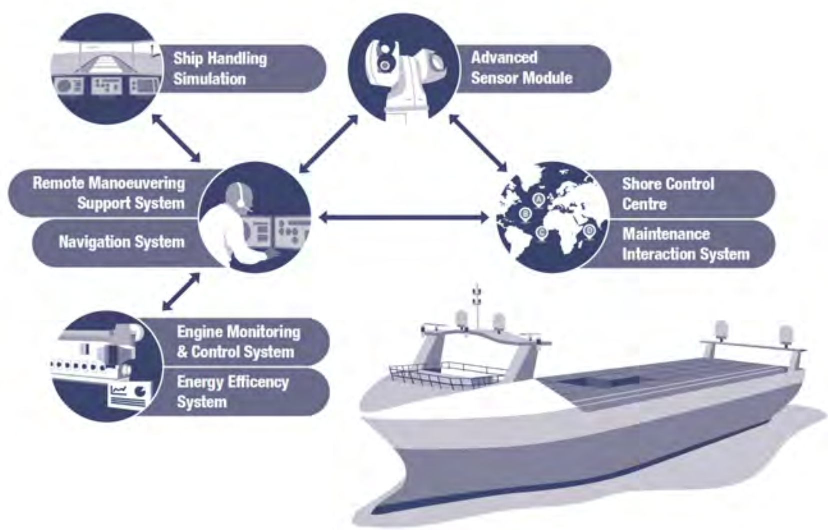
Development of Canadian Asset Map and Assessment of Global Competitiveness in the Area of Autonomous Surface Ships



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Executive Summary

- Interest in the prospect of autonomous surface ships operating in the waterways and oceans of the world has increased. This has manifested itself in a number of ways.

- Several large-scale projects in Europe, especially in countries like Finland, Norway, United Kingdom and Germany, have been completed and more are underway. The projects range from paper studies through to demonstration projects involving the design and construction of autonomous surface ships. The focus has been on short-sea shipping and ferries.

- Asian countries with big shipbuilding and marine industry have shown a similar interest. While also interested in ship types noted above, they have included large ocean-going ships as targets for autonomous operation.

- Along with the ship types mentioned above, there has been general interest in smaller vessels, especially those designed for special purposes such as hydrographic surveys, offshore support, aquaculture support, oil spill recovery and firefighting.

- While there is interest in Canada in autonomous surface ships, the activities have been modest. This is at least partly due to its relatively small number of fleets and the fact that Canada builds few ships. Canadian ship operators that have incorporated autonomy in their vessel operations have generally adopted technology developed outside Canada.

- There is very limited direct expertise in autonomous ship technology in Canada. However, Canada does have substantial expertise and experience in related areas, which have the potential to be adapted and applied to autonomous surface ships. The most relevant sectors are underwater autonomous vehicles and land-based autonomous vehicles. Furthermore, information technology which autonomous ships rely on is another area in which Canada has well-developed expertise. It has been applied to non-marine sectors and has great potential for application to autonomous surface ships.

- As for the next steps, a pilot project is outlined, which aims to develop a platform to explore the application of Canadian technology to autonomous surface ships.

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1 Introduction

A great deal of interest in the concept of autonomous surface ships is apparent in the world marine trade press. A number of well-funded initiatives have been undertaken and continue to be undertaken in several countries. Northern European countries, principally Finland and Norway, are in the forefront of this activity. There has also been interest in Asian countries, especially those that are active in the marine business, either as constructors of ships or owners and operators, or both. Some commercial organizations anticipate business opportunities in the medium- and long-term. According to BIS Research, a US-based market intelligence company, the estimated world revenue from the autonomous ship market is expected to be US$3.48 billion by 2035 (BIS Research, 2018). Much of these work is oriented towards the kinds of shipping that business and research organizations see promise as commercial and research ventures.

While activities in this area in Canada are limited, there have been a few relevant initiatives and there is ongoing interest in the subject. Direct experience of the relevant technologies is also limited in Canada, however, there is a high level of expertise in allied fields which, if the opportunities arose, could potentially be applied to the design, construction and operation of autonomous surface ships.

The subject of this report is autonomous surface ships as it relates to Canada. The primary objective is to establish what Canadian capabilities are in this technology area. To address this, it is important to understand the current state of progress internationally. As noted above, certain regions of the world have made substantial investments in autonomous surface ship technology and there are lessons that can be learned from these efforts. Key initiatives, especially in Europe and Asia, are summarized. Thus, this report presents a summary of international initiatives related to autonomous shipping and then makes an assessment of the capabilities that exist in Canada with a focus on frontline companies and organizations that could potentially have direct involvement in the design and development of relevant technology for autonomous ships.

A preliminary version of some of the findings in this report were presented at a workshop in Québec City on November 27-28, 2019. This workshop was hosted by CISMaRT in partnership with Transport Canada, Innovation, Science and Economic Development (ISED) and National Research Council (NRC). During the workshop, a number of presentations were made by subject matter experts. Opening presentations by Transport Canada and NRC summarized the interest of Canadian government agencies in the subject and the efforts made to establish a dialogue between interested parties in Canada. In regard to the latter the work of CFMASS[1] was outlined. This was followed by a series of presentations by subject

[1] Canadian Forum for Maritime Autonomous Surface Ships

matter experts, covering aspects such as technology, regulatory issues, design aspects, operator perspectives, etc. In the brainstorming session after the presentations, workshop participants discussed a number of general and specific aspects of autonomous surface ships. The presentations and the results of the brainstorming session can be found in a CISMaRT Report[2].

1.1 Report Overview

A review of major collaborative projects on autonomous surface ships, mainly in Europe and Asia, are summarized in Chapter 2. Chapter 3 contains a review of related activities in Canada. The capabilities in this subject area in Canada are presented in tables of Chapter 4, each addressing an aspect of autonomous ships. Chapter 5 draws on the results of the brainstorming session to recommend actions that could be taken to promote autonomous shipping in Canada. Conclusions are presented in Chapter 6. Chapter 7 lists the references employed in compiling this report.

[2] Report on CISMaRT Workshop on Autonomous Surface Ships, Québec City, November 27-28, 2019

2 Collaborative Initiatives on Autonomous Ships

A number of initiatives have been launched over the last several years on various aspects of autonomous shipping. The earliest such enterprises are European in origin and the most prominent of them are still European. More recently, similar developments have taken place in Asia, especially among nations that are heavily involved in the marine industry typically as shipbuilders or ship operators. The focus varies from region to region in terms of the types of ship trades.

The most prominent of these projects are outlined in this chapter. There are some lessons learned from these projects that apply to Canada. The information of most value to Canada from these studies is the identification of the types of ship trade that are considered most suitable for some level of autonomous operation. However, it is prudent to recognize that few of these projects examine autonomy alone. Many are conducted within the context of green shipping. Hence to isolate the benefits and cost saving caused by a level of autonomous shipping is sometimes difficult. Among the most popular green shipping initiatives are those that use new advanced fuels, battery power, hybrid power systems, etc.

While many projects are described in this chapter, it is impossible to present a complete catalogue of projects and initiatives. The projects are selected to be broadly representative of initiatives worldwide. Note that the large number of projects currently underway also indicates the high level of interest in this subject.

2.1 Projects in Europe

2.1.1 MUNIN

The project, MUNIN (Maritime Unmanned Navigation through Intelligence in Networks), was among the first major collaborative research projects on autonomous shipping (MUNIN, 2016a). It was co-funded by the European Commission under its Seventh Framework Programme. MUNIN aimed to develop and verify a concept for an autonomous ship, which is defined as a vessel primarily guided by automated on-board decision systems but controlled by a remote operator in a shore side control station.

