is shown in Figure 3.

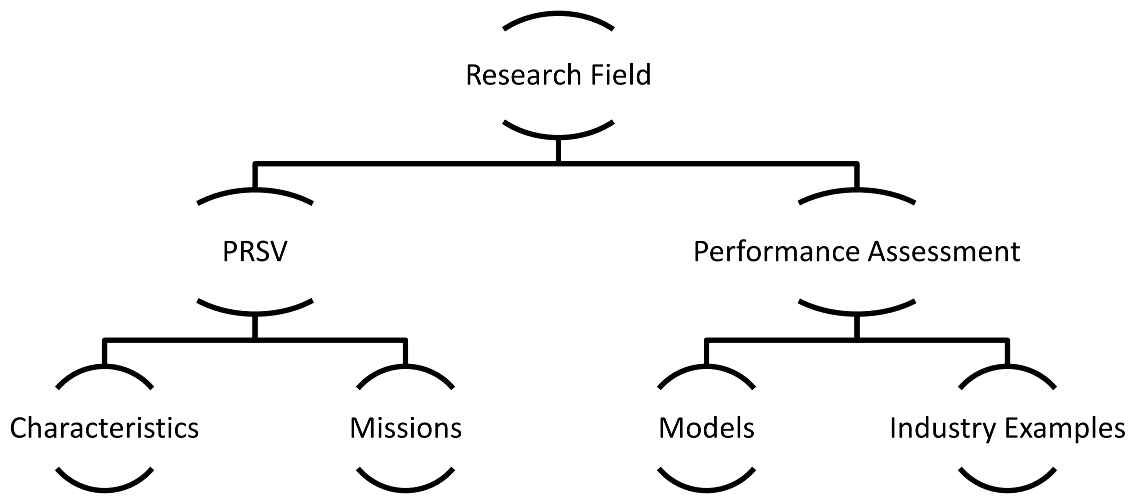

Figure 3. Research field

1.3 Outline

The thesis is organised in six chapters, including the Introduction. Chapter two will review academic literature on performance assessments for ships, presenting selected models while underlining key findings. Chapter three covers the applied methodology and describes the research process. Chapter four presents results, combining the presented models of

Chapter two and the data collected described in Chapter three into an adapted model and applying it on selected vessel information collected during the research process. Chapter five discusses the findings of the research and highlights limitations. The last chapter presents the conclusion of this study and recommendations for further research. The structure and their relationships are shown below.

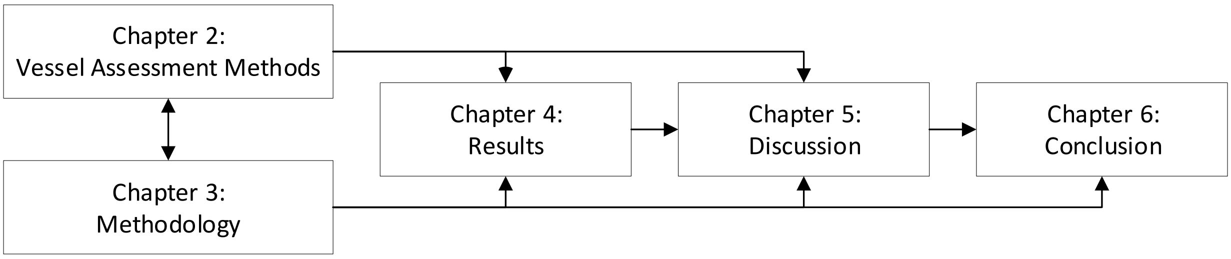

Figure 4. Thesis Structure

2 Literature review on vessel performance assessments

The maritime industry uses several developed systems, catering different stakeholders. This chapter is concerned with the secondary research question: “*How are vessel performances assessed in the maritime industry?”*. The aim is to provide examples of models currently in use in the industry or presented in the academic literature. This shall help identifying important steps and characteristics for the adaption of one or multiple approaches to PRSV.

A comprehensive introduction into the topic is given by Ernstsen and Nazir (2018). The authors conducted a literature review on performance assessment methods in the maritime domain based on four major segments within the industry: (1) port logistics, (2) ship handling, (3) safety and (4) environment research.

They identify four basic concepts on which performance assessments methods can be developed.

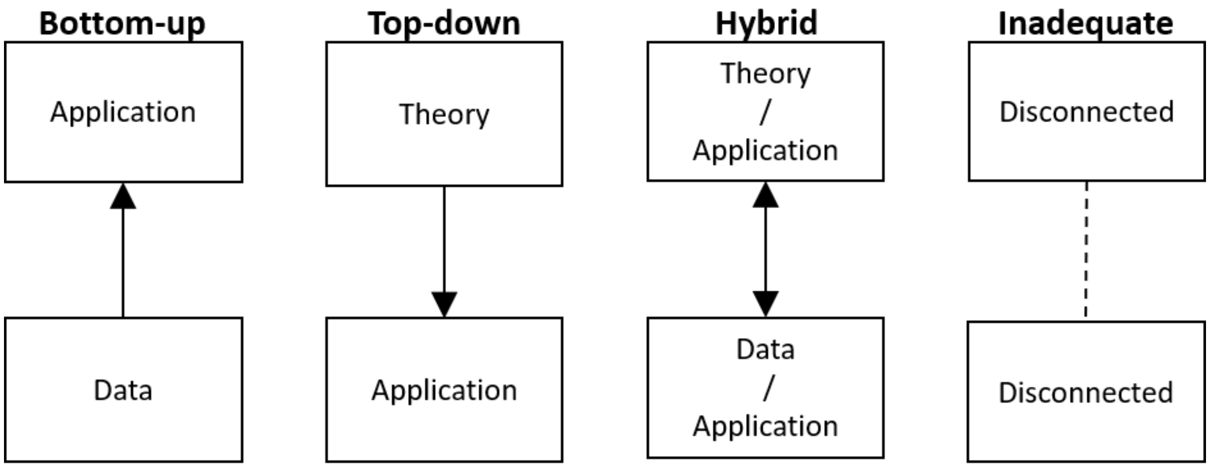

Figure 5. Four methods of performance assessment. Adapted from Ernstsen & Nazir (2018) p.73.

The bottom-up approach tries to identify performance indicators (PIs) in a defined application. The generated PIs might only be applicable to this specific frame but might be widened for generic usage. Top-down approaches make use of already established literature, frameworks or other kind of framing literature to evaluate the PIs of an operation. The advantage using this are the already fixed definitions, regulations or standardisations which might add to the validity. The hybrid approach combines both methods by gathering data, generating PIs and evaluating them with already defined assessment frameworks. This is generally more resource intensive but might add needed flexibility and add validity to the establishment of new frames. The fourth, inadequate, approach selects indicators on a highly subjective basis, compromising the credibility, consistency and accuracy of the overall aim. (Ernstsen & Nazir, 2018)

The following section presents examples of systems or models and show the variety of goals, purposes and areas of interest. Each is finished with a short summary including considerations for PRSV. At first holistic models are presented which is then followed by one concrete, established, industry example.

2.1 Sustainability Models

The topic of sustainable development received international recognition with the release of the book “Our Common Future” in 1987 which also became known as the “Brundtland Report” (WCED, 1987). It gives a concluding definition for the term which states: “[…] development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (p.41). The sustainability concept is based on three aspects: Environmental sustainability, social sustainability and economic sustainability. The concept has since been developed on and, naturally, different perspectives were established. General classification is given, for example, by Lozano (2008) who identifies five distinct categories:

(1) Conventional economists' perspective. This is an economy focused view that sees the economic sustainability as growth and self-sufficiency thus resulting in a limited scope and neglecting the impact of economic activities on environment and societies.

(2) Non-environmental degradation perspective. The focus is on scarcity of resources and that they should be used without surpassing their carrying capacities. It considers negative effects of industries and is mainly environmental focused. (Figure 6 – Environmental Aspects)

(3) Integrational perspective. Here the aim is to integrate all three aspects in a way that full interaction is achieved (Figure 6 – right side). Not all aspects are treated equally in scope. This can be visualised in the Figure by having circles of different sizes representing the individual weighting. Furthermore, time is not considered in this perspective.

(4) Inter-generational perspective. This is the first perspective that approaches the Brundtland report quote (stated in the beginning of the section) by considering the time with its drawback being the lesser focus on the aspects itself thus loosing applicability for practical activities. This would add another, temporal, dimension to Figure 6 and has been included here.

(5) Holistic perspective. Finally, the integrational (3) and inter-generational (4) approaches are combined. It tries to achieve balance in all three aspects and the temporal, short-, medium, and long-term perspective.

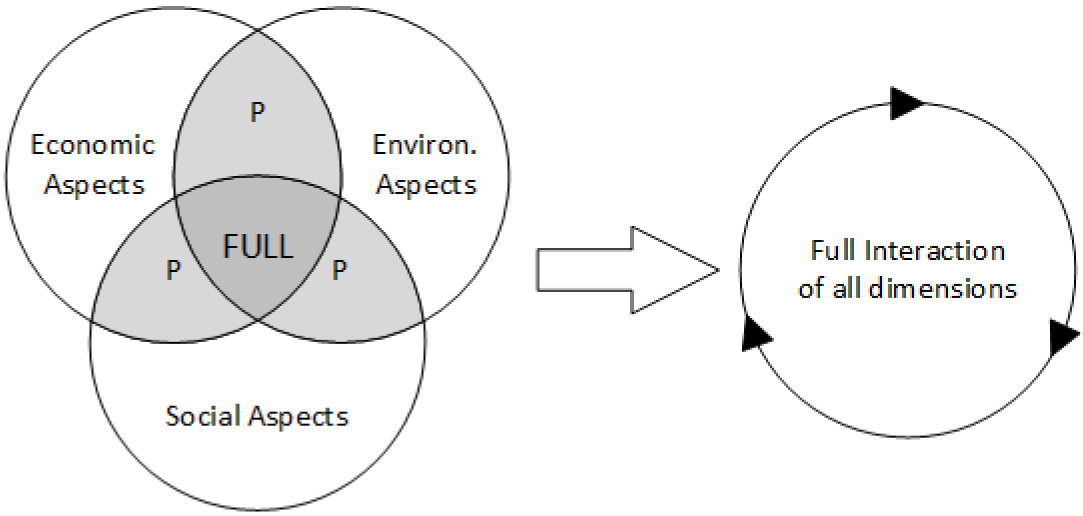

Figure 6. Sustainability Dimensions and First Tier Sustainability Equilibrium. Adapted from Lozano (2008)

This short introduction to sustainable development shall give an overview to the topic and its main foci points. The term is sometimes used interchangeably with sustainability, but the latter is concerned with the ability to continue into the long-term future while the former is concerned with achieving this goal of sustainability (Martin, Brannigan & Hall, 2005, p. 85). The following two sections will present two related models for their intended application in the maritime industry.

2.1.1 Sustainability Analysis of Ships

A holistic model (Type 5 – Introduction List) for the sustainability analysis of ships is presented by Cabezas-Basurko, Mesbahi and Moloney (2008). This means it not only considers the operational aspect of the ship but also includes the building, maintenance & repair and decommissioning phase.

The initially stated definition by WCED (1987) is picked up again and adapted for this specific case, giving a definition for sustainable shipping:

> A cost-effective commercial activity, in which the environmental load is not bigger than that which the environment can currently and in the future bear, and that the social

> community (directly and indirectly) in contact with is not being negatively affected. (Cabezas-Basurko et al., 2008, p. 3)

The basis for this analysis are drivers, indicators, indices, methods and techniques. Drivers or parameters generate the impact, positive or negative, on one or more sustainability dimensions. Indicators are used to describe a performance whereas indices are used to combine more than one parameter to indicate a performance. Techniques are used to analyse or present data, whereas methods are using one or more techniques to achieve a certain goal. (Cabezas-Basurko et al., 2008)

This important sentence underlines the significance of all three pillars in this concept. To assess the performances in each pillar different techniques are used. The economic impact utilises Life Cycle Costing (LCC) and Cost-Effectiveness Analysis (CEA). The environmental impact uses the Environmental Impact Assessment (EIA), a method that is regulated by the EU Directive 85/337/EEC (EU, 1985) for many business sectors and projects of large scale. However, it is not regulated for the maritime industry. Besides the environmental aspect this also covers a cost analysis and social impact investigations. Alternatively, they propose a Life Cycle Assessment (LCA) approach which is a standardised method to assess environmental impact during the whole lifecycle. The technique is covered in ISO 14040 (ISO, 2006). The final, social, pillar uses two methods that cover different areas of the social field. A risk assessment covers the structural safety of ships whereas Social Impact Assessments (SIA) are concerned with identification, quantification and estimation of impacts. (Cabezas-Basurko et al., 2008)

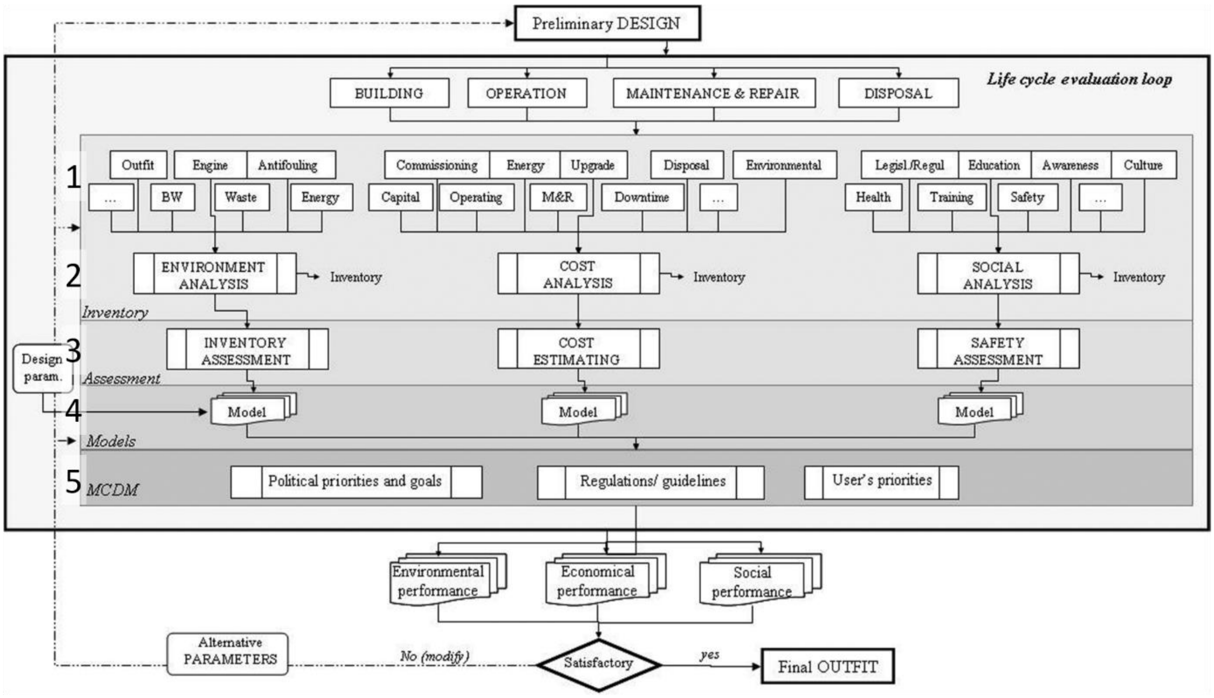

Figure 7. Holistic approach to maritime sustainability. Taken from Cabezas-Basurko et al. (2008, p. 8). Note: Author added numbers to aid readability.

Every aspect of the sustainability is represented as an own tree with own impact assessment strategies and outcomes. The approach is designed as iterative solution where a preliminary design of a ship, facility or project is created and is then evaluated on either the complete lifecycle or only parts of it. Afterwards the whole project is evaluated in detail. Cabezas-Basurko et al. (2008) propose a methodology consisting of five steps (marked with numbers in Figure 7):

(1) Itemisation of a specific system onboard. The ship needs to be split into subsystems which have individual sustainability impact. Example: ballast water management, propulsion system.

(2) Identification of impact parameters. After all systems are itemised, individual life cycle analyses are conducted and parameters are identified that impact the environment, impacting safety and generate a cost. Example: treatment chemicals for the ballast water system. Due to the life cycle approach, analysing the same system in different cycles will produces different or additional parameters.

(3) Creation of an inventory and assessment of the data. The data processing step where the collected parameters are processed to form indices and indicators. Exemplary impact assessment methods that are used here are mentioned in the beginning of the chapter.