The project started in September 2012 and concluded in August 2015. The overall budget was €3.8m of which the European Union contributed €2.9m. The remaining funds were contributed by the partners, including the following eight research and academic institutions:

1. Aptomar AS
2. Chalmers Technical University
3. Fraunhofer Center for Maritime Logistics
4. Hochschule Wismar

5. MarineSoft - benntec Systemtechnik GmbH
6. MARINTEK, Trondheim
7. Marorka ehf
8. University College Cork

The objectives (MUNIN, 2016b) of the project were to:

- Develop the technology concept needed to implement the autonomous and unmanned ship.
- Develop the critical integration mechanisms, including the ICT[3] architecture and the cooperative procedural specifications, which ensure that the technology works seamlessly enabling safe and efficient implementation of autonomy.
- Verify and validate the concept through tests runs in a range of scenarios and critical situations.
- Document how legislation and commercial contracts need to be changed to allow for autonomous and unmanned ships.
- Provide an in-depth economic, safety and legal assessment showing how the results will impact European shipping's competitiveness and safety.
- Show how the concept gives direct benefits, e.g., in reduced off-hire[4] due to fewer unexpected technical problems, and provides efficiency, safety and sustainability advantages for existing vessels in short term, without necessitating the use of autonomous ships.

The use case[5] employed by the project was a dry bulk carrier operating in intercontinental tramp trades. This configuration was attractive to the project for the following reasons:

- Additional cargo requirements are low
- Good candidate for slow steaming
- Typically voyages are long, uninterrupted and deep-sea

The components of the ship concept that were studied are summarized in Figure 1.

The final reason is particularly important as it aligns with the view of the MUNIN project which "… only envisages autonomous operation of an unmanned vessel during deep-sea voyage and not in congested or restricted waters".

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[3] Information and Communication Technologies

[4] A shipping term in contracts which allows time for an owner to repair the vessel under contract

[5] A term originating in software engineering that describes a scenario that is used for exercising, or testing, the system. In the current context it refers to a ship concept that is used as a basis for examining various operational situations.

The key elements of the concept developed by the MUNIN Project are:

- An Advanced Sensor Module
- An Autonomous Navigation System
- An Autonomous Engine and Monitoring Control system
- A Shore Control Centre
    - A Shore Control Centre Operator
    - A Shore Control Centre Engineer
    - A Shore Control Centre Situation Room

Among the analyses conducted by the project are:

- Cost-benefit analysis
- Safety and security analysis
- Legal and liability analysis

The savings identified in the MUNIN study are summarized in Figure 2.

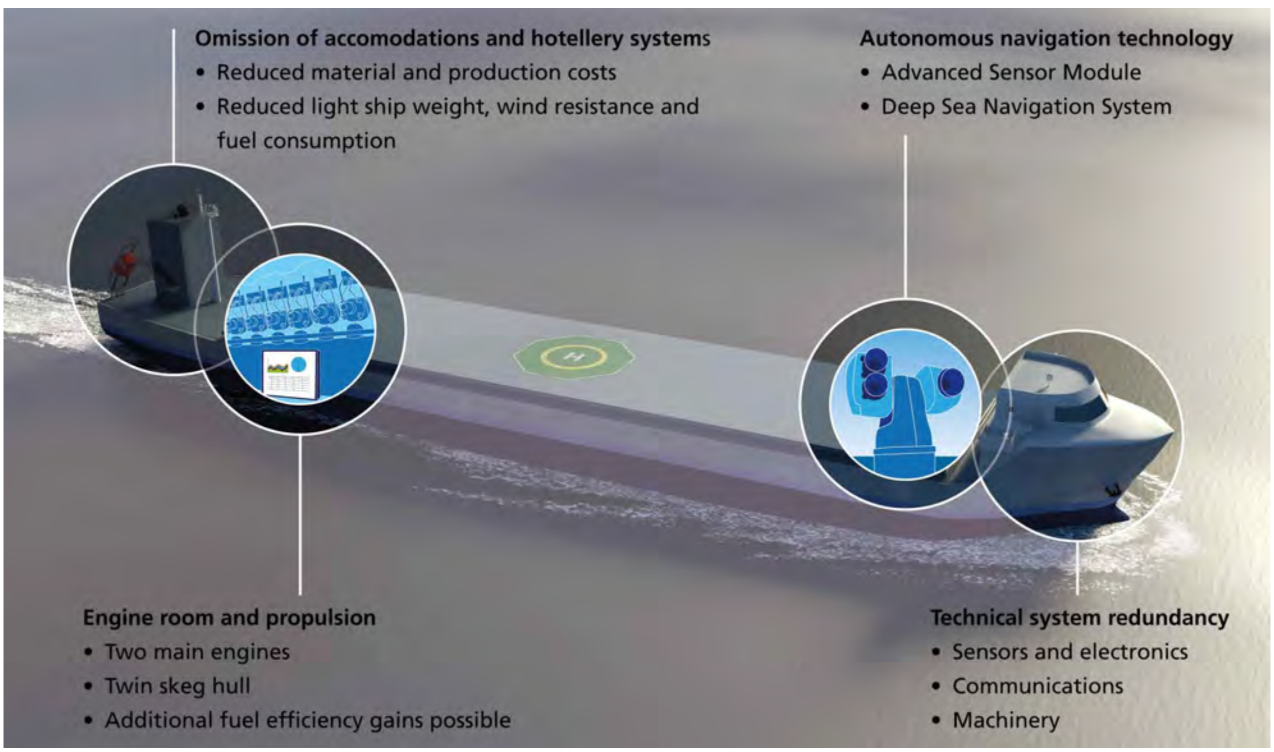

Figure 1. Components of the ship concept investigated by MUNIN (MUNIN, 2016)

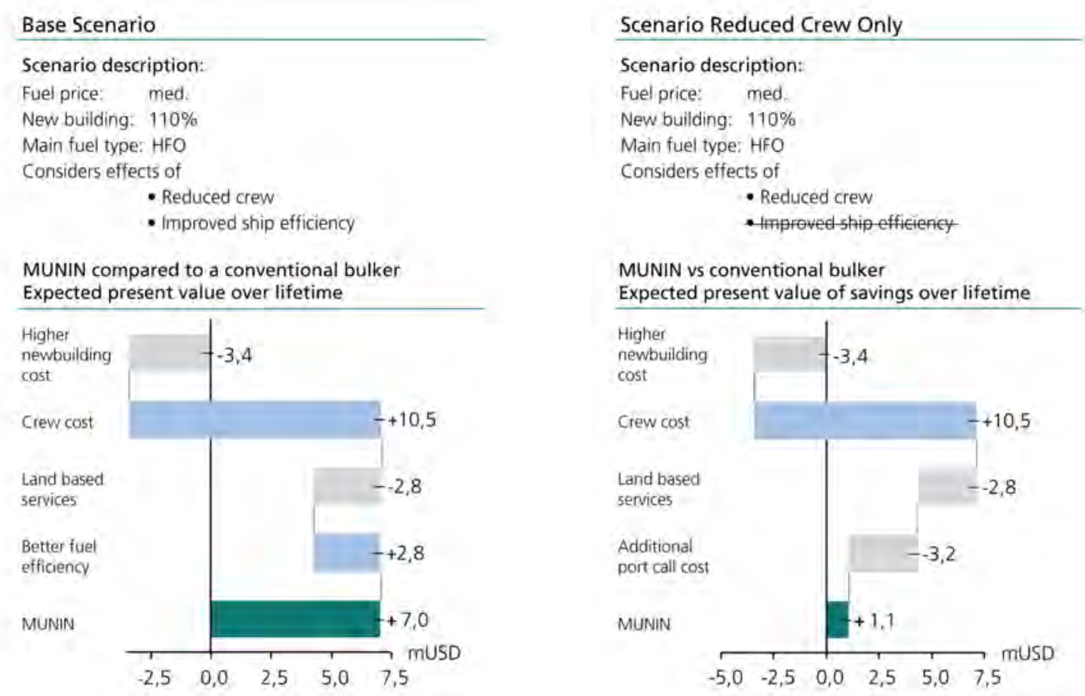

Figure 2. Cost savings for two scenarios investigated by MUNIN (MUNIN, 2016)