(4) Pollution, cost and social modelling. Non-compulsory step used to model sustainability performances in relating them to external management and design objectives.

(5) Comparison with the established requirements. Finally, a multi-criterion decision-making step (MCDM) is used where obtained values are compared with frames that are already existing. This can be shipowner's priorities, legislation, rules in the area of operation, political agendas or any other external framework that allows evaluation. The outcome of this decision-making is the evaluation if the chosen design is acceptable or not. If yes, it is chosen as the design to pursue. If it is not, alternative designs need to be created.

Summary. The presented model is a holistic approach to capture the whole life-cycle of a ship in the perspective of the three aspects of sustainability. Naturally this is a very complex and labour-intensive approach, very comparable to the hybrid methods mentioned in Figure 5 as the applied methodology is developed from data and already present frames from the practical applications. Relevant evaluation methods and techniques are mentioned and relevant, already established, frameworks are pointed out. The three dimensions are dominant in structuring the whole approach and try to cover all possible factors that might influence the design.

2.1.2 Sustainability Assessment of Marine Technologies

Basurko and Mesbahi (2014) present a further developed model (Figure 8) for the assessment of marine technologies. It uses the same base, three-pillar sustainability approach for assessment and expands the stage model presented in Section 2.1.1 (Figure 7). It is now an eight-step approach with an additional first *Scope* step which enables the limitation and framing of the study and shows boundaries. Another step was included after the modelling which is called *Sustainability Indices*. These are the results of their respective sustainability dimension modelling which might require additional normalization to make them comparable to external frames like eventual legislation limits. Afterwards, step seven *Weighting* is added which enables the weighting of the indices according to legislation, user- or political requirements. (Basurko & Mesbahi, 2014)

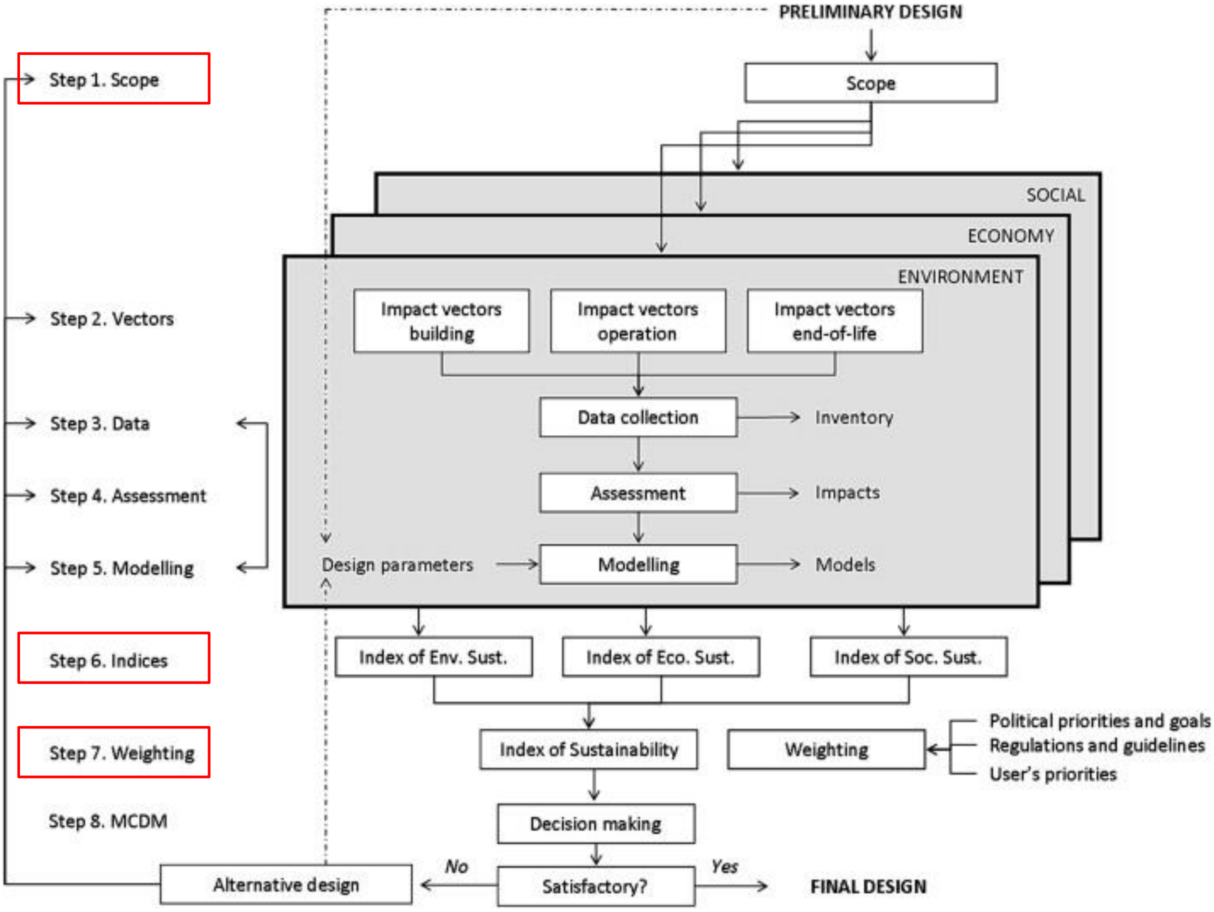

Figure 8. Methodology for the sustainability assessment of marine technologies.Red frames indicate added steps. Taken from Basurko and Mesbahi (2014, p. 157).

Summary. This model was intentionally selected from the same main author to showcase the development that has been made and how the scales of the respective models interact with each other. The presented model can be applied to the holistic ship assessment model in Figure 7 step 2, to provide individual scores for the itemised ship components. Nonetheless, the new option to weight priorities provides flexibility and the three added steps improve clarity to the overall process. The author fully recognizes the importance of the presented sustainability aspects and will refer to them at a later point (Chapter 4 – Results).

2.2 Shipping KPI

After presenting theoretical complex and sophisticated models this section shall create a contrast and show a practical example of performance assessment. Before the system is introduced, a general overview is given.

Key Performance Indicators (KPI) are frequently used throughout the industries, and even before they got the name they have today, values like revenue or sales were used to measure performances. Nowadays, the field of KPIs is much more diverse measuring all kinds of data and operational areas but still have a general frame to which they adhere, and their main points are according to Issar and Navon (2016): "For improving operation performance, measured KPIs, needs to be critical, accurate and significant." (p. 74). For this application BIMCO (2018) adds that they must be observable and quantifiable, sensitive to change, transparent and easy to understand and robust to manipulation. Wang and Hu (2016) point out that having KPIs that can be benchmarked to peers are extremely valuable and trends should be visible.

These key attributes are also used in the Shipping KPI system, which was originally developed and released in 2011 by InterManager, a cross-industry group, and subsequently taken over by BIMCO in 2015. In January 2018 the version 3.0 of the standard was launched. Its stated aims are: (1) boost internal performance improvements of companies active in ship operation and (2) providing a platform on which performance can be communicated to internal and external stakeholders. (BIMCO, 2018)

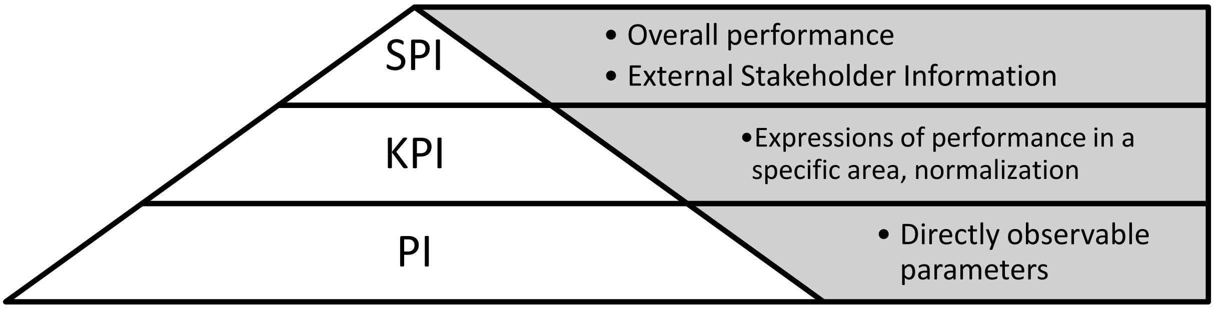

Figure 9. BIMCO Shipping KPI visualization. Adapted from BIMCO (2018).

The system divides the indicators on three different levels. On the lowest level the performance indicators (PI) are found which primarily act as a data collector. This can be for example the emitted mass CO_2 over the course of the voyage. Another tracks the transport work of a trip in ton miles and both datasets are then combined and normalised in the form of a key performance indicator (KPI). The KPI for the mentioned PI examples is the CO_2 efficiency, calculated by dividing emitted CO_2 by the accumulated ton-miles. The normalization at this stage results in a number from 0 to 100, with the former being ‘unacceptable’ and the latter being ‘outstanding performance’. One PI may be used for the calculation of multiple KPIs. The top level is represented by shipping performance indicators (SPI) which are aimed to provide information about overall performance in eight areas. They are presented in Table 1. (BIMCO, 2018)

Table 1. SPI Categories of BIMCO Shipping KPI

SPI	Performance	Contents
001	Environmental	Ability to avoid spills, reduce environmental impact from emissions caused by ship operation.
002	Health and Safety	Ability to manage health and safety of personnel onboard effectively.
003	HR Management	Ability to manage personnel with req. competencies to ensure safe and efficient operations.
004	Navigational Safety	Expression of safe navigation and absence of navigational deficiencies.
005	Operational	Operational effectiveness of the ship including passenger care, safe and efficient cargo handling, ship availability and budget adherence.
006	Security	Ability to manage ship security.
007	Technical	Ability to maintain ship, minimize number of condition of class and reduce failures of critical equipment and system.
008	Port State Control	Expresses ability to handle port state control inspections and associated corrective actions.

Note. Content adapted from Bimco (2018). Taken from https://www.shipping-kpi.org/book/pages/SPI#?kpiProfileId=1

The KPI rating is done using the following normalization formula, where KPI_{Target} is the value that is achieving a rating of 100 and the KPI_{MinReq} is the value that give a rating of zero.

$$KPI_{Rating} = 100 * \frac{(KPI_{Value} - KPI_{MinReq})}{(KPI_{Target} - KPI_{MinReq})}$$

This means that the boundaries of the performances are framed by the members of their group and are not depending on external numbers.

The academic literature covers the shipping KPIs as well. Duru, Bulut, Huang and Yoshida (2012) focused on the generation of the SPI which is originally done using the unweighted average. They propose a process to establish priorities of the KPIs using the quality function deployment (QFD). This approach aims to reflect shipowner's importance and experience in the weighting of the corresponding indicators. The study showed high variability in some SPI categories with regard to perceived importance of their respective KPIs.

Park, Jo and Choi (2016) introduced the KPI method on dynamic positioning systems (DPS/DP) which might enable more accurate performance measurements on vessels station keeping and is likely applicable for PRSV as well.

Summary. Shipping KPI is a bottom-up system designed for ship operators and relevant stakeholders with KPIs designed to aid this member group. A normalization of indices makes scores easily comparable but also abstracts from the original values. The final SPIs are grouped in eight dimensions, covering the relevant activities. Due to its shipping-oriented focus, the system is very streamlined in one application. While the general concept is adaptable due to the dimensions design adding specialist vessels to this model will probably not result in useful benchmark results beyond some common indicators. The focus is also set on the operation and does not include a life cycle approach concerning the building or disposal. It can also be referenced to the sustainability aspects where it covers all three to some extend but disregards the time aspect and mostly applies to the integrational perspective.

2.3 Capabilities and Performances

The review used the words performance and capability and at this point they need to be further explained to put the study in perspective of the goal that is trying to be achieved. The field of defining capabilities, performance and resource is vague and discussed a lot (Lu, 2007).

Hafeez, Zhang and Malak (2002) regard capability as the ability to make use of resources to perform a task or activity. A resource in that aspect is anything tangible or intangible owned by or acquired by a firm.

This is a fitting description and, although not defined for PRSV, it will be used to better define the scope of the research. The capabilities are thus regarded as 'what the vessel is able to do', specified in certain attributes that can be noted and are very close or converging with resources in some aspects of this study. An example is the scientific equipment on board of the vessels which might be a resource by having a physical sensor on board but also enables the vessel to take samples from 11,000 m water depth – a capability.

Performances on the other hand are more concerned with providing information about a process over a period as explained in Section 2.2. Strand (2018) summarizes this fittingly in stating that capabilities refer to attributes and can be answered 'can it do something?' whereas performance are a result of capabilities put to use.

3 Research Methodology

This chapter shall inform about the overall research design. It will describe the chosen methods, mentioning important limitations, inform about the research process and give examples on decisions taken.

3.1 Research Method

The presented research field is approached in form of an exploratory study. This research design differs from traditional quantitative or qualitative approaches as it does not aim to answer the working hypotheses or research questions in a precise and conclusive manner but rather use it as a tool to discover new ideas and insight. The design needs to be considerably more flexible and broadly defined. During the study the problem can be refined and narrowed once relevant data has been sighted. (Kothari, 2003)

Key characteristics are listed by Surbhi (2016):

(1) Research is conducted to formulate a problem for more clear investigation.

(2) The aim is the discovery of ideas and thoughts.

(3) The overall design is flexible in a way that multiple perspectives of the problem can be investigated.

(4) The research process is rather unstructured.

(5) Sampling is purposive or judgemental in contrary to probability (random) sampling.

(6) It has no pre-planned designs for analysis.

Data acquisition in exploratory studies is often considered unstructured and contains personal communications, unstructured interviews as well as a survey of available primary and secondary literature (Kothari, 2003; Surbhi, 2016). Three methods for data gathering are stated by Kothari (2003):

(1) The first is the *survey of concerning literature* which is the review of already published work concerning the problem. It can help to narrowing the research questions. Additionally, attempts should be made connecting established concept and theories from different research fields.

(2) The second method is the *Experience Survey* which is concerned with contacting people that have experience with the research field. It usually features longer interviews and a more open interview structure. Such a survey might enable a more concise definition of the research questions.

(3) The third method is the *Analysis of 'insight-stimulating' examples* which is fitting for areas with little experience that can guide the study. The research object or phenomenon is intensely studied using existing records, if available, unstructured interviewing or other approaches. The main driver of this feature is the ability of the author to combine diverse information of the research field into a unified interpretation and drawing conclusions and recommendations from these connections.

This study will mostly be focused on approach (1) and (3), whereas the first is used to research the field concerning performance assessment (used in Chapter 2) and (3) is used to investigate the PRSV and combine the resulting data into an adapted model in Chapter 4.

The core sentiment of explorative research is that it needs to remain flexible so that many perspectives and facets can be considered if they are discovered. (Kothari, 2003)

3.2 Methodological Validity

Validity is concerned with the trustworthiness, utility and dependability of the study and the author. (Zohrabi, 2013) It is also very dependent on the research instruments used which are presented in the next section. Joseph Maxwell (2009) as cited in Yin (2011) presents a seven point checklist that tries to counter threats to validity. As some points of the list only refer to interviews the core points for this study are listed and commented afterwards.

(1) **Intensive long-term involvement.** To gain a complete and in-depth understand of the field and its observations

(2) “**Rich” data.** To fully cover the field observations.

(3) **Search for discrepant evidence and negative cases.** To test rivalling explanation.

(4) **Triangulation.** Collect data about the same subject from different sources.

(5) **Quasi statistics.** Document data in actual numbers instead of adjectives.

While it will not be possible to achieve perfect validity in this study, steps taken will be present or referred to here. Point (1) is focused on the familiarisation of the author with the research field which is a point that is covered much through the presentation of work experiences and prior assignments in this study (See Introduction and Section 3.5). While the author is familiar with many concepts covering the general scope of the research field there will always be specialist areas where assumptions must be made and limitations that will be placed and detailed in Chapter 4 and 5. The research approach is still exploratory and thus is often subject to a judgemental data collection process. To aid this a general frame for rating of sources is mentioned in Section 3.7. Point (2) refers to the data used and acquired in this study. The established database is bigger than the attributes used in the modelling approach and is also aimed at providing a wider perspective of the field that is studied here. (See Database in Appendix 1, Model in Chapter 4). Points (3) and (4) are closely related here as due to the research design conflicting sources and explanations appeared and decisions had to be made. Triangulation shall be highlighted here as it was used to decide on trustworthy sources and which information to include. A detailed example is presented in Section 3.4.2. Point (5) can be referred to the type of data that is acquired and how it is expressed in the database. This was approached by having a database containing detailed information about many attributes and adjusting those only for the use in the developed model. These steps are covered in Section 3.4.3 and 4.3.

3.3 Research Instruments

The foundation is laid by a literature review, which is an essential component for most topics. It creates a base, uncovers knowledge gaps and shows already saturated areas and helps to identify topics to focus the current research on. It uses queries with keywords on scholarly databases to uncover existing works and provides possibilities for forward and backward search by investigation citations of individual works. (Webster & Watson, 2002). The review is based on the fact that science is a cumulative effort in which new knowledge is often created by combining existing findings. (Brocke et al., 2009)

To conduct the research, databases or search engines can be used. They differ in the type of information they offer, their creditability, their accessibility and stability of information. While library databases have access to journal articles, magazines, newspapers books and more, search engines will only find few of the free scholarly journal articles and book snippets. They are, however, very suited to inform about statistics, organizational websites, news and educational content. Despite this content needs to be carefully checked for correctness and pose a higher risk for misinformation than peer-reviewed journal articles. (Reynolds Community College, 2018)

The literature review concerns two parts of this study. Its main application is the investigation of methods of vessels assessment which are presented in Chapter 2 but plays an important role in finding additional information about PRSV for example in scientific magazines that cover these topics. For this the databases SCOPUS and the university libraries' BIBSYS are used. SCOPUS is a database for abstract and citation research and can be used to analyse and visualize the research process. It shall provide a comprehensive overview of research in the worldwide perspective of science, technology, social sciences, medicine and arts and humanities. (Elsevier B.V., 2017)

The exploratory part of the study will make extensive use of search engines to locate PRSV and gather data. As mentioned above the correctness is often difficult to assess and the adapted process will be mentioned in the next chapter as well.

3.4 Data Collection

To guide and structure the following Section a process chart is provided which frames the methodology.

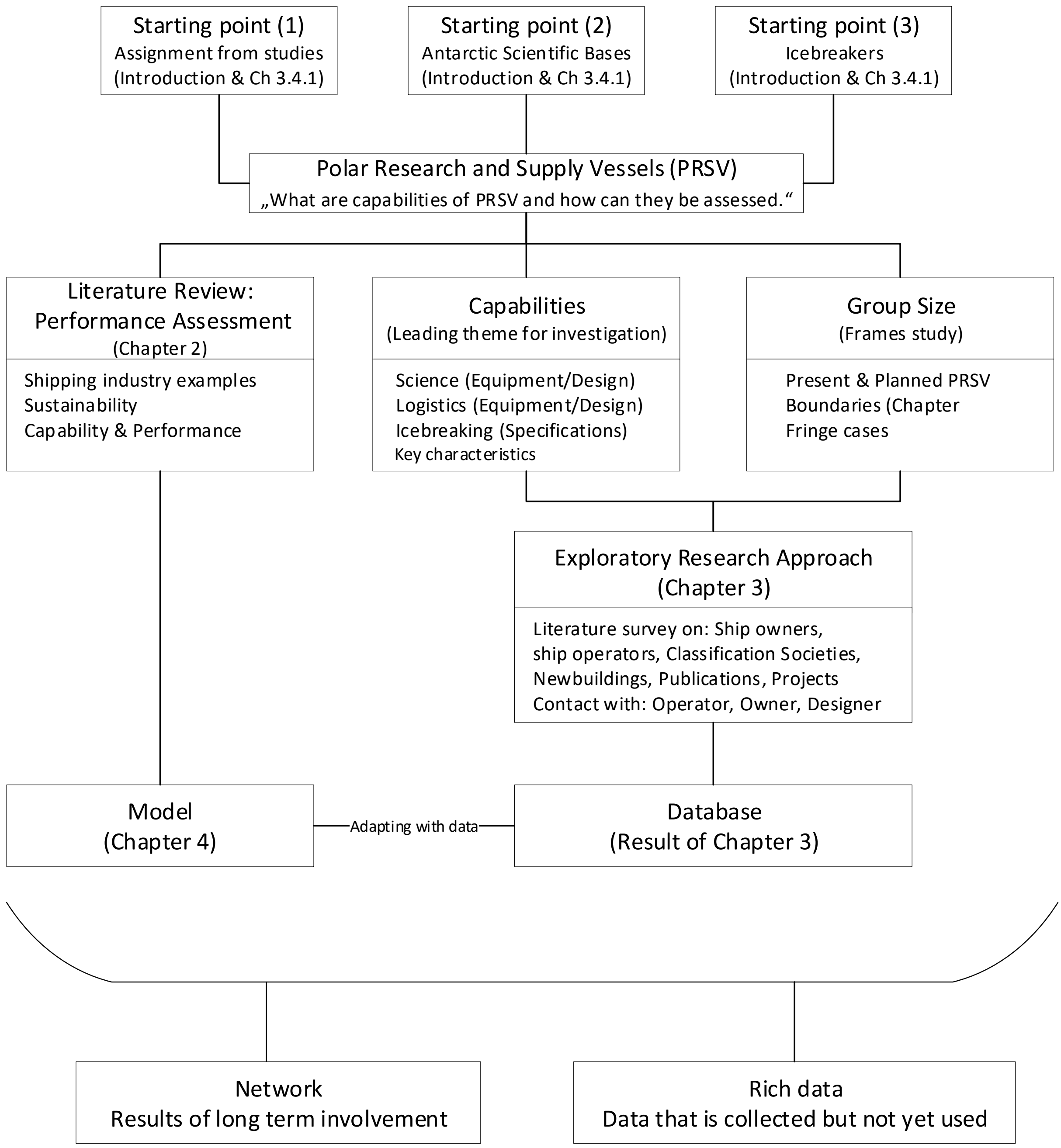

Figure 10. Visualization of the Research Approach. Note: Network and Rich data are outside of the scope of this study but helped to frame it.

Starting Points

Previous work done in this field created the first starting point for the investigation of PRSV. In the course ‘Ship Design’ the author wrote an assignment presenting four selected research vessels (UK, Germany, Norway and China) regarding their missions and technology. It also provided an overview of features and characteristics. The corresponding title is “Modern Polar Research Vessels: Overview, Missions and Technology” (Müller & Kukkonen, 2016). It formed the basis for the formulation of the secondary question (a) and encouraged to delve deeper into this field.

The second starting point was given by the already presented scientific bases in the Antarctic (Chapter 1 – Figure 1) which act as a guide on which nations to focus the initial search on.

The third starting point evolved from the author's interest in icebreakers and formed another entry point for the investigation on which icebreaker lists are investigated to find said vessels. An overview of the major icebreakers of the world was published by the United States Coast Guard in May 2017. It features 127 icebreakers above 10,000 HP, vessels below this threshold are not included. (USCG, 2017) This list was skimmed for possible PRSV and 16 were selected for investigation, by relating with prior knowledge, news and the assignment. They are presented in Figure 11 below.

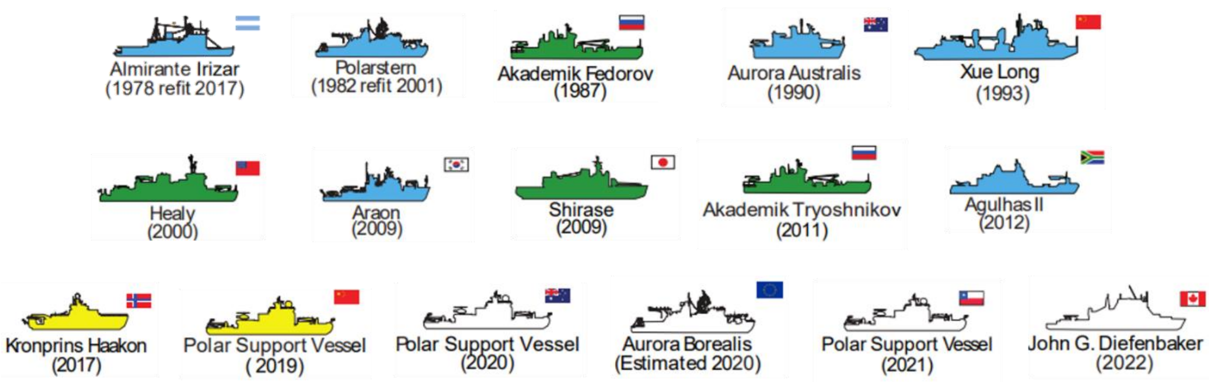

Figure 11. Results from the major icebreaker chart. Note: Adapted from USCG (2017). White: Planned, Yellow: Under construction, Blue: 10,000-20,000 HP, Green: 20,000-45,000 HP.

This initially established information needed to be structured and stored. For this an Excel database (Presented in Appendix 1) was created. The creation was a highly iterative process as information about the PRSV varied greatly in quality and quantity. This also led to decisions regarding abstraction of information. A common ground had to be established and sometimes, details were skipped as similar detailed information were not obtainable for other

PRSV. This would have led to convolution of the database and was avoided. A specific example of this are multibeam echo sounders (MBES), which are installed on nearly every PRSV but vary in their used frequencies, depth rating or data quality. Because of this the author decided to change the type of data from specific information to Boolean statements of ‘Yes’ and ‘No’ in many attribute categories. Comments were still added in brackets where they were deemed useful, but the main focus remained at surveying the field and following the exploratory approach. Detailed information can easily be gathered by following the references later on.

3.4.2 Existing databases and concerns of creditability

After having identified the scientific link to the Antarctic, the existence of databases was assumed and sought after. Especially the European region was found to be rich in research agreements and common projects. One of these is the Eurofleets2 project which has a vessel database linked to it (see e.g. EurOcean (2016)). It does also publish reports with information about the current status of research vessels and their foreseeable evolution (Eurofleets2, 2014). As they were closely related, cross checks on the research vessels were performed. A test on the RV *Polarstern* revealed differences in both documents. While gross tonnage is stated in the database the report names it gross register tons, which were replaced by the former in 1969 (IMO, 2018). This might be an oversight and the difference of 12,640 to 12,614 GT might be caused by the two years difference of the data and possible drydock changes. Nonetheless, the same comparison also states a crew complement of 29 in the report against 44 in the database. This time this was identified as error as the database divided crew into officers (15) and rankings (29). Readers of the report only might be surprised of the low crew complement for a 118m long ship built in 1982. Furthermore, the report only states two cranes while the database has three. The database details capacities of the A-Frame while the report does not for the RV *Polarstern* but lists it for similar featured vessels. The author decided to add one more cross reference, using the operators website for the vessel (Alfred-Wegener-Institut, 2017). The webpage is generally more unspecific than both, the database and the report, but contains assumingly the most accurate information. Selected values were compared again. The endurance is stated as 80 days with a range of 19,000 nm. The database has 320 days and 8,000 nm. The report does not state these values at all. An explanation or source of error about deviations of this margin cannot be given. The operator AWI is only part of the Eurofleets2 project and not listed as member at EurOcean. The project page of Eurofleets2 links to the EurOcean database for further details.

While rich in information and useful data, these issues raised concern in creditability and reliability. Especially concerning were the tight relations of presented examples and the, sometimes, enormous deviations.

3.4.3 Database feeding

Figure 12 shall aid to explain the process and steps mentioned below refer to this figure. The vessels were chosen in sequence, beginning with those where data was already present from the prior work (Step 1). After selection, data sources were reviewed (Step 2). Vessel registries contain basic information (e.g. length, draft, breadth, GT) whereas the official website of the owning or operating organisation often resulted in plenty of information about all aspects of the ship. Additionally, the building yard and design companies were identified and searched for data as well. Information about the design and building experiences could be found in magazines and technical journals as well.

Because of the plethora of different sources data conflicts were found regularly where stated values did not match. This was often encountered even in basic parameters like length, draft and gross tonnage and was explained on a detailed example in Section 3.4.2. This accurately corresponds with the concerns stated in the beginning of this chapter regarding the use of non-peer reviewed material. Therefore, a hierarchy of credibility had to be established. The first tier is always the information provided by the vessel registries if data can be accessed. Second are official operator and owner webpages as well as builder websites for the current newbuilding's. The builders were not considered on this tier for older vessels due to possible refits in the annual drydocking periods. The third tier contained the rest of the sources.

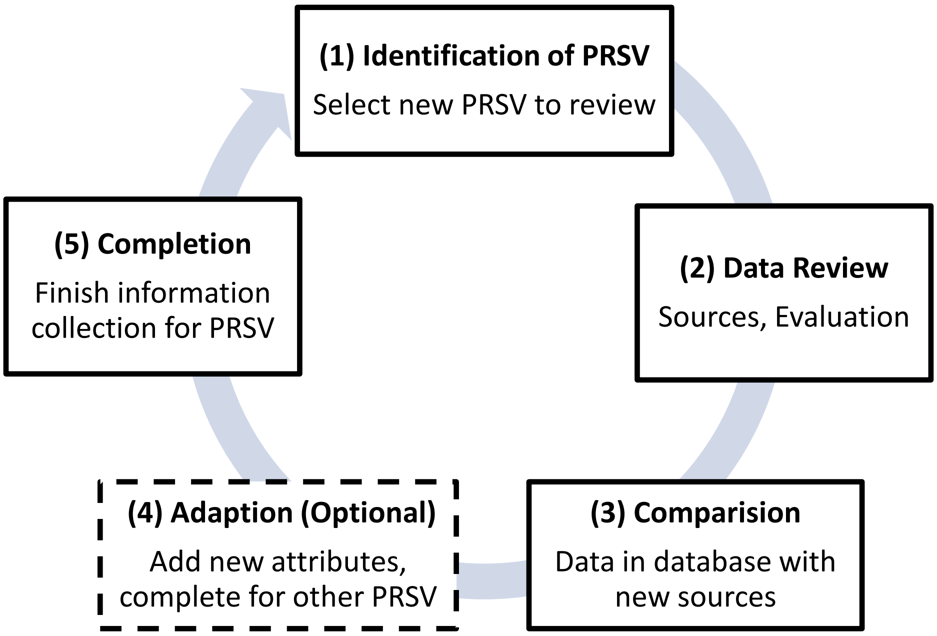

Figure 12. Iterative work with the created vessel database

The found data was compared with data from PRSV already in the list (Step 3). If there was sufficient overlap with existing data from entries in the database a new parameter was added (Step 4). This also included backtracking this kind of information for other vessels and finalising the data entries for the new PRSV and modifying the old one with new attributes (Step 5). Due to this cross-referencing most of the vessels were done in sequence. Afterwards only vessels with less information available remained and were added onto the then frozen database. This means that no additional parameters would be added in the database and only data matching the existing field would be accepted. The basis for the attributes are the research vessels from UK, Norway, Germany and Australia.

3.4.4 Group boundary decisions

Working with these vessels revealed fringes on which some possible vessels would be situated, hovering between the collected data ranges of PSRV and oceanographic research vessels. The author had to decide on a judgemental basis which vessel to include and which to leave out. The decision was to base this on the polar class of newbuilding's. Old vessels were included due to the lack of this class before its publishing in 2007. Vessels under polar class PC5 would not be included into the database. This value was chosen because it is the first one that classifies the vessel for year-round operation in medium first-year ice, while PC6 and 7 only refer to summer/autumn operations (IACS, 2006). This resulted in the exclusion of the Peruvian newbuilding BAP *Carrasco* which only has polar class 7 (DNV GL AS, 2017a). Another, purely judgemental observation was the absence of a typical icebreaker bow as it has a shape normal for not ice-going ocean sailing vessels. An additional criterion was the featuring of the mission and capability trinity of science, logistics and icebreaking. Due to this the French polar institute's vessel FNS *L'Astrolabe* was excluded as main mission did only state defence and support (IPEV, 2017).

Another boundary is given by the transition from icebreaker to PSRV. The Canadian CCGS *John G. Diefenbaker* is a planned to be completed in in 2020 and is much more powerful than most of the other PRSV in the group with 34MW propulsion power and icebreaking capabilities of 2.5m at 3 knots. The striking feature to still include it in the final list was the presence of a large moonpool for scientific instrumentation and other significant capabilities and the presence of logistic capacities. Still, the capabilities of the vessel are quite different from the other considered vessels and might influence the ability to assess the capability with the right scale.