The benefits and limitations of autonomous shipping were identified. The conclusions are complicated because the study simultaneously considered the effects of slow steaming and the use of alternative fuels. Also included in the assessment are the efficiencies gained by use of automatic energy management systems and improved routeing and navigation. The omission of accommodation superstructures was identified as making a large contribution to increased efficiency. The other broad benefit identified is associated with a perceived increase in safety which, of course, is difficult to quantify. In this regard the factor identified is the absence of (or reduced) personnel. The study also indicates there would be a reduction of casualties associated with human error in operations, such as look-out, navigation and collision avoidance. However, it is noted that these benefits would be accompanied by increased costs because of the need for more reliable and operator-independent technical systems in autonomous ships.

A number of limitations associated with autonomous shipping were also identified in the study with the main ones related to four areas:

Shore control - it is possible to envisage advanced onboard systems such that shore control would not be required. However, such onboard systems would not be cost-effective today.

Operational case - operational considerations impact the viability of autonomous ships. Among these would be the need for technical and operational infrastructure at the ports of departure and arrival, and the need for direct monitoring for operations in these areas.

New ship design - in regard to design, the study observed that unmanned ship would have to be designed from scratch presumably without a superstructure and accommodation section and would include simplified and redundant technical systems.

Monitoring and control – these considerations require that in the absence of crew, new systems would be required to monitor technical systems and cargo conditions. In addition, systems would be required to mitigate mechanical and electrical failures, and respond to accidents, fires, etc.

The MUNIN project undertook detailed studies of a number of systems relevant to autonomous ships. They are depicted in Figure 1.

The complete set of documentation published by the MUNIN Project can be found at the project website[6].

2.1.2 ReVolt

The ReVolt project was originally initiated in 2013 by DNV GL, the Norway-based classification society (DNV GL, 2019). It was further developed as part of the Norwegian Transport Plan 2014 -2023. The focus of the plan is short-sea shipping[7] with the vision of transferring road freight to waterways in the future to reduce road congestion. This is part of wider vision of an integrated supply chain where an appropriate level of autonomy is applied to each step. Figure 3 shows its application to loading and unloading operations. The operating route considered is between Oslo and Trondheim in Norway. The assumed configuration in the study is an unmanned vessel with a battery powered propulsion system. It was projected that the extra cost of the electric battery powered propulsion system would be more than compensated for by cost savings due to lower building cost (no accommodation deck, bridge and associated outfitting) and lower operating costs.

The design considered in this study is a 100 TEU container feeder propelled by two podded azimuth propulsors in the stern and one retractable azimuth bow thruster. Batteries of

[6] http://www.unmanned-ship.org/munin/news-information/downloads-information-material/munin-deliverables

[7] Short-sea shipping usually refers to movement of cargo over short distances such as coastal trade. It excludes ocean shipping which involve long transits.

around 3,000 kWh capacity are anticipated to yield a range of about 100 nautical miles. The transit speed would be 6 knots. A conceptual view of the vessel is shown in Figure 4.

Figure 3. View of loading/unloading operations in the ReVolt concept (DNV GL, 2019)

Figure 4. Conceptual view of vessel design

As part of the project, a working model in 1:20 scale was built and is shown in Figure 5. The model, which is operated in collaboration with NTNU (Norwegian University of Science and

Technology), is used to investigate how advanced control systems and navigation software could control an unmanned vessel. Among technologies investigated are sensor fusion and collision avoidance.

Figure 5. Working scaled model (1:20) of ReVolt concept

2.1.3 Advanced Autonomous Waterborne Applications (AAWA)

The AAWA Initiative is a €6.6 million project funded by the Finnish Funding Agency for Technology. The primary objectives of this project are to develop preliminary designs and specifications for the next generation of advanced ship solutions. The objectives summarized by Jokioinen (2016) were to

1. Create competence for remote controlled vessel in commercial use
2. Create hotspot for waterborne remote control technology
3. Develop commercial viable short to medium term solutions

The research areas covered were technology, safety & security, societal & legal acceptance, and economy and business models. Organizations collaborated on the projects were drawn from industry and academia, including

1. Companies: Rolls-Royce, Delta Marin, Inmarsat, DNV GL, and NAPA

2. Universities: Aalto/VTT (Technical Research Centre of Finland), Tampere University of Technology / University of Turku, and Åbo Akademi / University of Turku

The concept developed as part of this project is illustrated in Figure 6.

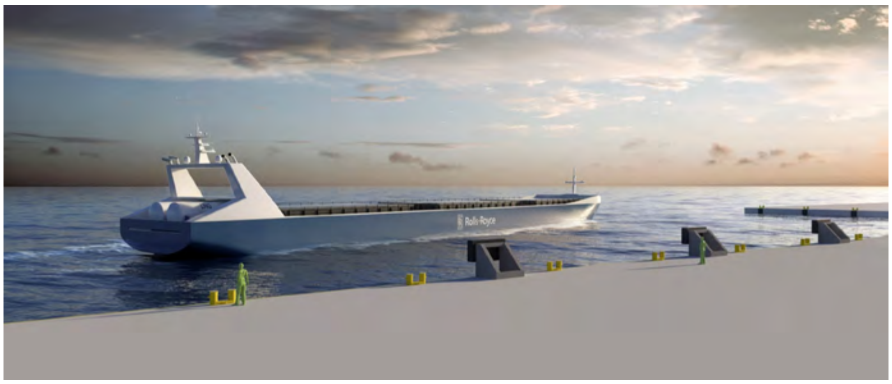

Figure 6. Autonomous ship concept developed by AAWA Project

2.1.4 Norwegian Forum for Autonomous Ships (NFAS)

Unlike the other initiatives discussed above, NFAS is primarily a vehicle for exchanging information on autonomous ships. It is based in Norway and targets Norwegian organizations with an interest in autonomous ships.

The objectives of the organisation are to:

1. Encourage cooperation between users, researchers, authorities and others. Methods used include arranging conferences, producing newsletters and courses.
2. Contribute to the development of common Norwegian strategies for development and use of autonomous ships.
3. Act as a common voice for the development and use of autonomous ships.
4. Foster international contacts and influence within the area of autonomous ships.

Further information can be found on its website[8].