3.4.5 Further investigations

Besides this, most websites offered also possibilities for direct contact. The UK, Germany, USA and Norway were inquired by the author using e-mail in preparation for this thesis in November 2017. Addressed were respective project managers or scientific operators. They were usually identified during data collection on the owner and operator homepages. The Australian Antarctic Division states on its website that student inquiries will not be processed due to workload and thus was not approached by a general inquiry. The USA (USCG) did not reply. The German scientific operator AWI replied but was not allowed to release information about their newbuilding project RV *Polarstern 2* as tender award processes are ongoing until Summer 2018. Full access to data concerning all areas would be possible afterwards. The Norwegian contacts replied as well but stated that it is probably not possible to support the thesis with information due to very high work load of the project team. The vessel RV *Kronprins Haakon* was just conducting sea trials in the Mediterranean by the time of the inquiry. In the meantime, a dedicated website was setup which covers many of possible ship characteristic questionnaires and informs about the progress which could be used instead (UiT, HI & NPI, 2018). The British Antarctic Survey replied positive. Contact was established with the Programme Manager of the newbuilding RRS *Sir David Attenborough* who provided data proactively and allowed further insight into the design process, science (business) case and preliminary usage plans. During the course of this thesis the information were also publicly published and can be accessed on BAS' website (British Antarctic Survey, 2017).

Besides the data that has been acquired to feed the database a lot of intangible knowledge has been collected in the research field which does not directly fit the study's objectives but helps to 'see the bigger picture' in this multi-disciplinary field. This includes for examples the considerations for the awarding of ship time for science projects, the vessel planning key-parameters and the existence of intergovernmental cooperation's to share access to ships and reduce transit time. Besides this an extensive network could be established with relevant personnel, mostly in the scientific area. Additional information directly related to the ship (e.g. design reasons) are not included in the database but were still processed in the form of 'PRSV Profiles' which contain background information the vessels presented and used in model (presented in the next chapter). The intention is to provide a link between the collected data, the assessed capabilities in the model and the background of the presented PRSV.

Additionally, the author used an opportunity to attend Oceanology International 2018 in London. This is a tradeshow covering ocean technology and marine science and has live boat demonstrations and a conference included (Reed Exhibitions Ltd., 2018). This proved to be advantageous as Rolls-Royce plc presented their designs of the British *RRS Sir David Attenborough* and the Norwegian *RV Kronprins Haakon*. This helped nuancing the already collected information by adding minor details about ship features, for example the moonpool installations can be closed in the bottom to reduce underwater noise and friction. At the same occasion, contact with the German ship operator F. Laeisz OHG was arranged. They operate the German PRSV RV *Polarstern* in combination with the main scientific user AWI. Two superintendents from F. Laeisz and a ship and logistics operator from the AWI provided some basic insight into the management and highlighted that currently there is lack of performance evaluation techniques for research vessels. While there exist few metrics, most of the established shipping KPI standard is not applicable due to the vastly different scopes and mission profile of research vessels.

Due to personal and work-associated relations personnel from other organisations like the International Hydrographic Organisation (IHO) and research vessel building project managers also signalled willingness to provide data. Due to the very technical and scientific backgrounds this was not utilised to not widen the scope of the study even more but is important to mention to emphasize the networking effect of the exploratory approach.

3.4.6 Scientific database search

After the main data inquiry for this part was completed, a SCOPUS databank query has been conducted. The first query was done independently. The already obtained results and only contained general terms covering the topic with slight link to the third and fourth research question as well. Many overlapping topics to arctic shipping and sea routes were expected so it keywords containing words (see Figure 13) related with these topics were inserted as exclusion criteria. The search was limited to only display work published from 1982 onwards only, which is the year the second-oldest of the modern PRSV, the German RV *Polarstern*, was built. The query is visualised in Figure 13.

SCOPUS
Polar Research and Supply Vessel

(TITLE-ABS-KEY (arctic OR polar OR ice OR antarctic OR arctic) AND TITLE-ABS-KEY (icebreaker OR "Research Vessel" OR "Research Ship" OR "Support Vessel" OR "Support Ship" OR vessel) AND NOT TITLE-ABS-KEY ("Northern Sea Route" AND nsr AND nwp AND shipping)) AND PUBYEAR > 1981

Figure 13. Keywords used for the research field Polar Research and Supply Vessels.

The query resulted in 7,445 documents (SCOPUS, 14. April 2018). SCOPUS did allow post-filtering of the results by selecting keywords. The words “Oceanography”, “Ship Design” and “Research Vessel” were selected as the most closely fitted the topic out of the presented list. This limited the number to 588 documents. These documents were skimmed for vessel names already present in the database. This resulted in 17 documents related to their names which were examined closer. After disregarding eleven documents because of other vessels or not relevant research fields six publications remained that provided additional information about the vessels.

Table 2. Overview of relevant publications

Author(s)	PRSV	Subject Area
(Sennet, 2017)	Sir David Attenborough	LI Battery propulsion
(International Ocean Systems, 2017)	Sir David Attenborough	General Characteristics
(Alexander, Duncan, Bose, Wilkes, Lewis & De Souza, 2014)	Aurora Australis	Noise cancellation, Physics
(Ishizawa & Kitagawa, 2007)	Aurora Australis	Cargo Transportation
(Berkson, DuPree, 2000)	Healy	General Information
(Dupree, Berkson, Osmer, Klingler & Pond, 1999)	Healy	General Information

After this modest result the approach was reversed, only stating the exact names of the vessels. This had a surprising result which is shown in the table below.

Table 3. Publications per PRSV

Nation	PRSV	Vessel related Publications	Built
Canada	John G Diefenbaker	1	~2020
China	Xue Long	4	1993
United Kingdom	James Clark Ross	43	1990
United Kingdom	Sir David Attenborough	3	~2019
Germany	Polarstern	677	1982
Japan	Shirase	~40	2009
Norway	Kronprins Haakon	2	2018
Russia	Akademik Fedorov	38	1987
Russia	Akademik Tryoshnikov	2	2011
South Africa	S.A. Agulhas II	21	2012
South Korea	Araon	44	2009
USA	Healy	27	1997

There are publications stating the PRSV, in *Polarstern*'s case even in very high numbers. The topics of those works are rarely related to the vessels, barring some presentations about a newbuilding's capability and investigations about vibration at *S.A. Agulhas II*. While this finding was interesting it did not fit the primary scope of the work and was not further followed, nonetheless a link to the field will be established in the conclusions chapter as it contained information that correspond with insights obtained during the talks with F. Laeisz OHG at the OI:London 2018 (see Section 3.4.5). Afterwards the data collection was completed, and focus was set on the development of a model and its application which will be presented in the following chapter.

4 Results

The introduction presented a figure showing the Antarctic bases that formed one starting point for the investigation towards PRSV. This figure is picked up and used to visualize the findings. The corresponding PRSV are listed in Table 4 below.

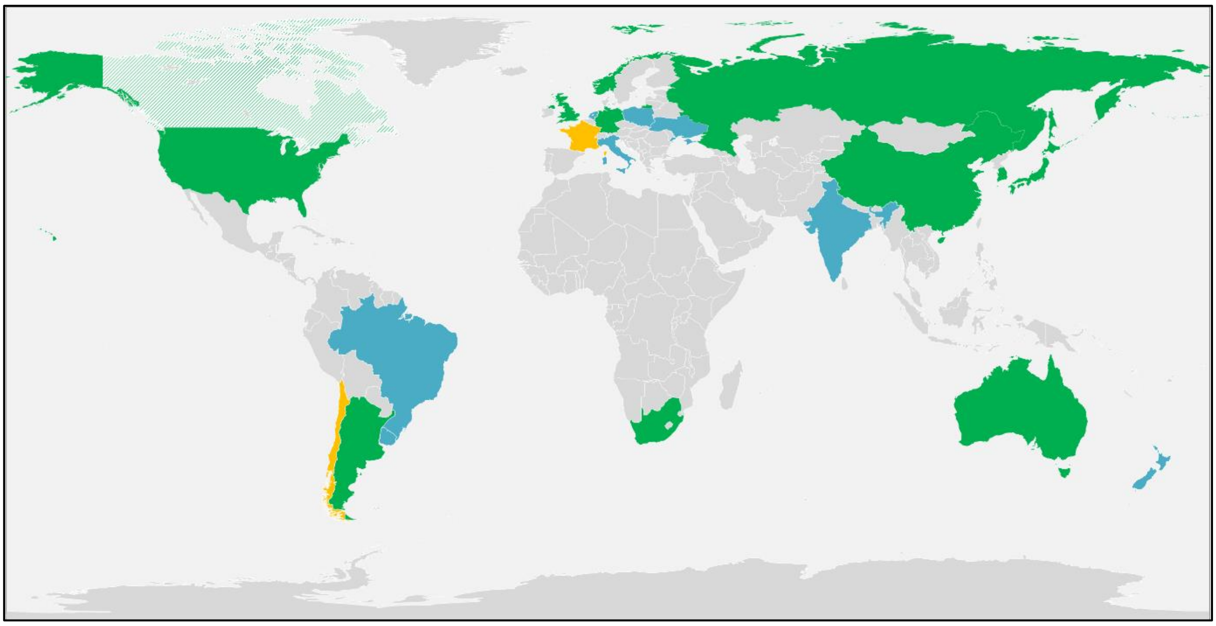

Figure 14. Visualization the PRSV results. Green: Antarctic Scientific Base and PRSV present, Green striped: Only PSRV present, Blue: Antarctic Scientific Base present, Orange: Base and Vessel which did not meet set criteria and are part of regular oceanographic research vessels.

Table 4. List of PRSV.

#	Nation	Name	Built
1	Australia	Aurora Australis	1989
2	Australia	Nuyina	~2020
3	Argentina	Alimirante Irizar	1978 (Refit 2007-2017)
4	Canada	John G Diefenbaker	~2020
5	China	Xue Long	1993
6	China	Xue Long 2	2019
7	Chile	Antárctica 1	~2021-22
8	Germany	Polarstern	1982
9	Japan	Shirase	2009
10	Norway	Kronprins Haakon	2018
11	Russia	Akademik Fedorov	2011
12	Russia	Akademik Tryoshnikov	2012
13	South Africa	S.A. Agulhas II	2012
14	South Korea	Araon	2009
15	United Kingdom	James Clark Ross	1990
16	United Kingdom	Ernest Shackleton	1995
17	United Kingdom	Sir David Attenborough	~2019
18	USA	Healy	1997

In total 18 vessels were included in the final list and used as frame for data collection. Based on those, 57 attributes were established. This ranges from basic fields with information like name, built date, IMO-number to scientific capabilities like sonars, coring and drilling capacities, to logistical capabilities like cargo hold volume, cranes and tender assets to icebreaking performances and engine and propulsion setup. Due to the exploratory nature of the study the collected data is far wider than the scope finally used to answer the primary research question. The chosen ship parameters are presented in Appendix 4 with short descriptions and links to the literature for further reading.

4.1 Model for PRSV capability assessment

A model is proposed to answer the fourth sub-question specifically: How can the performance assessments be applied to modern PRSV?

It uses an adapted concept from Basurko and Mesbahi (2014) and BIMCO (2018) as presented in Chapter 2. It is visualised in Figure 15. Both models are characterised by multiple dimensions, or aspects, in which unique final scores were calculated to inform about the respective performance. They differ in their scopes and abstraction, whereas the sustainability assessment models are very general and universally applicable, the Shipping KPI is an applied assessment for performances in maritime shipping. The developed model is situated in between both in terms of abstraction. It can also be seen as an applied approach from Basurko and Mesbahi (2014). The here established aspects are Icebreaking, Logistics and Science, established after the three main purposes and missions of PRSV. Additionally, the fourth aspect, Size, was included to reflect a sense of scaling in the model. Section 4.2 will present them in more detailed form.

This does not follow the sustainability aspects in the same manner as the presented methodologies and this first attempt of comparison is mostly focused on the economical aspect, which is not necessarily expressed in monetary numbers. Social aspects were not investigated, and environmental ones are rather subtle integrated into basic capability attributes but are also not considered separately.

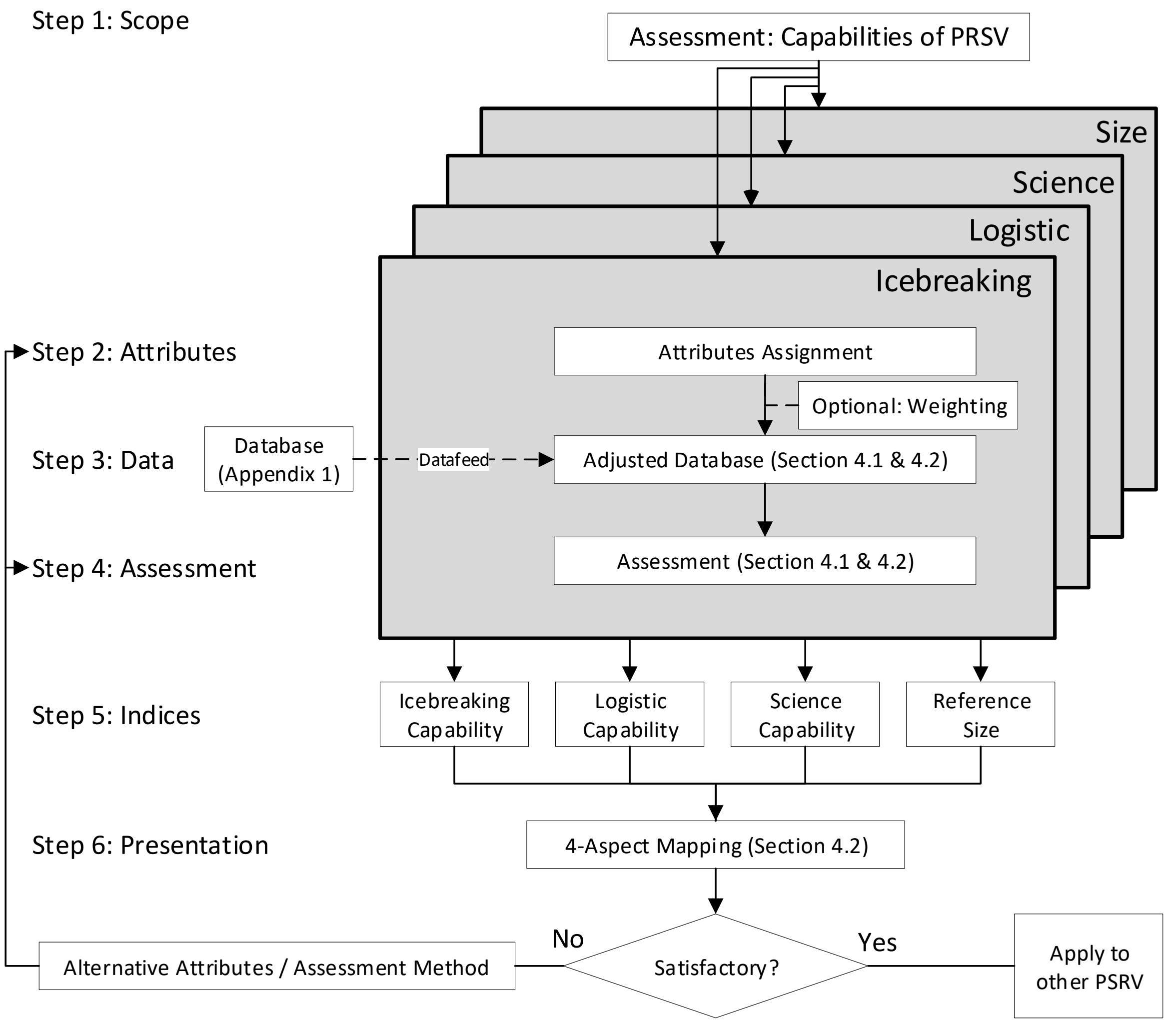

Figure 15. Capability Assessment of PRSV.Adapted from Basurko and Mesbahi (2014) and BIMCO (2018)

For streamlining the approach, the model starts with defining the scope of the assessment which is the topic of the thesis and its primary research question.

Afterwards separate aspects or dimensions are generated which were described in the beginning of the chapter. These are now assigned corresponding attributes (Step 2) that fit the purpose, not all collected attributes may be incorporated into the aspect.

Then, data from the database is assigned to the chosen attributes. Adjustments to the data might be necessary to allow assessment, a step that is detailed in Section 4.3. Some attributes have been collected as a Boolean type (Is the type of equipment present or not) whereas other parameters were collected in numerical form (e.g. Propulsion power and level icebreaking).