2.1.5 Autonomous Shipping Initiative for European Waters (AUTOSHIP)

This European Union (EU) project will build two remotely operated and autonomous vessels together with the associated shore control infrastructure. The focus of the ship operations is

[8] http://nfas.autonomous-ship.org/index-en.html

for the movement of goods from the Baltic Corridor to a major EU seaport and hinterland. The budget for this project is €27.7m of which €20.1m will be funded by the EU Horizon 2020[9] program; and the remainder will be funded by the partners. The partners are:

- Ciaotech
- Bureau Veritas
- Blue Line Logistics
- Kongsberg
- SINTEF Ocean
- De Vlaamse Waterweg
- Upm-Kymmene
- Rolls-Royce (acquired by Kongsberg in April 2019)
- University of Strathclyde

The technology package will include fully autonomous navigation, self-diagnostic, prognostics and operation scheduling. It will also focus on the development of communication technology which incorporates a high level of cyber security.

It is intended that the technology developed for the project will be available on a commercial basis in five years.

2.1.6 Yara Birkeland

The project is a collaboration between Yara, a leading fertilizer company in Norway, and Kongsberg, a marine technology company which is a leading proponent of autonomous ships. The project entails the design, construction and operation of an autonomous containership for transporting fertilizer. As stated in Kongsberg (2017), this would be world's first fully digitalized and zero emission cargo ship.

The ship is a 120 TEU open-hatch container feeder ship, which is being built by VARD in Norway and is due to be delivered in 2020. The plan is for the vessel to initially operate in conventional mode and gradually transition to autonomous mode by 2022.

A general view of the ship is shown in Figure 7. The main characteristics of the vessel are:

Length	80 m
Beam	15 m
Depth	12 m
Speed	6 -7 knots (Eco speed)
	13 knots (Max speed)

[9] Horizon 2020 is the EU Research and Innovation program with nearly €80 billions of funding available over seven years (2014 to 2020)

Figure 7. Depiction of the *Yara Birkeland* (Kongsberg, 2017)

2.1.7 SVAN

Rolls-Royce (acquired by Kongsberg in April 2019) and Finferries [10] collaborated on a research project starting in May 2018, which is dubbed SVAN (Safer Vessel with Autonomous Navigation). The objectives of the project were to jointly develop strategies and solutions to optimise the safety and efficiency of marine operations through developing the technology for decision supporting systems and to demonstrate remote and autonomous ferry operations (Finferries, 2018a).

The project culminated in the successful demonstration of the world's first autonomous ferry operations. The double-ended ferry *Falco* travelled between Parainen and Nauvo, on the South West coast of Finland in December 2018 (Finferries, 2018b). Figure 8 shows the docking of the *Falco*. Also demonstrated at this time was the Rolls-Royce Autodocking system.

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[10] Finferries manages the ferry services in Finland at over 40 ferry sites. The maintained connections range from minor, secluded strait crossings to demanding sea passages: the shortest ferry ride is in Kivimo in Houtskär, spanning 169 meters, and the longest is a 9.5 km route from Korppoo to Houtskar.

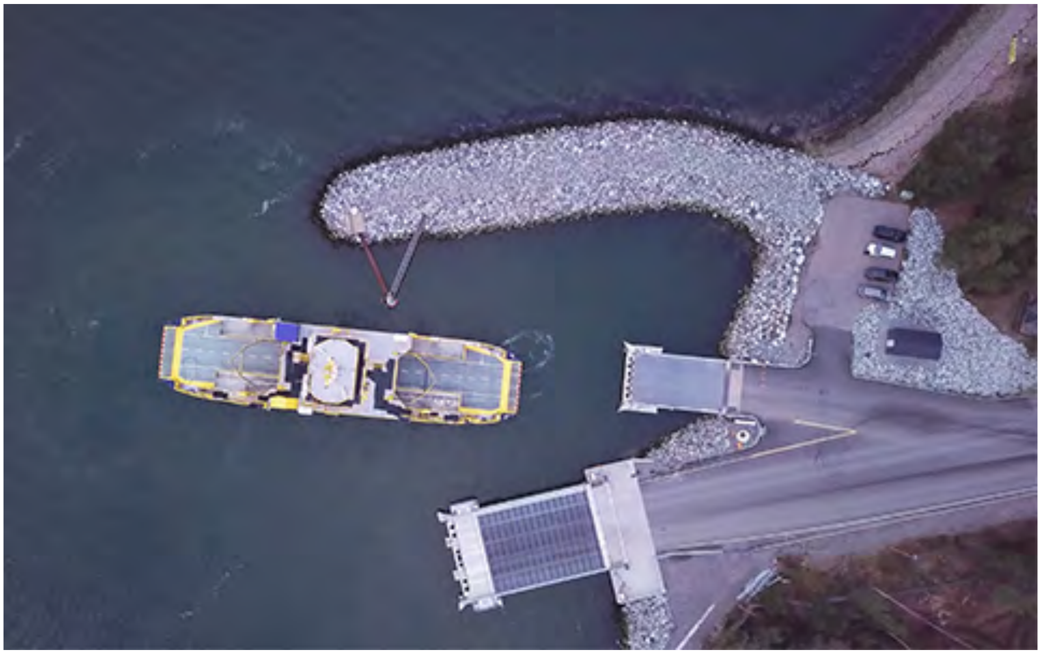

Figure 8. Docking of *Falco* (Finferries, 2018a)

2.1.8 One Sea

One Sea is based in Finland and is a collaborative venture with a primary aim to lead the way towards an operating autonomous maritime ecosystem by 2025 (Merenluoto, 2017). The membership of One Sea is comprised of

- DIMECC
- ABB
- Awake.AI
- Business Finland
- Cargotec
- Ericsson
- Finnpilot Pilotage
- Inmarsat
- Kongsberg
- Monohakobi Technology Institute
- Tieto
- Wärtsilä

One of the deliverables of the project are roadmaps for the various elements that need to be defined in order for autonomous ships to become a reality. The main themes that describe this venture are summarized in Figure 9.

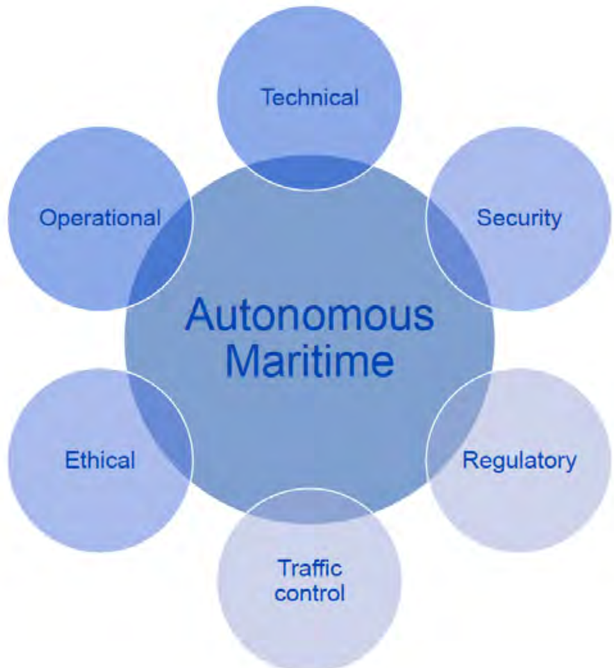

Figure 9. Main themes of the One Sea Project (Merenluoto, 2017)

2.2 Projects in Asia

Some countries in Asia are also interested in autonomous shipping. Their interests overlap, to some extent, with the European projects described above where the primary focus is short-sea shipping and ferry operations. Note that short-sea shipping is responsible for the number of projects involving feeder containerships. Short-sea and ferry voyages are typically characterized by short point-to-point journeys. In addition, Asian countries also focus on, at least in terms of major projects, long ocean voyages. Most large trading ocean-going ships are built in Asia, and this part of the world is also home to some of the major ship owners of this kind of ship.