The assessment (Step 4) will vary slightly depending on the type of data that is collected. Most will be assessed using the averaging method. This is especially true for Boolean type data that is used in groups. Others are calculated using the normalization mentioned at the presentation of the Shipping KPI model in Section 2.3. This uses maximum and minimum values from the PRSV to normalize the specific attributes value in relation to its group. If the aspects had sub-groups respective score are weighted according to the number of attributes corresponding with this score.

The result are three indices being a number between 0 and 100, indicating the degree of sophistication or capability in the respective area.

4.2 Presentation of the four aspects

Icebreaking capability. The first aspect contains three attributes: Ice class, icebreaking and propulsion power. Ice class is a numerical representation of the polar classes adapted to the group of PSRV, this means the boundaries are set by the maximum and minimum polar class or equivalent of the investigated vessels. Because of this the maximum value is 2 and minimum 6. Deciding on equivalent values is a process presented in the next Section (4.3). The icebreaking refers to the thickness of level ice they PSRV can break by going a certain speed, usually between 2 and 5 knots. This also often includes a snow layer on top which has not been noted in the databases. The performance is the speed before the vessel needs to engage in ramming operation. In this application only considers the thickness of level icebreaking and does not take the individual speed into account. The propulsion power is also considered here as the polar class notation itself does not take this in consideration (Nyseth & Bertelsen, 2014). Stated values are explicit targeted at propulsion and not general output of the engines. All values are normalised using the minimum and maximum and the final score is calculated by averaging the three sub-scores.

Scientific capability. The category with the highest number of attributes, mostly aggregated in the Boolean format. It contains information about scientific equipment (11 attributes) that is present on the vessel and includes a second part, listing vessel specifics (7 attributes) like the presence of a moonpool, dynamic positioning systems, drop keels, ROVs and AUVs. Finally, the laboratory space is evaluated by comparing the sizes (m^2). Detailed information about this metric are given in the next Section (4.3). The three individual scores are weighted according to their number of attributes and combined into a final score.

Logistic capability. This category has many potential attributes but only one which delivered consistent information, the cargo hold volume, given in m^3. Additionally, a second consideration in this aspect are the TEU capacity which is stated for some, but not all PSRV. Additional considerations were given extra cargo tenders, helicopter capacity, additional holds for aviation or base fuel and cranes. Generally, the information in this area where often too unspecific to be applied in calculations.

Size. Initially the model was only concerned with the three main aspects, but the results were lacking a way of putting them in perspective, thus this aspect was added. Ideally the gross tonnage would be a fitting reflection of most interior spaces. Unfortunately, some newbuilding's did not have this information yet and substitutes had to be taken into consideration. Displacement and the basic dimensions were considered. As displacement is rather a measure of weight than size it was discarded. This was also influenced by the different icebreaker design, which naturally feature heavy steel plating but some PRSV like the RV *Polarstern* are also built with a double hull, increasing the weight further. The final method for assessment is the creation of individual scales for length, breadth and depth in a normalised way and assessing the final score afterwards by averaging the three resulting values. Creating a volume by multiplication did not seem to reflect the special hull forms in an appropriate way.

The following section will focus on the data and the adjustments that had to be made for their application in the model.

4.3 Database attribute adaption

To use some attributes in the model the values had to be made comparable. One important part was the ice class of the vessel which is aimed to be stated in polar classes, another important one is the laboratory spaces. Other attributes needed adaption as well and selected, important ones, are presented in this Section.

Laboratory spaces. This attribute has a large variation of details for the investigated vessel. Sometimes, only total area is given whereas other sources present all laboratories on the PRSV in detail. In rare cases laboratories were only mentioned and neither presented nor detailed. The spaces are an important criterion for research vessels and have been studied before, relating it with other features like deck space, ship noise or accommodations (Subbaiah, Sai & Suresh, 2016). The resulting importance of the spaces is reflected in the model by including absolute numbers. The following assumptions are created to transform the information into comparable numbers:

(6) The size of a single laboratory is set to $20m^2$ if no other figures are given.

(7) Containerised lab spaces are calculated as $14.5m^2$ per TEU.

This shall help defining a basis for the comparison of the spaces, limitations of this are highlighted in Section 5.2.

Ice classes. Another very important attribute is the ice class of the PRSV. In 2007 the Polar Classes were published by the IACS in an attempt to uniformize the various ice classing rules and regulations (IACS, 2006). Direct comparison is very difficult because of varying criteria in these rules. Some classifications consider engine power, others are only focused on structural strength. The polar class was developed by experts in the field of all major ice classifications, thus it presents a suited way to compare PRSV (Daley, 2014). An attempted visualization is presented in Figure 16 and it must be highlighted that comparisons are only possible on a case by case basis and should not be applied in a generalised way. Vessels that needed adjusting were RSV *Aurora Australis* (1AS Baltic Classes), MV *Xue Long* (1AS Baltic Classes), RRS *Ernest Shackleton* (1A1 BC), RV *Polarstern* (Arc-3 GL), *II, Akademik Fedorov* (Arc 7 – Russian Reg), *Akademik Tryoshnikov* (Arc 7 – RR) and IBRV *Araon (PL-10 DNV)*. This substantial number of vessels made consideration regarding the ice class and their conversation mandatory but due to the very technical nature of the topic cannot be covered in full in this study.

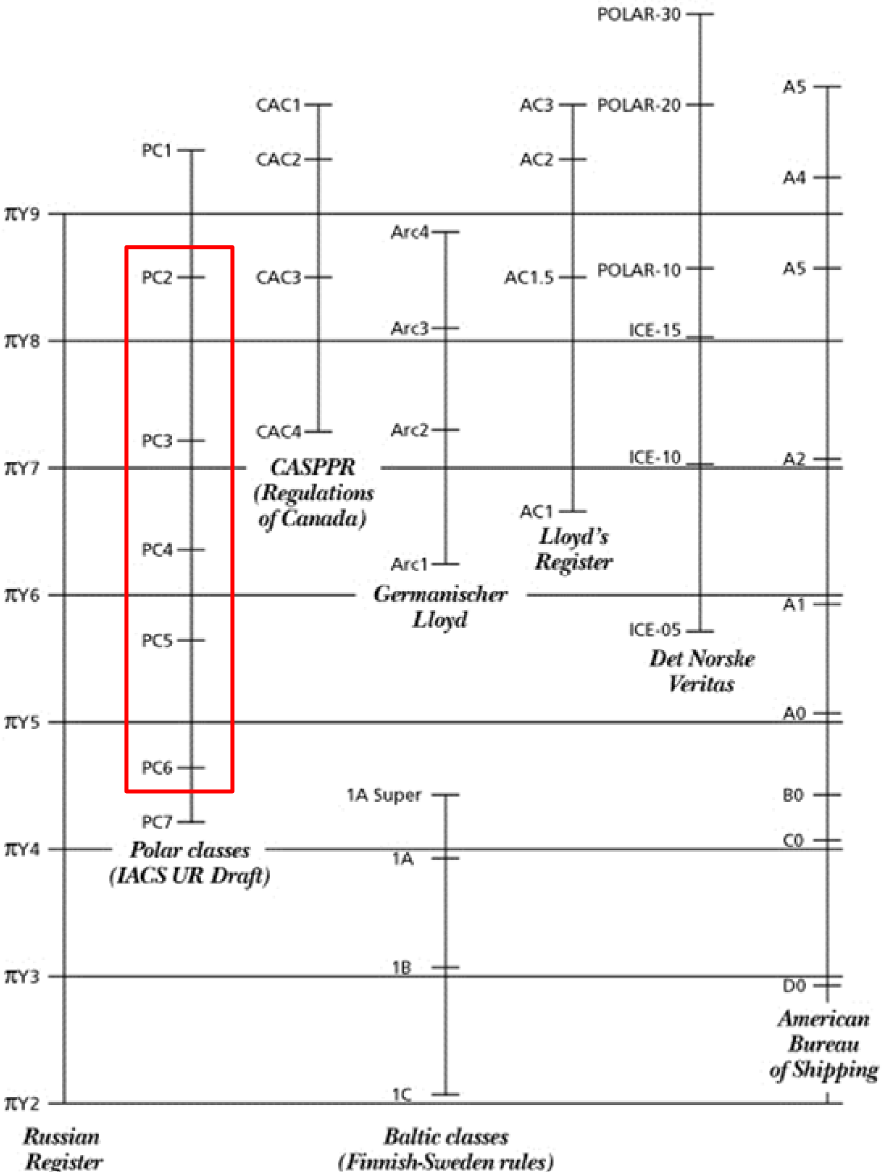

Figure 16. Comparison between rules for ice strengthening. Red frame shows the range of the PSRV. Taken from: Nyseth and Bertelsen (2014) originally created by Krylov Institute in St. Petersburg.

Dynamic positioning. Dynamic positioning capabilities are subject to evaluation and framing by classification societies. The IMO (1994) proposed three equipment classes based on redundancy.

- Equipment Class 1: No redundancy. Single fault can lead to loss of position.
- Equipment Class 2: Redundancy. No single fault of active components or systems will lead to positioning loss. (Components like cables, pipes, valves are allowed to cause this)

- Equipment Class 3: Class 2 but also must withstand fire or flooding in any compartment without system failure.

Table 5. DP Class comparison.

IMO DP Class	ABS class	LRS Class	DNV Class
-	DPS-0	DP (CM)	DPS 0 DYNPOS-AUTS
Class 1	DPS-1	DP (AM)	DPS 1 DYNPOS-AUT
Class 2	DPS-2	DP (AA)	DPS 2 DYNPOS-AUTR
Class 3	DPS-3	DP (AAA)	DPS 3 DYNPOS-AUTRO

Note: Taken from Giddings (2013)

This information could be collected reliably for most vessel but the influence on the actual capabilities of the vessel from the classes is relatively minor as they are mostly concerned with reliability instead of accuracy of position. Because of this the detailed information in the database were reduced to Boolean type for the assessment.

Other attributes. During data collection many information where split up with the aim to categorize as much as possible. This lead to attributes that are hard to see as defining any more. The biological nets and trawling gear were initially kept as separate entries but as neither of the objects is fixed to a specific vessel and rather dependant on the available winches they were combined into one for the scientific evaluation. Similar steps were taken with the acoustical instrumentation where the attribute 'Sonar' was deleted as it was too general and different sources referred to different type of instrumentation.

4.4 Application of the model

This Section will present the developed model on five ships with the most complete information in the database. It features the RSV *Aurora Australis*, RSV *Nuyina*, RRS *Sir David Attenborough*, RV *Polarstern* and RV *Kronprins Haakon*. The selected attributes for evaluation with the corresponding values are shown in the table below.

Table 6. Adjusted Database.

	RSV Aurora Australis AUS 1989	RSV Nuyina AUS ~2020	RV Polarstern GER 1982	RV Kronprins Haakon NOR 2018	RRS Sir David Attenborough UK ~2019		
SIZE						MAX	MIN
Length (m)	94.9	160.3	117.9	100.0	128.0	167.0	80.0
Length (Score)	**17.1**	**92.3**	**43.6**	**23.0**	**55.2**		
Breadth (m)	20.3	25.6	25.0	21.0	24.0	28.0	17.0
Breadth (Score)	**30.0**	**78.2**	**72.7**	**36.4**	**63.6**		
Draft (m)	7.9	9.3	11.2	8.5	7.0	14.4	6.4
Draft (Score)	**18.3**	**36.3**	**60.0**	**26.3**	**7.5**		
Displacement (t)	8,158	24,000	17,300	9,000	12,790	24,000	4,028
Discplacement (Score)	**20.7**	**100.0**	**66.5**	**24.9**	**43.9**		
GT	6,574		12,614	9,145	15,000	16,000	4,028
Size Score	**21.8**	**68.9**	**58.8**	**28.5**	**42.1**		
ICEBREAKING						MAX	MIN
Ice Class	6	3	3	3	4	2	6
Ice Class (Score)	**0.0**	**75.0**	**75.0**	**75.0**	**50.0**		
Icebreaking	1.2	1.7	1.5	1.0	1.0	2.5	1.0
Icebreaking (Score)	**15.3**	**43.3**	**33.3**	**0.0**	**0.0**		
Propulsion Power (kW)	10,000	26,600	14,120	11,000	5,500	34,000	5,369
Propulsion Power (Score)	**16.2**	**74.2**	**30.6**	**19.7**	**0.5**		
Icebreaking Score	**10.5**	**64.2**	**46.3**	**31.6**	**16.8**		
LOGISTIC						MAX	MIN
Cargo hold (m^3)	1,790	5,030	1,039	1,180	2,200	8,595	567
Cargo hold (Score)	**15.2**	**55.6**	**5.9**	**7.6**	**20.3**		
TEU (Cargo)	37	96	8	20		96	0
TEU (Score)	**38.5**	**100.0**	**8.3**	**20.8**	0		
Logistic Score	**26.9**	**77.8**	**7.1**	**14.2**	**10.2**		

RSV Aurora Australis RSV Nuyina RV Polarstern RV Kronprins Haakon RRS Sir David Attenborough

	AUS 1989	AUS ~2020	GER 1982	NOR 2018	UK ~2019		
SCIENCE						MAX	MIN
Instrumentation							
Air & Aerosol Sampling	Yes	Yes	Yes	Yes	Yes		
ADCP	Yes	Yes	Yes	Yes	Yes		
Fishery Sonar	Yes	Yes	Yes	Yes	Yes		
Multibeam	Yes	Yes	Yes	Yes	Yes		
Sub-bottom Profiler	Yes	Yes	Yes	Yes	Yes		
Nets & Trawling	Yes	Yes	Yes	Yes	Yes		
Sediment corer	No	Yes	Yes	Yes	Yes		
Rock Drills	No		Yes	Yes	Yes		
Seismic	No	Yes	Yes	Yes	Yes		
Magnetometer	No		Yes	Yes	Yes		
Gravimeter	No		Yes	Yes	Yes		
CTD & Water	Yes	Yes	Yes	Yes	Yes		
Instrumentation Score	**58**	**75**	**100**	**100**	**100**		
Laboratiories (m²)	160	500	576.5	343.5	620	620	68
Laboratories (Score)	**17**	**78**	**92**	**50**	**100**		
Scientific Ship Features							
Dynamic Positioning	No	Yes	Yes	Yes	Yes		
A-Frame (Y/N)	Yes	Yes	Yes	Yes	Yes		
Drop Keel (Y/N)	No	Yes	No	Yes	Yes		
Silent Operation (Y/N)	No	Yes	No	Yes	Yes		
Moonpool (Y/N)	No	Yes	No	Yes	Yes		
ROV (Y/N)	No	Yes	Yes	Yes	Yes		
AUV (Y/N)	No	Yes	Yes	Yes	Yes		
Ship Features Score	**14**	**100**	**57**	**100**	**100**		
Science Score	**40.8**	**83.9**	**82.6**	**97.5**	**100.0**		

The individual scores are combined into a matrix (Table 7) and give a quick overview about the capabilities of the selected PRSV. Afterwards they can be mapped into the four aspects and visualised as a radar diagram as shown in Figure 17

Table 7. Resulting Scores.