A selection of key projects is summarized below.

2.2.1 Autonomous Ocean Transport System

This project is the joint initiative of Mitsui O.S.K. Lines & Mitsui Engineering & Shipbuilding in Japan (Mitsui O.S.K. Lines (2017). They, in collaboration with other organizations in Japan, are developing a technological concept for an Autonomous Ocean Transport System with the belief that autonomous vessels can provide reliable, safe, and efficient ocean transport. The project structure together with the participating organizations are summarized in Figure 10.

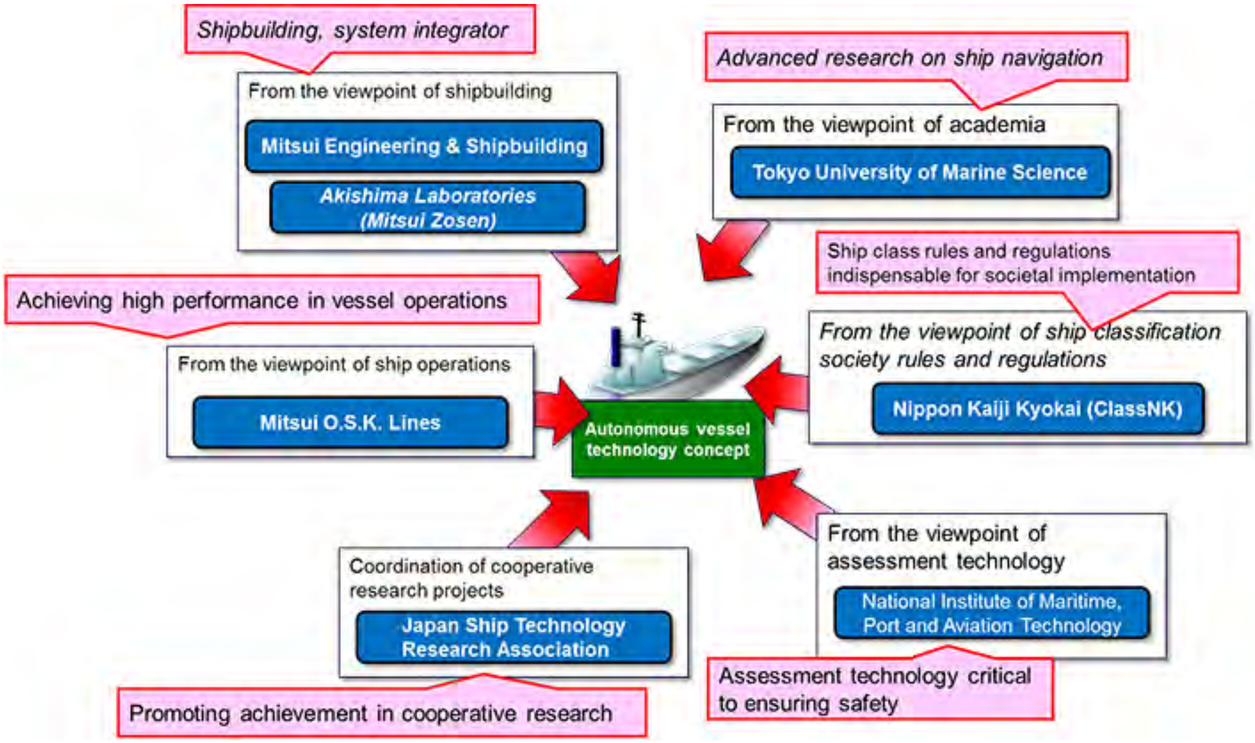

Figure 10. Autonomous Ocean Transport System project structure and participants (Mitsui O.S.K. Lines (2017)

Although the primary objective is to promote technology for autonomous ocean transport systems, the project will also include consideration of the infrastructure required. Another aim of the project is to advocate for the concept of autonomous shipping with the public.

2.2.2 World's Largest Ocean-Going Autonomous Vessel Programme

This project is the initiative of Singapore's Maritime and Port Authority (MPA) who have set up a new laboratory, the Maritime Innovation Lab, to work on this and other projects. Partners of this project include Mitsui, ST Engineering, Smart City Solutions, and Lloyd's Register of Shipping.

As with the project in Japan described previously, the focus is on ocean transport. The project was announced in April 2019 and the emphasis of the project will be on autonomous navigational technology in an ocean-going commercial vessel. This is one of several related projects as described in MPA (2019).

2.2.3 Autonomous Ship Research Facility in Ulsan, South Korea

The South Korean government announced that it would invest the equivalent of US$110m over three years in a new state-of-the-art autonomous ship research facility (Smart Maritime Network, 2019). Kongsberg Digital are in the process of supplying a fully featured bridge for the testing of autonomous vessel technologies in a safe virtual environment. In later phases trials of autonomous ship systems will be conducted.

2.2.4 Wanshan Marine Test Field

A test establishment dedicated to the development of China's unmanned ship industry was opened in December 2018. This is a joint venture of:

- China Classification Society
- Wuhan University of Technology
- Oceanalpha

Oceanalpha is a Zhuhai-based company specializing in unmanned surface vessel design. An example of their work, an unmanned cargo ship design, is shown in Figure 11 below.

Figure 11. Unmanned Cargo Ship Design by Oceanalpha[11]

[11] Source: https://www.oceanalpha.com/product-item/cloudborne/

2.2.5 Smaller-Scale Initiatives in Asia

ABB, in collaboration with Singapore's Keppel O&M's technology arm, Keppel Marine and Deepwater Technology (KMDTech), will jointly develop the technology for autonomous vessels and retrofit a 32-meter harbor tugboat with leading-edge digital solutions, enabling autonomous vessel operations in the Port of Singapore at the end of 2020. Upon project completion, the vessel is anticipated to be South Asia's first autonomous tug.

2.3 Projects in North America

This section excludes activities in Canada. Canadian projects are discussed in Chapter 3. This chapter presents two initiatives based in the USA although there is Canadian involvement in one of them. The focus here is on US projects.

2.3.1 Autonomous Spill Recovery Vessel

This project was initiated by the US Maritime Administration (MARAD). The interest is in the feasibility of autonomous vessels performing oil spill recovery operations in ports. To demonstrate the feasibility of such operations, Sea Machine Robotics was contracted to install their SM300 autonomous-command systems on an oil recovery vessel, a Marine Spill Response Corp. (MSRC)-owned MARCO skimming vessel. A demonstration was held in August 2019 at a MARAD-organized trial in Portland harbour in Maine, USA (Sea Machines, 2018a). The vessel is shown in Figure 12.

Figure 12. SM300-equipped skimmer boat (Sea Machine, 2019a)

Sea Machine offers systems for autonomous operation of certain types of vessel. Two systems currently being offered are SM200, ideal for tugboats, fireboats, target boats, ferries, utility craft and other workboats, and SM300, ideal for survey vessels, patrol boats, ferries and other workboat. The company is working on the SM400 system which is intended for merchant and cruise ships.

Sea Machine is also collaborating with Maersk on the world's first AI-powered situational awareness system which is due to be trialled on one Maersk's containerships (Sea Machine, 2018b).