	RSV *Aurora Australis*	**RSV *Nuyina***	**RV *Polarstern***	**RV *Kronprins Haakon***	**RRS *Sir David Attenborough***
SIZE	21.8	68.9	58.8	28.5	42.1
ICEBREAKING	10.5	64.2	46.3	31.6	16.8
SCIENCE	40.8	83.9	84.6	97.5	100
LOGISTIC	26.9	77.8	32.3	14.2	10.2

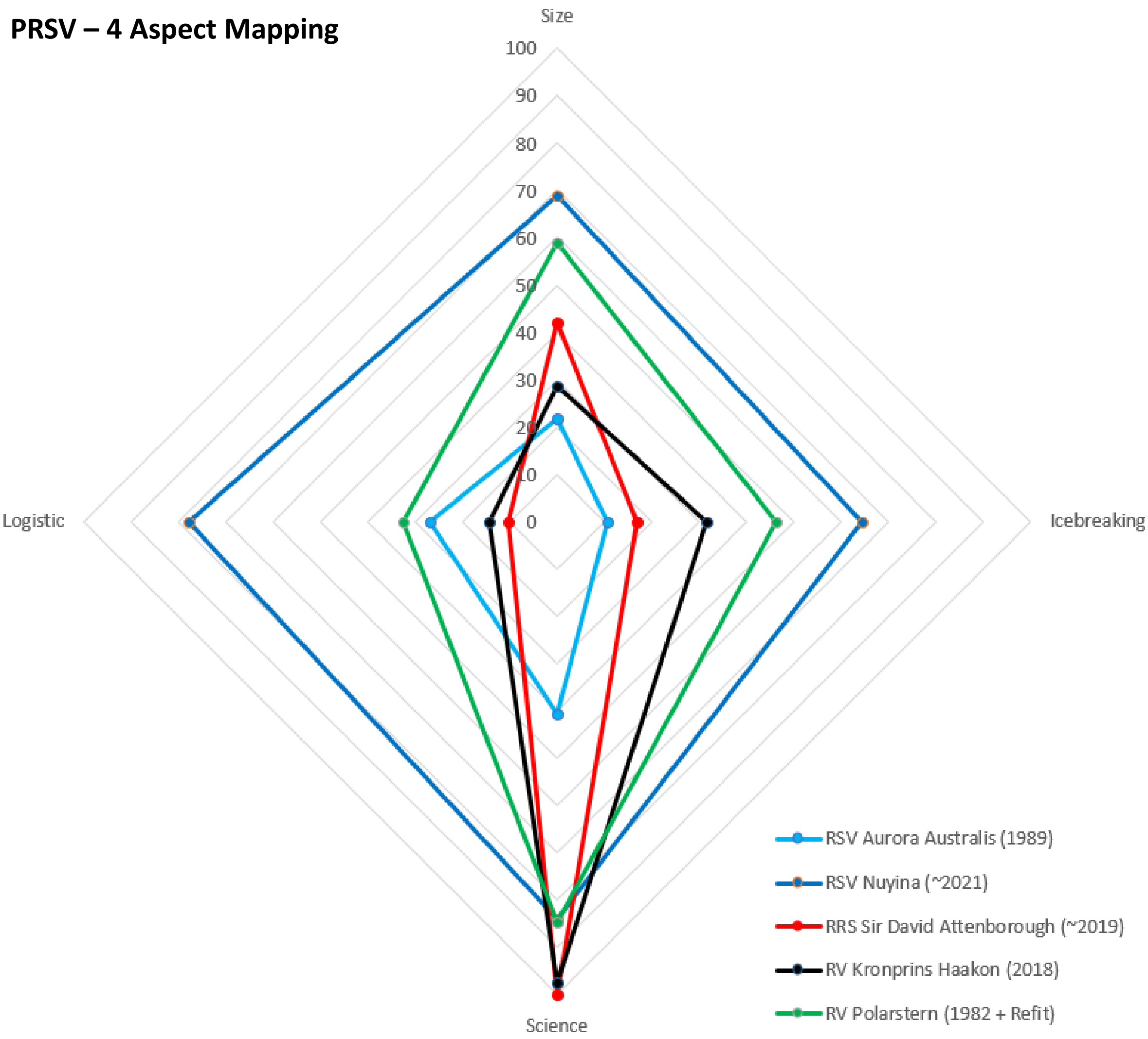

Figure 17. PRSV - 4 Aspect Mapping

The results show pretty large difference in size, logistic and icebreaking but are quite similar on the science capabilities. Only the RSV *Aurora Australis* is lacking behind the other vessels, possibly because of her age.

5 Discussion

This approach of modelling the capabilities of PRSV was developed by adapting general sustainability models developed by Basurko and Mesbahi (2014) and using the insights gained from ranking, rating and benchmarking used in the Shipping KPI standard by BIMCO (2018). The result is preliminary but is important because it shows the viability of capability assessments for PRSV. The model is built up in flexible modules and aspects that do not interact with each other and are not aggregated in a final score. Adding new aspects that have previously not been considered is thus simple as long the underlying database supplies the necessary information.

While the model copes reasonably well with data of the past which has been collected in this study, there is currently no room to assess capabilities of the future. Yet, the ship lifetime of newbuildings will cover the next thirty years. This means that research demands that are still unknown need to be considered and integrated into the designs. (Australian Antarctic Division, 2017b; NERC, 2014) The model currently does not reflect these capabilities. To cope with these, additional attributes are needed which would naturally influence the scores of all other vessels of the group. Thus, attributes and their interaction must be carefully considered, also in relation to their weighting and importance for the research itself. This can be put into perspective with currently piloted projects that test new ways of doing scientific investigations. Project Ocean Infinity (2018) uses multiple autonomous underwater vehicles (AUV) simultaneously to multiply the area of effect of the gathered data without the need of using the expensive and slow main vessel for the whole region. Unmanned Surface Vehicles (USV) are used to transmit the vast amounts of data to the ship. The whole operation is now a swarm instead of a single vessel and extensive artificial intelligence systems are used to provide autonomy to the AUVs. Even this concept could not be evaluated in the proposed model due to the sheer number of AUVs and multiplication of survey capabilities. The attribute types of AUV would need to be changed and possibilities to reflect this extensive survey capability needs to be added with the correct significant weighting.

Currently, no upper boundary on vessels to add is set. Extremely sophisticated icebreakers with large laboratory spaces and excessive equipment in all areas could for example skew the comparability of the other vessels in the database as their score would be pressed down, losing a lot of the ability to gain information 'at a glance'. Even with establishing an upper boundary, providing a frame for the group on data collected proved much more complex than on commercial shipping classes. A panamax bulk carrier is stated to be between 60,000 and 75,000 tonnes deadweight with the width restriction of 32.5m (Stopford, 2008). To put this into perspective the GT range of the group of PSRV is 4,000 to 16,000 and their length varies between 80m and 167m. The relative differences are much more extreme than in the defined classes of shipping. Thus, the boundaries were defined rather soft and focused on creating a border between the comparatively large group of oceanographic research vessel or global research vessels (EurOcean, 2016). The exact boundaries and group compositions vary in the sources. Nonetheless, it was decided to use the ice class as criterion to divide the groups. Scientific capabilities were found to be largely comparable. Logistic capabilities are also included in the boundary but due to the very strong ties to the respective national Antarctic programs this might not be a deciding factor (Compare Appendix 3 RSV *Nuyina with* RV *Kronprins Haakon*).

The database itself tries to deliver information about the complete group of these vessels. Current databases were found to focus on regional units or mixing them with other classes of research vessels. Unifying them into one database, established after a common sourcing hierarchy enables potential users to quickly get a general impression about the capabilities of PRSV in question.

The chosen method and the collected data have limitations which will discussed below.

Access to Data. Much of the data was available on websites and database documents but some investigated vessels are part of the armed forces where information is much harder to acquire. Additionally, major sources of information about Chinese, Japanese, Argentinian and Russian vessels was only available in their own languages. While English translations were offered by them occasionally they were generally lacking or not understandable.

Data Quality & Reliability. The first important limitation in the conducted study is the quality of collected data. Due to the large number of sources and sometimes vague descriptions of values it was at times difficult to decide on which source to trust if stated attributes conflicted with each other. This is problematic for the reliability of the data acquisition as it depends on the judgement of the author. To counteract, a general hierarchy for results was established in the methodology but general concerns remained.

Data Format. Much of the data has been collected in Boolean format which can make the further development into performance assessing parameter more difficult. Having more detailed information available would have led to a possible broader evaluation to assess the parameters performance. To provide opportunities to further development the model uses adapted attributes of the main database. The latter often includes additional information beyond Boolean statements.

Scientific Capabilities. The literature was surveyed for scientific equipment and the author recognizes the fact that a lot of instrumentation is portable and could be installed on the vessel on a project basis. The database still aims to cover the main scientific areas of equipment used on PRSV. Further refinement into permanent installed equipment and operational capabilities could have led to more nuanced results and a score that better reflects the capabilities. Additionally, current trends of robotics, drones and future capabilities should be considered.

Logistical Capabilities. The final attributes used in the model are important but not exhaustive for this capability. Additionally, the scientific laboratory spaces were calculated by the authors assumptions on vessels were specific numbers on space were not available. This probably led to skewed numbers in the scientific scores. More details about cranes, helicopters and boats were collected as well but were not integrated.

Icebreaking Capabilities. The used attributes try to reflect the ability of the vessels in this field, but the technical nature made consideration very difficult in the scope of this study. Especially the conversion of ice classes, referencing on external literature, leaves much room for misinterpretation and has a significant impact on the total score.

Many of the limitations are a result of the chosen research method and data collection and further research might be able to circumvent issues experienced in this study. Some possible developments are presented in the next chapter.

6 Conclusion

The study investigated current and planned polar research and supply vessels. The research questions asked: *What are the capabilities of PRSV and how can they be assessed?* This question was supported by secondary questions aimed to guide the research approach. The question is answered by the creation a four-aspect model, mapping the identified capabilities of size, icebreaking, science and logistics on a normalised scale and allowing basic assessments within the boundaries of the group. The study achieved its exploratory aim and scope by providing a basic model, a framed group of PRSV and a database containing key characteristics. Limitations were already presented in the prior chapter. Nonetheless, could further research enrich this result by considering future possibilities of science, refining of the icebreaking assessment and generally increasing the number of attributes that define the individual scores.

6.1 Implications

The main goal for this study was to address the rather untouched field of PRSV, where data was found to be scattered, inconsistent and sometimes contradicting. The group itself was not framed in the literature and sources contained data in varied quality and quantity. As a first step the whole range of that would fit conditions set by the author would be investigated and collected in a common database. This database is the practical contribution of this thesis, providing possibilities for further development and use in managerial aspects. The theoretical contribution stems from the developed model, which is adapted from already established academic literature and allows the basic capability assessment of PRSV with possibilities of expansion.

6.2 Recommendations for further research

6.2.1 Development of database and model

Currently the model does not represent the chosen PRSV to full extend. Further works could significantly enhance the data quality and ability to represent the group. In contrary to the exploratory approach here the development could happen in contact with operators and standardised questionnaires developed from the attributes of the databases. With more data, the model could then be used to find fitting ships for project owners resulting in fitting projects for both owner and user, increasing overall efficiency.

6.2.2 Case study on sustainability of PRSV

The presented models from Cabezas-Basurko et al. (2008) and Basurko and Mesbahi (2014) cover the assessment of the vessels and provide a method for marine technologies as well. It seems to the author as these models could provide an excellent starting point for a case study on PRSV. Especially newbuildings are suited for this as more regulatory frames by the classification societies are set which can guide the approach much more than on older vessels with vague information.

6.2.3 Performance assessments from scientific publications

Near the end of the timeframe for this thesis contact with F.Laeisz OHG was re-established. It was confirmed that scientific publications are used as soft indicators for performance (see Table 3). While this poses an interesting opportunity, research is often uncertain, and outcomes vary. Data is sometimes only useful, or insightful enough, after a long period of observations. This means that this indicator is currently very weak as stand-alone. Further research could focus on alternative means for scientific assessment for PRSV, not only focused on publications but also incorporating capabilities. This could include science time per year or degree of cross-national research projects and shipborne performance itself. The study could cover how efficient data is collected, what means of new technology, e.g. gliders, AUVs, UAVs, are used to automatize collections and more. Business case for privately funded polar research (and supply) vessels

6.2.4 Business case for privately owned PRSV

During data collection, the science cases of the British vessel RRS *Sir David Attenborough* indicated a need for research vessels, as currently the need for research platforms is bigger than the supply (NERC, 2014, pp. 8, 10). This is also visible in the Ocean Facilities Exchange Group (OFEG) which a barter exchange and co-operation platform for European research vessels. So far this includes France, Germany, Netherlands, Norway, Spain and the UK. It features a vessel database and has ship barter requests with ship requirement profiles. Research in this area could survey the ‘market’ and propose solutions to this vessel shortage with possible economical background. Providing a commercial solution for routine tasks that involve long transits, like collection of ocean current meters, could free up expensive ship time of more sophisticated vessels which could be dedicated to actual research projects.

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Appendix 1 – Vessel Database

	Australia RSV Aurora Australis	Australia RSV Nuyina	Argentinia ARA Almirante Irízar
Built	1989	~2020	1978 (Refit 2007-17)
Costs		AUD 500,000,000	
Class notation	Lloyds Register Ice Class 1A Super Icebreaker X100A1 XLMC UMS DP(CM)	Lloyd's Register of Shipping: X100A1 Research/ Supply Ship, Icebreaker (+), Ice Class PC3, *IWS, Helideck, TA3, Winterisation H(-40), D(-30), S(B), ECO (BIO, BWT, GW, NOX-2, OW, P, R, SOX, IHM, SEEMP, EnMS, IBTS), LA XLMC, UMS, DP(AA), CAC(2), PSMR* Shipright (SERS, ES, SCM)	
Operator	Australian Antarctic Division	Australian Antarctic Division	Argentinian Navy
IMO Number	8717283	9797060	7533628
Ship Characteristics			
Length (m)	94.91	160.3	121.3
Breadth (m)	20.3	25.6	25
Draft (m)	7.86	9.3	9.2
Speed (Cruise)	11 kts / 18t fuel p day	12 kts	
Speed (Max)	16 kts	16 kts	17.2
Icebreaking	1.23 m @ 3kts	1.65 m @ 3 kts	1 m @ 3 kts
Ice Class	1A Super (PC6-7)	PC3	
Displacement	8,158	24,000	14,899
GT	6,574		10,065
DWT	3,893		4,600
Endurance	90 d	90 d	
Range	25,000	> 16,000	
Personnel (Crew)	24	32	Total 313
Personnel (Project)	116	117	
Ship Features			
Cranes	4 t gantry crane stern;	Bow 2 x 55 t, Side 1 x 15 t, Aft 1 x 15 t	
A-Frame	4 t	15 t	
Drop Keel	No	Yes 2 x	
Dynamic Positioning	"-" / DPS-0 / DP (CM)	DP2 / DPS-2 / DP (AA)	
Silent Operation	No	Yes	
Moon Pool	No	Yes	
ROV	No	Yes	
AUV	No	Yes	
Laboratories (m²)	8 labs	500 m² + 24 container,	415
Additional		Retractable Bow boom, Wet Well	
Propulsion			
Engine	Diesel 13,400 HP	2 x Diesel direct (19,200 kW) 2 x Electric (7,400 kW)	
Propeller	1 x CPP	2 x CPP	
Propulsion Power	10 MW (13,596 HP)	26,600 Kw	
Thruster Bow	1 x Tunnel	3x	
Thruster Stern	2 x Azimuth	3x	
Aircraft & Boats			
Boat	1 x Tender	3 x Tender / 1 x Science, 2 x 45 t Barges	
Helicopter	2 x M	4 x S or 2 x M	2 x M
Cargo			
Cargo Hold (m³)	1,790	5,030	650
TEU	37	96	
Fuel (Own)		3,477 t (4.09 mil l)	
Fuel (Extra)	968 t (1.1 mil l)	1,623 t (1.98 mil l)	
Fuel (Aviation)	120 m³	500,000 l	
Science Instruments			
Air & Aerosol Sampling	Yes	Yes	
ADCP	Yes	Yes	
Fishery Sonar	Yes	Yes	
Multibeam	Yes	Yes (11km Range)	
Sonar	Yes	Yes	
Sub-bottom Profiler	Yes	Yes	
Nets	Yes	Yes	
Trawling Gear	Yes	Yes	
Sediment corer	No	Yes (24m)	
Rock Drills	No	No Info	
Seismic	No	Yes	
Magnetometer	No	No Info	
Gravimeter	No	No info	
CTD	Yes (6,000m)	Yes	
Water Sampler	Yes (6,000m)	Yes	