2.3.2 Maritime Autonomy Research Site (MARS)

This initiative has been set up under the auspices of the Smart Ships Coalition of the Great Lakes – St. Lawrence[12]. It is a broad stakeholder community of academic, state and federal agencies, private and non-profit industry, and international organizations who share a common interest in the advancement and application of autonomous technologies operated in marine environments. The current membership is as follows:

1. Buffalo Automation
2. Fincantieri – Marinette Marine
3. Grand Valley State University – Robert B. Annis Water Resources Institute
4. Great Lakes Research Center – Michigan Technological University
5. Great Lakes-St. Lawrence Governors and Premiers
6. Memorial University
7. Mercury
8. Michigan Office of the Great Lakes
9. Michigan State University
10. Moran Iron Works
11. Netsco
12. NOAA - Great Lakes Environmental Research Laboratory (GLERL)
13. Northern Michigan University
14. ProNav
15. Schottel
16. Sea Grant Michigan
17. Seaview Systems
18. The Interlake Steamship Company
19. Transport Canada
20. United States Geological Survey

[12] https://smartshipscoalition.org/

21. University of Wisconsin, Superior – Transport & Logistics Research Center
22. Wärtsilä
23. Western Norway University of Applied Sciences

In broad terms, the coalition has an interest in the advancement and application of autonomous technologies particularly in marine environments. The main geographical areas that the coalition are interested in are the Great Lakes region and the coastal seas of the USA.

As part of this initiative, the Marine Autonomy Research Site (MARS) has been set up. It is noted that testing is required "… to verify associated risks and compliance with real-world conditions, including the interaction with fully crewed vessels, recreational vessels, compliance with existing maritime regulations and the amount of oversight and control needed for safe and efficient operation."

The site is located near the campus of Michigan Technological University in the Keweenaw Peninsula Waterway which is in northern-most part of the state of Michigan on the South coast of Lake Superior. This is the first freshwater facility dedicated to the study of autonomous marine vehicles. It is intended that the test bed area will be open to all companies, research institutions, government agencies and others wishing to test autonomous surface and sub-surface vehicles and related technologies. The formal dedication of the facility took place in August 2018.

The plan in the near term is to restrict the test areas to small vessels (<10 meters) and the most likely types of ship envisaged for testing are research and survey vessels. It is expected that these types of vessel are among the most likely candidates for autonomous operation in terms of commercial viability. The small size is also attractive from the safety point of view as they pose smaller risk consequences than would larger commercial vessels. Beginning with these types of vessel will enable industry, regulators and partners to test operation, safety and other factors on navigable waters of the United States in a controlled environment where they can interact with commercial and recreational vessels in a limited capacity.

2.4 Key General Findings

The primary application of autonomous ship operations of interest to the Northern European projects are short-sea shipping, short haul ferries and a number of specialist vessels to perform specific tasks not associated with the transport of cargo or passengers. Examples of the latter include oil skimmers, dredgers, tugs, etc. There are also considerable interests in Asia among the major shipbuilding countries which, in some case, are major shipowners as well. While they have many of the same interests as the European shipbuilding and ship owning countries, the Asian countries also have an interest in large ocean-going ships. This owes much to the types of ships built and operated by the countries in the regions mentioned.

In both cases, large sums are being invested in all aspects of autonomous shipping by governments and by commercial enterprises, often in collaborative initiatives.

The most prominent agency in regard to Northern Europe is the EU, which has invested well over a hundred million Euros in supporting research and development initiatives. Many of these have been high TRL efforts involving the construction and (eventual) operation of vessels to be used as platforms for exploring the relevant technologies and the broad range of challenges presented by autonomous operations.

The kind of effort outlined above has largely been absent elsewhere in the world including North America. Consistent with the general approach to innovation that applies in the USA, greater reliance has been placed on private industry and there have been some notable efforts by certain companies. Many of the US-based companies are start-ups and SMEs. This is in contrast to Europe where many of the large technology companies with maritime interests, such as Wärtsilä, Kongsberg, ABB and other similar organizations, are playing a leading role. Observations about Canada in this regard are postponed to the concluding sections of the next chapter.

A conclusion, common to most of the projects, is that the underlying individual technology needs for autonomous ships are essentially available. The primary technical challenge is the integration of the individual technologies and marrying them with the appropriate information technology methodologies. The other broad conclusion is that the regulatory framework, of the kind associated with conventional shipping, is currently absent for autonomous shipping. The process of developing this framework is expected to take some decades, and hence autonomous shipping in the near future will be on a case-by-case basis under strict conditions.

3 Autonomous Surface Ships in Canada

This chapter is devoted to autonomous surface ships in Canada. Two topics are addressed:

1. Types of operations in Canada that are suitable for autonomous operation
2. Current operations in Canada that involve some level of autonomy

3.1 Autonomous Operations Suitable for Canadian Operations

There are various level of autonomy and various organizations have attempted to describe these levels. Among the best known are those devised by regulatory bodies ranging from the International Maritime Organization (IMO) through to Classification Societies. As an illustration, the IMO scheme (IMO, 2018) is reproduced below. This scheme with four levels is perhaps the most authoritative and simpler than others, which rely on more levels:

- Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated.
- Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location, but seafarers are on board.
- Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
- Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

The level of autonomy appropriate to a particular kind of operation depends on a number of factors including economics, safety, technology available, etc. In addition, some organizations, such as ship operators, may choose to incorporate autonomy in an incremental manner where the level of autonomy is increased over time.

Several bodies have attempted to classify the types of ship operations that are most amenable for autonomous operation. A few such attempts are introduced and an assessment how they might apply to the Canadian context is made below. In addition, some relevant observations that originate from the Canadian marine ecosystem are also summarized.

BMT developed a general table (see Table 1) identifying the types of marine operation that are amenable to a degree of autonomy. The examples are categorized in three groups ranging in degree of suitability for autonomous operation.

Table 1. Examples of ship operations amenable to autonomous operation (BMT, 2019)

Feasible roles for complete unmanned operations today.	**'Middle Ground' roles that are suitable for lean or reduced manning through the application of remote or autonomous technologies.**	**Vessels / roles likely to have a high level of human involvement onboard for the foreseeable future.**
Hydrographic Survey Launches Small open ocean data gathering platforms Acoustic positioning / communications vessels in Oil and Gas operations Oil spill response / boom boats Weapons training targets MCM vessels (sweep, hunt, dispose) ASW Barrier vessels Small, dedicated ISR platforms	Warships ROV ships Deepwater survey vessels Standby tug roles Short sea freight Short sea / inland water ferries Offshore supply vessels	Large open sea RORO passenger ferries Cruise Ships Fishing vessels *Note to reader: what else do you think will remain largely unchanged for a long time, with the same or more crew count?*

A report by the Technical University of Denmark (DTU, 2016) made a similar assessment and identified the kinds of ship operation that could, in principle, be made autonomous to a degree. They identified the following ship types and operations:

- Service vessels for offshore wind farms and oil/gas production.
- Engine-driven barges and lighters for the carriage of goods and equipment.
- Tugboats.
- Unmanned vessels used by the Navy for exercises.

O'Brien (2018) notes that the most likely initial application of autonomous ships will be in simple inland and coastal trades, including the transport of bulk cargoes, passenger or ro-ro ships. An attractive feature of some of these trades is the relative calm of the waters, low volumes of traffic, and simple routes.

As noted in the previous chapter , certain Northern European countries are in the forefront of developing projects on autonomous ships. Those projects have ranged from small research projects through larger-scale research, development and design projects through to demonstration projects including purpose-built ships with autonomous features. Thus far the focus in those projects have been small feeder containerships and ferries. The former category of ship is intended for the short-sea shipping trade.

There are some general similarities between this kind of trade on the coasts of countries like Finland, Norway, Denmark and others on the one hand, and the trade experienced on the Great Lakes – St. Lawrence Seaway on the other (See Figure 13 for an illustration of the latter (Chamber of Marine Commerce, 2019)). However, an important distinction needs to be made, i.e., while this kind of trade (short-sea shipping) is year-round Europe, this is not the case with shipping in the Great Lakes – St. Lawrence Seaway system. Typically, the latter system closes down for about three months over the winter. Hence, the case made by proponents of short-sea shipping that traffic can be diverted from highways to sea is not as easily made with regard to trade on Great Lakes – St. Lawrence Seaway.

Figure 13. The Great Lakes – St. Lawrence Seaway System

Further, short-sea shipping is hindered by the absence of financial signals reflecting the environmental and social advantages of moving freight by ship. Short-sea shipping for "non-traditional" cargoes can be a challenge due to the lack of proper ships and, in some cases, infrastructure in the maritime transportation system (Conference of Great Lakes and St. Lawrence Governors and Premiers, 2016). It was noted in the Conference of Great Lakes and St. Lawrence Governors and Premiers (2016): "Autonomous vessels present long-range potential for some portion of the Great Lakes maritime system, whether as research and investigation vessels, for navigation support, or for transport of goods across the Great Lakes. Accordingly, governments and private industry are engaged in research, development and innovation in this area."

There is significant ferry traffic in Canada on the East and West Coasts and also at various points along the Great Lakes – St. Lawrence Seaway. The European experience in this regard appears to be relevant to Canada circumstances.

Other operations mentioned as possible candidates for some level of autonomy are pilot operations. Mark Fisher, the President and CEO of the Council of the Great Lakes Region, a non-profit agency in Ottawa, suggested that specialist Great Lakes pilots who go onboard vessels from abroad to steer them through the Great Lakes may be good candidates (Canadian Broadcasting Corporation, 2017). In addition, autonomous operation of support vessels have been suggested for offshore oil and gas supply, and aquaculture operations.

3.2 Canadian Experience With Autonomous Surface Ship Operations

There have been a few experiences with at least some level of autonomy in Canadian waters. Four are summarized as below:

1. Algoma Central Corporation
2. CSL
3. Canadian Hydrographic Service
4. Robert Allan Ltd.

Relevant activities are summarized in the paragraphs below.

3.2.1 Algoma Central Corporation

Algoma owns and operates a fleet of dry and liquid bulk carriers. They have the largest fleet in the Great Lakes – St. Lawrence Waterway. Algoma have decided to implement certain elements of autonomy. In this endeavour, they are taking an incremental approach. Among the elements of current interest are navigation assist, training, performance optimization, and condition-based maintenance.

Algoma has teamed up with Buffalo Automation in the USA, which is an artificial intelligence start-up that develops autonomous navigation technology for commercial ships and recreational boats with the goal to improve maritime safety. Their product, AutoMate, is being trialed with Algoma. The capabilities of the system include the ability to assess situational awareness and to provide navigational assistance.

Further information on Algoma's initiatives and Buffalo Automation's technology can be found at the CISMaRT website[13].

[13] http://cismart.ca/2019-workshop-on-autonomous-surface-ships/)

3.2.2 CSL

CSL operates a diversified fleet of dry bulk cargo handling vessels. Sister companies operate in the US, Australia, Europe and Asia. CSL is also active in using advanced information technologies to enhance its operations (Ryan, 2019). Among them is Wärtsilä's Lock Entry System. This system helps them navigate in various locks that are part of the Great Lakes – St. Lawrence Seaway System. Wärtsilä has, with the cooperation with CSL, deployed the technology on the *CSL St Laurent*, a CSL bulk carrier. The technology relies on GPS to locate the vessel in relation to the lock and allows the master to focus on other tasks, such as speed control.

CSL is also working on a broader initiative, known as O2 which is part of the digitalization program. The objectives of the program are to employ information technology to better manage and monitor vessels performance, fleet performance, environment & regulatory compliance, energy efficiency, and condition-based maintenance. This is an ambitious initiative that started in 2016 and the system to accomplish these functions were due to be deployed on 16 ships in 2019. In this work, CSL is being assisted by Maya HTT, a Montreal-based information technology company.

3.2.3 Canadian Hydrographic Services

The Canadian Hydrographic Services (CHS) conducts hydrographic surveys that capture water depths, geographical features, hazards to navigation, man-made and natural features that aid navigation, tides, currents and water levels, and sea bottom characteristics.

The CHS has been an early adopter in Canada of autonomous vessels. Two projects illustrate this. ASV Global[14] has converted a 26 ft hydrographic survey launch to enable it to operate autonomously (unmanned) using the ASView control system, while maintaining its ability to operate in a conventional manned mode. The launch, which is part of the Canadian Coast Guard's fleet dedicated to the survey operations of the Canadian Hydrographic Service, will be used as a test platform for unmanned survey work.

More recently, the CHS has acquired four small unmanned surface vessels (2.6 m length) with associated hardware for transporting and deploying the vessels. These vessels were supplied by SeaRobotics Corporation, a Florida, US-based company which specializes in developing products and technology for the maritime industry associated with autonomous, semi-

[14] ASV Global has its roots in the UK supporting the defence industries. The company developed drones and other unmanned marine systems for the defence and other industries. ASV Global was acquired in 2018 by L3Harris, a US-based technology company, defense contractor and information technology services provider.

autonomous and remote-control systems. CHS will use these vessels to improve bathymetric, hydrographic and nautical data throughout Canada for waterways, estuaries and coastal bathymetric surveys.

3.2.4 Robert Allan Ltd.

Robert Allan Ltd. (RAL) of Vancouver, BC is a prominent designer of tugboats and other small vessels, and is investing in autonomous vessel design. In this regard they differ from the examples presented above where the companies concerned are primarily users of at least some elements of autonomy rather than developers.

RAL has developed a series of autonomous firefighting tug designs, the so-called RAmora and RALamander series. The latest design is the RALamander 1600. This is a rapid response and remotely operated vessel designed for close-in firefighting. In this design, RAL is collaborating with Kongsberg Maritime, a leading provider of technology solutions for autonomous surface ships. See Figure 14 for illustration.

RAL appear to be the only Canadian engineering company offering autonomous surface ship designs albeit for a very specific type of operation.

Figure 14. Graphic of the un-crewed *RALamander* fireboat (Robert Allan Ltd, 2018)

4 Assessment of Canadian Capabilities

As discussed in the previous chapter, activities in autonomous surface ships in Canada have been limited. In the few cases, the organizations have used autonomous ship technology developed outside Canada. In investing in newer technology, organizations seek to minimize risk and the approach adopted is entirely consistent with that objective.

Nevertheless, there is interest in autonomous surface ships in Canada. Apart from the handful of initiatives summarized in Chapter 3, there are various new activities, including the setting up of the Canadian Forum for Marine Autonomous Surface Ships (CFMASS). Furthermore, there are recent promising developments that could potentially spark innovation by encouraging collaboration. Two recently instituted business-led innovation superclusters, namely the Scale.AI and the Ocean Superclusters, are examples. Such initiatives have the potential to encourage Canadian companies to become actively involved in autonomous surface ships at higher levels than hitherto. However, ideally this will occur in the context of increased demand in Canada for autonomous surface ships.