	Canada CCGS John G. Diefenbaker	China MV Xue Long	China MV Xue Long 2
Built	~2020	1993	2019
Costs	CAD 1,300,000,000	31 000 000	$ 1,000,000,000
Class notation	Lloyd's Register, X 100A1 ICE CLASS PC2, ICEBREAKER+, LMC, NAV1, IBS, DP(AM), UMS, CCS, ICC, PSMR, IFP, CAC3, WINTERIZATION: H(-35), A(-40)	Ice Class B1*; Loading Computer (S, I, D); BWMP(MEPC.127(53))	China classification society, Lloyds register
Operator	Canadian Coast Guard	Polar Research Institute of China	Polar Research Institute of China
IMO Number	n/a	8877899	n/a
Ship Characteristics			
Length (m)	150.1	167	122.5
Breadth (m)	28	22.6	22.3
Draft (m)	10.5	9	8
Speed (Cruise)	12 kts		
Speed (Max)	20 kts	18	15kts
Icebreaking	2.5 m @ 3 kts	1.1m @ 1.5kts	1.5m @ 3kts
Ice Class	Polar Class 2(+)	1A Super (PC6-7)	PC3
Displacement	23,500	21,025	14,300
GT		15,352	
DWT		8,759	
Endurance	270 d (25 d full power)		
Range	> 26,200 nm	20,000 nm	20,000
Personnel (Crew)	60	34	
Personnel (Project)	40	128	90
Ship Features			
Cranes	6+	yes	yes
A-Frame			yes
Drop Keel	No		
Dynamic Positioning	DPS-1 / DP (AM)		DPS
Silent Operation			
Moonpool	Yes		yes
ROV	No		
AUV	No	Yes	
Laboratories (m²)	>40	updated to 200m²	
Additional	Towing capabilities, Air bubbling system (Ice)		
Propulsion			
Engine	6 x Diesel Electric 39.6 MW,	13,200kw	4 x Diesel Electric
Propeller	2 x Wing Shafts (11MW each), 1 x Azimuth Thruster (12 MW)		2x Azimuth (7,5MW)
Propulsion Power	34 MW		
Thruster Bow	2 x Tunnel (1.9 MW each)		2x
Thruster Stern			
Aircraft & Boats			
Boat	Various light and medium crafts		
Helicopter	2 x M (Hangar), 1 x L deck	Yes - Xueying	2x medium sized
Cargo			
Cargo Hold (m³)	Yes (no figures)		yes
TEU	Yes (no figures)		
Fuel (Own)			
Extra holds			yes (Cargo fuel tank)
Science			
Air & Aerosol Sampling	Yes		
ADCP	Yes	Yes	
Fishery Sonar			
Multibeam	Yes		
Sonar	Yes		
Sub-bottom Profiler	Yes		
Nets	Yes		
Trawling Gear			
Sediment corer	Yes		
Rock Drills			
Seismic			
Magnetometer			
Gravimeter	Yes		
CTD	Yes	Yes	Yes
Water Sampler	Yes	Yes	

	United Kingdom RRS James Clark Ross	United Kingdom RRS Ernest Shackleton	United Kingdom RRS Sir David Attenborough
Built	1990	1995	~2019
Costs	£ 50,000,000.00		£ 200,000,000
Class notation	Lloyds +100A1 ICE CLASS IAS + LMS UMS (Research/Survey/Cargo)	DnV +1A1 ICEBREAKER ICE 05 EO HELIDK ICS DYNPOS-AUTR W1 (Research/Survey/Cargo)	LRS 100A1, LMC, Polar Research Vessel, UMS, DP (AA), NAV1, IBS, IceClass PC4 (main propulsion lines PC5), CAC1, LFPL, ECO (BWT, GW, OW, SILENT R
Operator	British Antarctic Survey	British Antarctic Survey	British Antarctic Survey
IMO Number	8904496	9114256	9798222
Ship Characteristics			
Length (m)	99.04	80.00	128
Breadth (m)	18.85	17.00	24
Draft (m)	6.40	6.85	7
Speed (Cruise)	12 kts	12 kts	13 kts
Speed (Max)	16 kts		17.5 kts
Icebreaking	1 m @ 2 kts		1 m @ 3 kts
Ice Class	1AS (PC6)	1A1 (PC5)	PC4 (propulsion PC5)
Displacement	5,732	4,028	12,790
GT	5,732	4,028	15,000
DWT		2,134	4,475
Endurance	57 d	130 d	60 d
Range	16,416 nm	40,000 nm	19,000 nm
Personnel (Crew)	29	22	30
Personnel (Project)	46	50	60
Ship Features			
Cranes	Crane 20t	Cargo 30 t	Cargo 50 t
A-Frame	20 t		30 t
Drop Keel			Yes
Dynamic Positioning	Yes	Yes	DP2
Silent Operation	Yes	slow speed and position-keeping facilities	Yes
Moon Pool			4m x 4m with hatch
ROV		ROV Crane 5 t	Yes
AUV			Yes
Laboratories (m²)	23.5 wet, 44 dry + 5 containers	90m² + 2 Container Labs	620.2
Additional			UAV
Propulsion			
Engine	Diesel Electric	2 x Diesel	2 x Diesel Electric 5,400 kW 2 x Diesel Electric 3,600 kW, Batteries
Propeller	Single fixed Propeller	1 x CPP, Azimuth thruster	2 x CPP Promas installation
Propulsion Power	8,500 SHP, 6338,449 KW	7,200 SHP, 5369,039 KW	2 x 2,750 kW
Thruster Bow	360°, 10 t thrust	1x Tunnel 1,100 SHP	2 x Tees White Gill, 1,580kW
Thruster Stern	360°, 4t thrust	3 x Tunnel 800 SHP	2 x Tees White Gill, 1,580kW
Aircraft & Boats			
Boat			Cargo Tender / Workboat / inflatable
Helicopter	No	10 t max (20m rotor)	4 S or 2 M-size
Cargo			
Cargo Hold (m³)	1,500 m³	3,000 m³	2,200 m³ + 650 m² Deck
TEU		4 Reefers	
Fuel (Own)		1,380m³	
Fuel (Aviation)		195 m³	660 m³
Science			
Air & Aerosol Sampling			Yes
ADCP			Yes
Fishery Sonar	Yes		Yes
Multibeam		Yes	Yes (3 models
Sonar	Yes		Yes,(Omnidirectional and forward looking)
Sub-bottom Profiler		No	Yes
Nets	Yes		Yes (3 x Bongo nets)
Trawling Gear	Yes		Yes
Sediment corer	Yes, 30m		Yes, Box, Gravity, Vibro, 42m piston
Rock Drills			Yes (RD2 system - 50m)
Seismic	Yes		Yes
Magnetometer	Yes		Yes
Gravimeter			Yes
CTD	Yes		Yes, 2 Systems
Water Sampler	Yes		Yes

	Germany RV Polarstern	Japan JMSDF Shirase	Norway RV Kronprins Haakon
Built	1982	2009	2018
Costs			1,400,000,000 NOK
Class notation	100 A5 Research vessel Special purpose ship ARC3 ERS		1A1 Icebreaker Clean(Design) COMF(C-2, V-3) DAT(-35 °C) DK(+) DYNPOS(AUT) E0 HELDK(S, H, F) NAUT(OSV(A)) PC(3) RP Winterized(Basic)
Operator	Alfred Wegener Institut	Maritime Self-Defense Force Japan	Norwegian Polar Institute, the Institute of Marine Research
IMO Number	8013132	n/a	9739587
Ship Characteristics			
Length (m)	117.91	138	100
Breadth (m)	25	28	21
Draft (m)	11.2	14.4	8.5
Speed (Cruise)	10.5 kts	0	15 kts
Speed (Max)	16.5 kts	19.5 kts	
Icebreaking	1.5m	1.5m @ 3kts	1m @ 5 kts | 0.4m @ 12 kts
Ice Class	ARC-3 (IC) / 100 A5		PC3
Displacement	17,300	20,000	9,000
GT	12.614		9,145 (DNV) / 10,900
DWT	4,374		3,613
Endurance	80 d		65 d
Range	19,000 nm		17,000 nm
Personnel (Crew)	44	175	15-17
Personnel (Project)	55	80	35
Ship Features			
Cranes	1 x 25t Foreship, 1 x 15 t astern, 20 t slidebeam,5 t slidebram		1 x 12 t, 3 x 5 t, 1 x 3 t
A-Frame	30 t		Yes
Drop Keel	No		Yes
Dynamic Positioning	Yes		DP1
Silent Operation	No		Yes
Moonpool	No		Yes
ROV	Yes		Yes
AUV	Yes		Yes
Laboratories (m²)	359+15 Containers		15 + 3 container lab
Additional	Double Hull		Diving facilities (w. pressure chamber)
Propulsion			
Engine	4 x Diesel 14,120 kW, (19,198 PS)	Disel-electric	4 x Diesel Electric 15MW
Propeller	2 x CPP	2 x FPP	2 x Z-Drives
Propulsion Power	19,198 HP	22,000 kW	11,000 kW
Thruster Bow			2 x Tunnel 2,200kW
Thruster Stern			See Propeller
Aircraft & Boats			
Boat	2		
Helicopter	2	CH101 x2, A355, class x1	Yes ,2 S / M Hangar
Cargo			
Cargo Hold (m³)	1,230	1,100 t	1,180
TEU	54TEU		20
Fuel (Own)			
Science			
Air & Aerosol Sampling	Yes		Yes
ADCP	Yes		Yes
Fishery Sonar	Yes		Yes
Multibeam	Yes		Yes
Sonar			Yes
Sub-bottom Profiler	Yes		Yes
Nets	Yes		Yes
Trawling Gear	Yes		Yes
Sediment corer	Yes		Yes, (Gravity/Calypso/Multicore/Vibro)
Rock Drills	Yes		Yes (80m)
Seismic	Yes		Yes
Magnetometer	Yes		Yes
Gravimeter	Yes		Yes
CTD	Yes		Yes
Water Sampler	Yes		Yes

Ss	Russia **Akademik Fedorov**	Russia **Akademik Tryoshnikov**	South Africa **S.A. Agulhas II**
Built	1987	2011	2012
Costs			
Class notation	KM ULA AUT2 special purpose ship	KM Arc7 AUT2 special purpose ship	1A1 Passenger ship BIS Clean(Design) COMF(C-2, V-2) DAT(-35 °C) DEICE DYNPOS(AUT) E0 HELDK(S, H, F) LFL(*) NAUT(AW) PC(5) RP TMON Winterized(Basic)
Operator	Arctic and Antarctic Research Institute	Arctic and Antarctic Research Institute	SANAP
IMO Number	8519837	9548536	9577135
Ship Characteristics			
Length (m)	141.2	133.53	134.2
Breadth (m)	23.5	23.25	21.7
Draft (m)	8.5	8.5	7.65
Speed (Cruise)	16 kts	16 kts	14 kts
Speed (Max)			
Icebreaking	1m @ 2 kts	1.1m @ 2kts	1m @ 5 kts
Ice Class	(PC5) ULA	(PC4) Arc 7	PC5
Displacement	16,200	16,539	13,687
GT	12,660	12,701	12,897
DWT			4,780
Endurance		45 d	
Range		15,000 nm	15,000 m,
Personnel (Crew)	80	60	45
Personnel (Project)	160	80	100
Ship Features			
Cranes	1x 2t; 2x 50t; 2x 10t		1 x 35 t
A-Frame	yes		
Drop Keel			Yes 3m
Dynamic Positioning		No	DP1
Silent Operation		No	
Moon Pool			Yes 2.4 x 2.4 m
ROV	Yes	No	No
AUV		No	No
Laboratories (m²)	10 á TEU	250m²+ 4 TEU	8 + 6 containerised
Additional		Diving	
Propulsion			
Engine	HFO IFO-80/Gasoil	3 x Diesel,2 x 6,525 kW,1 x 4,350 kW	4 x Diesel Electric 3,000 kW
Propeller	FPP, detachable blades	FPP, detachable blades	2 x CPP (4,500kW ea)
Propulsion Power	12,000 kW	14,000 kW	9,000 kW
Thruster Bow	Yes		2 x ca 730 - 1050 kW each
Thruster Stern	Yes		1 x
Aircraft & Boats			
Boat			2 x Fast rescue craft
Helicopter	Yes, 2 x L (Mi-8 Type)	2 x Kamov Ka-32	Yes, 2 x M + Hangar
Cargo			
Cargo Hold (m³)	8,595 m³	3,961 dry + 2,643 refrigerated	4,000 m³
TEU	28	24TEU +5 Reefer TEU	No Info
Fuel (Own)	3,850 t	2479 t	No Info
Fuel (Extra)		4 x 1,810 m³	500 m³
Fuel (Aviation)	50 t		No Info
Science			
Air & Aerosol Sampling		Yes	Yes
ADCP		Yes	Yes
Fishery Sonar			Yes
Multibeam		Yes	No info
Sonar		Yes	No
Sub-bottom Profiler		Yes	No
Nets	Yes	Yes	Yes
Trawling Gear	Yes	Yes	Yes
Sediment corer			Yes
Rock Drills			Likely
Seismic			No
Magnetometer		Yes	No info
Gravimeter			No
CTD		Yes	Yes
Water Sampler		Yes	Yes

	Chile Antártica 1	South Korea IBRV Araon	USA USCGC Healy
Built	2021-22	2009	1997
Costs	$ 315,000,000	₩ 108,000,000,000	
Class notation		KRS1-Special purpose ship (Research vessel) PL10, DAT (-30 deg. C), HMS1, KRM1-UMA3, DPS2, NBS2	
Operator	Chilean Navy	Korea institute of Ocean Science and Technology	U.S. Coast Guard
IMO Number	n/a	9490935	9083380
Ship Characteristics			
Length (m)	111	111	128
Breadth (m)	21	19	25
Draft (m)	7.2	7.5	9.4
Speed (Cruise)		12 kts	12.5
Speed (Max)	15kts	16 kts	17
Icebreaking	1 m @ 2kts	1m @ 2 kts	1.4m @ 3 kts / 2.44m ramming
Ice Class	PC5	PL-10	PC2?
Displacement			
GT		7,507	16,000
DWT		2,901	
Endurance	60 d	70 d	
Range	14,000	17,000	16,000
Personnel (Crew)		25	75
Personnel (Project)	120	60	50
Ship Features			
Cranes	2 x 20t Cargo	1 x 25t, 1 x 10t, 1 x 3 t	1 x 3 t forecastle,2 x 15 t aft working deck + cargo,1 x 5 t aft
A-Frame			Aft 20.974t
Drop Keel			No
Dynamic Positioning		DPS2	DP1
Silent Operation			No
Moon Pool			No
ROV		Yes	No
AUV			Yes
Laboratories (m²)	>3	Dry: 8; Wet: 6	390
Additional			Diving capabilities Bow wash system
Propulsion			
Engine		4 x 3,400 KW	4 x diesel electric
Propeller		Azimuth 2 x 5,000 KW	2 x FPP
Propulsion Power		10,000 kW	22,400 kW
Thruster Bow			
Thruster Stern			
Aircraft & Boats			
Boat		7 m Research support, 10 m Logistics	2 x 7.9m CBL, 2 x RHIB
Helicopter	for 2 transport helicopters	Yes	
Cargo			
Cargo Hold (m³)	910		567
TEU		31	
Fuel (Own)			
Fuel (Extra)	400 m³		
Science			
Air & Aerosol Sampling		Yes	No
ADCP	Yes	Yes	Yes
Fishery Sonar		Yes	No
Multibeam	Yes	Yes	Yes
Sonar	Yes	Yes	Yes
Sub-bottom Profiler		Yes	Yes
Nets			Yes
Trawling Gear			Yes
Sediment corer	Yes	Yes, Piston 39 m	Yes
Rock Drills		No	Yes
Seismic		Yes	No
Magnetometer		Yes	Yes
Gravimeter		Yes	Yes
CTD		Yes	Yes
Water Sampler	Yes	Yes (120 cups)	Yes

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Appendix 3 – PRSV Profiles

Australia

The location of the continent and country makes Australia a natural player in the polar research. The southernmost city of Tasmania, Hobart, is used as starting point for Antarctic expeditions of many countries. Additionally, the city is home of the headquarter of Australia's Antarctic Program. They currently operate four stations with year-round personnel which are situated along the coast for supply by boat. Some uninhabited islands within the Australian Antarctic sector are visited for research purposes as well. Figure 18 below gives an overview of main destinations for Australian PRSV. (Australian Antarctic Division, 2012) These logistical constraints are an important basis for the design specifications of Australia's vessels. <

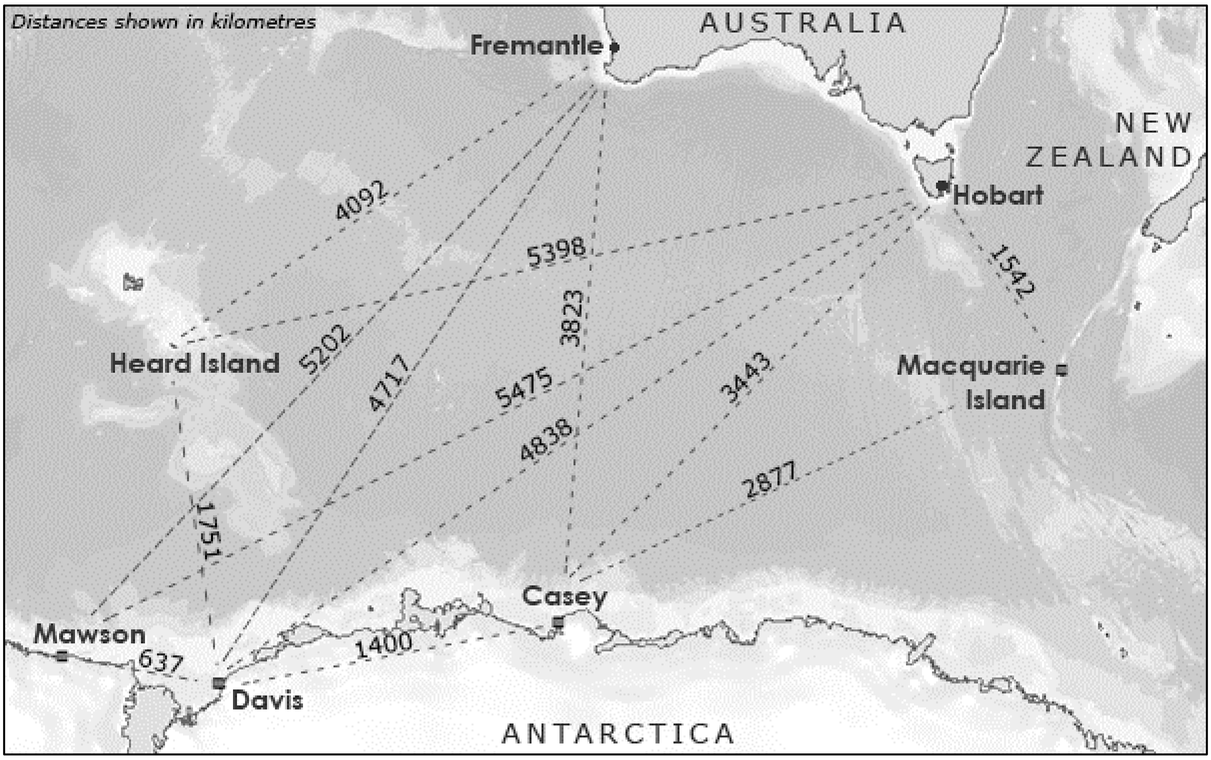

Figure 18: Starting points and destinations for the Australian Antarctic Division.
Retrieved April 04, 2018 from http://www.antarctica.gov.au/living-and-working/stations

There is currently a newbuilding underway that shall replace the aging RSV *Aurora Australis* in 2020. It is called the RSV *Nuyina* and is a result of a 30-year investment plan in polar research of the Australian government. The building itself is budgeted at AUD 500 mil and gives an example of a modern PRSV that is focused on logistics while still maintaining state-of-the-art science and icebreaking capabilities. A comparison between major differences of both vessels can be found in Table 8. To its predecessor RSV *Nuyina* increases by more than 65m in length and 5m in breadth resulting in a ship more than 50% larger. The speed was kept comparable with a major increase in icebreaking capabilities.

Table 8. Comparision of RSV Aurora Australis and RSV Nuyina

Name	RSV Aurora Australis	RSV Nuyina
Built	1989	~2020
Length	94.91 m	160.3 m
Breadth	20.3 m	25.6 m
Draught	7.86 m	9.3 m
Speed (Cruise)	11 kts	12 kts
Icebreaking	1.23 m @ 3kts	1.65 m @ 3 kts
Ice Class	1A Super (PC6-7)	Polar Class 3
Endurance	90 d	90 d
Range	25,000 nm	> 16,000 nm
Cargo Hold	1,790 m^3	5,030 m^3
Fuel (Extra)	968 t (1.1 mil L)	1,623 t (1.98 mil L)
TEU	37	96

From: P&O Maritime Ltd. (2014) & Australian Antarctic Division (2017b)

The most recognizable difference is the increase in cargo capacity which is more than doubled for general cargo and TEU capacity. Combined with the increased fuel storage possibilities it enables the PRSV to supply two Antarctic stations in one voyage, freeing up time from lengthy transits back to its home base. (Australian Antarctic Division, 2017b) Besides increased cargo capabilities the new vessel is structured in a way that allows multi-mission operation while it is on a location and is shown in detail in Figure 19. For example, it enables the ship to conduct cargo transfer to the ice, utilizing the front cranes to lift cargo on board while the aft cargo hold is discharged using helicopters. Additionally, science missions can already be prepared on the dedicated multipurpose/science deck which is sheltered from cargo operations and situated below the aft helicopter deck. Besides operational optimizations it will also have a built-in moon pool for scientific instrumentation deployment like ROVs, AUVs, Nets and many more. In addition, it is stated that this vessel will be the only one equipped with a wet well.

> This watertight space, below the water line, will be connected to the ocean by large inlets, two and five metres below the surface, and in the keel. […] The idea is that seawater will gravity feed into the space and on to 'filter tables' designed to catch krill and more fragile life forms like jellyfish and salps. Viewing tanks above each filter table will allow operators to watch for fragile life forms, collect them, and place them in a temporary aquarium. (Australian Antarctic Division, 2017b, Wet well, para. 1&2).

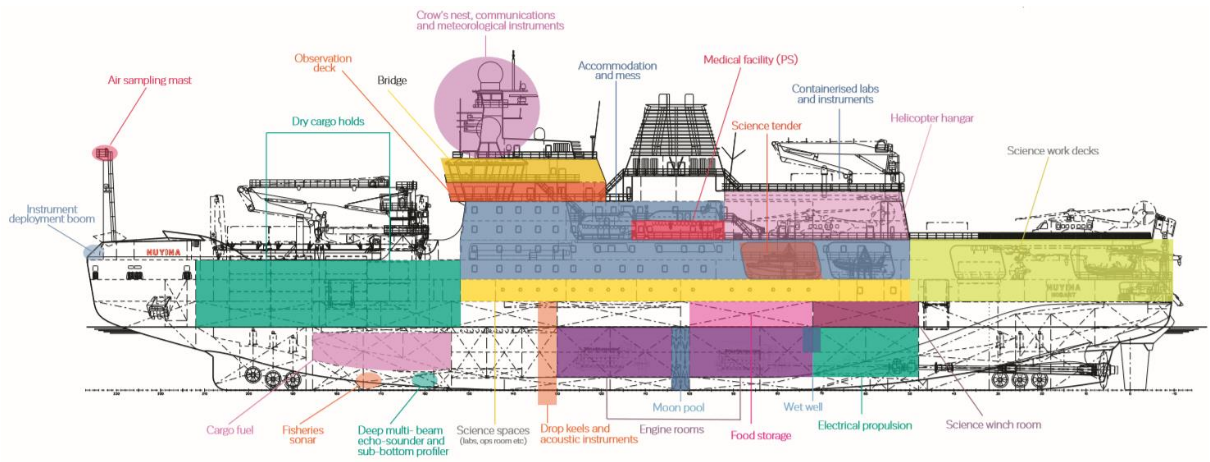

Figure 19. RSV Nuyina with annotations Taken from Australian Antarctic Division (2018)

It is also planned to come with a retractable ten metre bow boom with ice radar and similar installations equipped which will record snow cover and ice-thickness and can be used to refine satellite data regarding thickness predictions. (Australian Antarctic Division, 2017b)

Just like the British newbuilding RRS *Sir David Attenborough,* the RSV *Nuyina* will be built with the DNV 'Silent R' notation which is a noise reduced mode for acoustical data acquisition. Main engines are not operating in this mode and the ship is propelled using electrical motors, providing 7,400 kW of power. The speed is limited to 8 knots in this mode. (Damen Schelde Naval Shipbuilding b.v., 2016)

Summary. The newbuilding RSV *Nuyina* will be the largest science focused PRSV upon completion. The only planned vessel surpassing it is the Canadian CCGS *John G. Diefenbaker* which is primary an icebreaker with advanced science capabilities. The most defining features of this vessel are the logistics capabilities of 96 TEU containers in holds and nearly two million litres of extra fuel. It can cover the yearly supply of two Australian Antarctic bases in one voyage. Scientifically, it incorporates features of other new buildings like electric propulsion for the DNV Silent-R notation, a moon pool, two drop keels and modern flexible scientific laboratories. Unique among the vessels is the wet well for continuous live sampling of krill and other near-surface organisms.

Norway

Figure 20: RV Kronprins Haakon Source: Mikelborg (2015)

Table 9. RV *Kronprins Haakon – Ship Profile*

RV Kronprins Haakon – Ice class PC3			
Ship Characteristics		**Science Capabilities**	
Length	100.00 m	Drop Keel	Yes
Breadth	21.00 m	Moonpool	Yes
Draught	8.5	Dynamic Pos.	Yes DP2
Speed (Cruise)	7.65 m	ROV / AUV	Yes (Ægir 6000) / Yes (Huigin)
Endurance	65 d	CTD	Yes
Range	17,000 nm	Geological	Sediment cores + Drilling
Icebreaking	1m @ 5 kts | 0.4 m @ 12 kts	Sensors	Sonar / MBES / SBP / ADCP
Crew	15-17	**Cargo**	
Scientists	35	Hold	1,180 m³
Propulsion Power	2 x 5.5 MW / Z-Drives	TEU	20

Note: Data from DNV GL AS (2017b) & Havforsknings Institutet (2018)

The RV *Kronprins Haakon* is Norway's newbuilding project and is in the process of final commissioning. It replaces the older vessels RV *Lance* (Norwegian Polar Institute) and RV *Helmer Hanssen* (University of Tromsø). (Havforsknings Institutet, 2018)

The vessel is equipped with a highly sophisticated sensor suite and is tailored towards scientific exploration. Sensors are placed into two drop keels for undisturbed data acquisition and are also present in arctic tanks. More than eleven echo sounders for various purposes are mounted on the vessel. Additionally, a moonpool can be used to launch and recover systems.

While underway the vessel collects data from all echo sounders, gravimeter, magnetometers, weather station, salinometer and thermosalinographs. It has native capability to support all common geological sampling methods (Gravity, Calypso, Box) and can use a drilling rig which can extract 80m long cores from the seabed. (Havforsknings Institutet, 2018)

Logistic capacities are present but with 1,180m³ of cargo hold volume and capacities for 20 twenty-foot containers, it is in the lower half compared to other PRSV. This also results in a slightly smaller size with a length of exactly 100m and 21m breadth. It has polar class 3, can break 1m thick ice at a continuous speed of 5 knots and has DP2 station-keeping capabilities. When on ice station it can use LNG generators instead its main diesel engines. Special design objective was low underwater radiated noise and icebreaking capabilities with strong focus on multidisciplinary science. (Mikelborg, 2015)

On top of the scientific capabilities it is Firefighting class 1 compliant which means it can assist firefighting on other vessels by using water cannons and has a 158-ton bollard pull capability.

Summary. Norway is in the process of commissioning the new PRSV RV *Kronprins Haakon*. It has very advanced scientific equipment on board and is the one most specialised towards science operation while foregoing some logistic capacities. This is probably partly because of the limited presence in the Antarctic, the station Troll has an airfield which can be used for supplies. The vessel is equipped with multiple sensors in different arrangements, drop keels for less noise and arctic tanks to sustain the use in ice infested waters. The low crew complement indicates a high grade of integration and automation compared to similar sized vessels like South Koreas’ IBRV *Araon*.

Appendix 4 – Database Parameter Explanation and Reference

Nation	Operating nation.
Name	Name.
Built	The year the ship was finished. There can be a difference of up to one year when it was put onto a mission, depending on the Antarctic season. Dates in the future are marked with a ~ sign.
Costs	The costs for building the ship, without lifetime budget. Where information is available this is added in brackets.
Class Notation	Registration type notations for classing authorities.
IMO Number	Official designated IMO number, if already available. (Dokkum, 2013, p. 119)
Length	The length over all (LOA) is used unless noted. (Dokkum, 2013, p. 26)
Breadth	Breadth over all (BOA) is used unless noted. (Dokkum, 2013, p. 28)
Draught	Maximum Depth underwater. (Dokkum, 2013, p. 26)
Speed (Cruise)	Economical speed.
Speed (Max)	Maximum speed.
Icebreaking	Leve icebreaking performance (Stated in thickness at speed).
Ice Class	Rating for operability in ice. Introduction provided by Nyseth and Bertelsen (2014)
Displacement	The weight of volume of water displaced by the ship. (Dokkum, 2013, p. 30)
GT	Ships volume below main deck and all enclosed spaces above main deck. (Dokkum, 2013, p. 30)
DWT	Weight the ship can load from to go from lightship draft to summer load line draft. Fixed value. (Dokkum, 2013, p. 30)
Endurance	Days the ship can operate without refuelling or resupplying.
Range	Range in nautical miles the ship can travel in economic speed.
Personnel (Crew)	Vessel crew (Officers and Ranks).
Personnel (Project)	Passengers/Scientist/Non-ship operation related persons.
Cranes	Cranes available for cargo and equipment handling.
A-Frame	Special crane system usually deployed on the stern or side of the vessel. Used for ROV operations, special research, anchor handling and similar.
Drop Keel	Extendable sensor platform that can be extended from the keel of the vessel to increase distance from sensitive sensor to noise sources and possible air bubble streams that flow beneath the vessel.
Dynamic Positioning	Un-aided position keeping capabilities of vessels. Divided in classes. (IMO, 1994)
Silent Operation	Ability to enable silent mode for acoustic acquisition or similar objective. Award of official notation regulated by DNV (2010)
Moon Pool	Rectangular opening near the centre of gravity of the vessel. Used to conduct scientific operation while minimizing external influences or enable research in sea states where deck work is deemed too dangerous
ROV	Remotely operated vehicle used for investigation and construction projects. Can be fitted with a variety of sensors and is available in different sizes. Basic introduction in the scientific ROVs is given by Marum (2018) &
AUV	Automated underwater vehicles are used for investigations along predefined routes. Different sizes and equipment's. Can have extensive mapping and sensor capabilities and survey areas with ice cover that is not breakable by the PRSV. Scientific development presented by Marum (2018) and big sized example from Kongsberg Maritime AS (2018)
Laboratories	Number of laboratories or space available for scientific projects on board. If possible the area (m^2) is given.
Engine	Type of engine used.

Propeller	Type and number of propellers used. (Dokkum, 2013, pp. 264-277)
Propulsion Power	Power used for propulsion only (Shaft horse power) in HP or kW.
Thruster Bow	Bow thruster arrangement.
Thruster Stern	Stern thruster arrangement.
Boat	Additional boats the PRSV carries like crew tender, science tender or logistic barges.
Helicopter	Capability of operating and storing helicopters. Sizes given in S/M/L.
Cargo Hold	Cargo capacity in the ship's hull, might be exclusive with TEU capacity.
TEU	Capacity of twenty-foot equivalent unit shipping containers. Capacity for scientific lab containers noted under laboratory space.
Fuel (Own)	Vessel's own bunker capacity.
Fuel (Extra)	Information about cargo fuel capacity which is not intended as ship fuel for example as supply for Antarctic stations.
Fuel (Aviation)	Information about fuel for helicopters and other aircraft stationed on the vessel or for use at Antarctic bases. The aviation fuel is Jet A1.
Extra holds	Any special arrangement that is not covered by the categories above.
Air & Aerosol Sampling	Usually comprises more and can be summarised to atmospheric research presented by Australian Antarctic Division (2017a)
ADCP	Instrument to measure current speeds in the water column. Presentation given by Woods Hole Oceanographic Institution (2018a)
Fishery Sonar	Mapping of the water column in different frequencies to classify fishes based on the air bladder size.
Multibeam	Instruments used for seafloor mapping. Versatile for other applications as well. In-depth information from L-3 Communications (2000)
Sub-bottom Profiler	Instruments to investigate the upper layers of the seafloor (up to 200m into the sediment). PRSV mostly use a special form called parametric SBP. Theory of operation presented in Wunderlich, Wendt and Müller (2005)
Nets & Trawling Gear	Ability to use nets and trawling gear, often limited by availability of cranes and winches.
Sediment corer	Instruments to sample the seafloor. Varying in lengths from a couple of cm to up to 60m.
Rock Drills	Sediment and rock drilling, an often used Marum (2018)
Seismic	Capabilities for operating airguns and deploying hydrophone streamers.
Magnetometer	Device to measure variations in the earth's magnetic field. (Woods Hole Oceanographic Institution, 2018b)
Gravimeter	Device to measure variation in the gravitational field of the earth.
CTD	Instrument to measure conductivity, temperature and water depth. Overview provided by Wikipedia Foundation Inc (2018)
Water Sampler	Often combined with a CTD. Recovers water sample from certain depths. Many individual sampling bottles are arranged around a frame to form a rosette.