Despite the relatively low level of current involvement in autonomous surface ships, there exists in Canada significant levels of expertise in a number of related technologies or in technologies that could potentially be applied to autonomous ships. These are summarized in tables towards the end of this chapter. Before the tables, some general considerations are presented to explain the approach used to populate the tables.

4.1 Preliminary Considerations

In this chapter, the "asset map" is presented in tabular form under headings each of which represents one of several systems that together comprise the ship and its support systems. While this is convenient, it does mask the fact that ships, in common with other complex engineering systems, are made up of subsystems that are interconnected to each other in various degrees.

The interconnectedness applies operationally and is recognized in some of the studies described in the previous chapter. And hence ship transport, as far as cargo transport is concerned, is recognized as part of a supply chain. The studies suggest that synergies exist between various phases of transporting goods from the point of origin to the point of final delivery. These studies further suggest that the advantages gained from ship autonomy are increased when the same strategies are applied to other parts of the supply chain in an integrated manner. These might include processes such as docking/undocking and loading/unloading.

It is recognized that the observation made immediately above only applies to the transport of goods, and perhaps passengers in ferries, but are much less relevant to operations that do not involve the transport of goods. As discussed in the previous chapter, there are examples of autonomous operations that do not involve transportation, but are designed to support specific operations, such as hydrographic surveys, oil spill skimming, surveillance, etc.

It should be noted that the advanced navies of the world have had an interest in autonomous operation for several decades. These are not considered in this report. Information on such applications of autonomy is generally not readily accessible.

4.2 Current Canadian Capabilities in Autonomous Ships

As part of the gradual increase of the use of automation in virtually all aspects of ship operations, information technology[15] plays an increasingly prominent role. This process will accelerate and broaden in scope with or without autonomy being widely adopted in ships. If autonomous ships find greater application in Canada than at present, then this process will expand, and more advanced forms of information technology will be used.

For the purpose of presenting an "asset map" of Canada's capabilities in related technologies, it is convenient to consider ship functions in two broad categories as follows:

Conventional ship functions. These include the engines, generators, propeller, rudder, pumps, closing appliances, etc., which also exist in autonomous ships. However, their capabilities are beyond those required in conventionally crewed ships. There will be a greater premium on reliability since repairs are a challenge in circumstances with a much-reduced crew, or no crew at all. In addition, real-time monitoring systems will be required to measure and monitor navigation functions, weather conditions, ship response characteristics, etc. In the absence of a crew, or if there is much reduced crew, these equipment and systems will have to be operated remotely. Beyond controlling these functions, monitoring systems will be required for maintenance and safety reasons. Control systems will comprise both hardware and software.

Autonomous ship functions. These include a host of new sophisticated functions required to be performed. Personnel at a control centre will be required to perform many of the functions normally carried out by the crew, but remotely. Therefore, existing systems will have to be enhanced to account for the lack of personnel. Completely new functions will also need to be performed. For situational awareness, it can take full advantage of existing

[15] "Information technology" is used in this discussion in its broadest meaning and includes a host of different technologies, mathematical modelling techniques, and advanced software systems.

systems, such as AIS[16], ECDIS[17], etc. For the entirely new systems to establish situational awareness, it will require greater reliance on sensors and data interpretation as well as smart systems to determine any required responses. A remote-control centre with a suitably trained workforce will be required to perform monitoring functions and may require intervention of the kind normally provided by an onboard crew. It should be pointed out that the greater reliance on communications and information technologies render the vessel vulnerable to cyberattack. Hence, this aspect will need to be given higher priority than that in conventional ships.

The following tables, Tables 2-9, list organizations in Canada with expertise in terms of offering services and/or products relevant to autonomous ships. The categories are:

- Companies with a broad range of related services/products
- Ship design
- Propulsion systems
- Underwater autonomous, remotely operated vehicles and robotics
- Communications
- Navigation systems
- Sensor technology
- Information technology

Accompanying each table are brief explanatory notes. Apart from the first category (Table 2), very few of the entries in the tables have direct experience in autonomous ships.

It should be noted again that in compiling the lists in Tables 2 to 9, reliance was placed on generally available information. The main sources are the marine trade press, websites, and information provided by personal communications.

[16] Automatic Identification System

[17] Electronic Chart Display and Information System

4.2.1 Companies with A Broad Range of Related Services/Products

Table 2. Companies with A Broad Range of Related Services/Products

Name	Location of HQ (in Canada)	Scope of services/products
ABB	Switzerland (Saint Laurent, QC)	Advanced power and automation technology
BAE Systems	UK (Ottawa, ON)	Systems integrator
Kongsberg	Norway	Comprehensive provider of autonomous ship technical services
L3 Harris[18]	USA (Ottawa, ON)	Defense contractor and information technology services
Lockheed Martin	USA (Ottawa, ON)	Systems integrator
Thales	France (Ottawa, ON)	Systems integrator
Wärtsilä	Finland (Richmond, BC)	Wide range of marine products including propulsion power, bridge control and navigation systems

This table includes pioneer companies that offer a broad range of services associated with autonomous surface ship design. Such companies have been among the most active promoters of autonomous surface ships. Most of these companies are based in Northern Europe, but generally have branch operations around the world including Canada.

Also included in the table are large system integrators who mainly work on large naval acquisition programs. These system integration programs may include autonomous naval surface ships (for which public information is severely limited). The reason for including this

[18] L3 Harris acquired ASV Global in September 2018. ASV Global, which is now known as L3 ASV, and has an extensive history as a supplier of autonomous vessels for the commercial and defence sectors. L3 ASV are suppliers to the Canadian Hydrographic Service of an autonomous hydrographic survey vessel.

type of company in the list is not because of their expertise they have in autonomous ships, but more because of their experience in managing large, high-technology projects integrating ships systems from diverse sources. Again, these companies have a presence in Canada although their headquarters are in other countries.

4.2.2 Ship Design Companies

Table 3. Ship Design Companies

Name	Location of HQ (in Canada)	Scope of services/products
BMT Fleetech	UK (Kanata, ON)	Ship design, specializing in naval vessel and wide range of related services from sister companies
VARD Marine Inc.	Norway (Vancouver, BC)	Ship design, specializing in government vessels and wide range of related services from sister companies
Robert Allan Ltd.	Vancouver, BC	Ship design, specializing in tugs and other small vessels
Fleetway	Halifax, NS	Engineering, technical, logistics and management services
Genoa Design International	Mount Pearl, NL	Production lofting, detail design and 3D modeling services to shipbuilding and offshore industries
Navtech	Québec	Naval architecture, marine engineering, brokerage and marine surveys
Concept Navale	Québec	Naval architects and marine engineers
3GA Marine	Victoria, BC	Naval architects and marine engineers

Ship design is accomplished by naval architects and marine engineers. This applies to an autonomous surface ship as much as it does to a conventional ship since the former will typically have many same systems as in the latter. A ship design company tasked with the design of an autonomous ship will, in general, seek needed expertise from specialist technology consultants and providers of autonomous ship technologies (some of which are listed in Table 2) to address all elements associated with autonomous operation.

4.2.3 Propulsion Systems Companies

Table 4. Propulsion Systems Companies

Name	**Location of HQ (in Canada)**	**Scope of services/products**
Aspin Kemp & Associates	PEI	Hybrid propulsion systems
Ballard Power Systems	Burnaby, BC	Fuel cells
Gastops	Ottawa, ON	Propulsion systems engineering, remote monitoring and condition assessment
Marimetrics Technologies Inc.	Dartmouth, NS	Condition-based asset maintenance through monitoring of ship propulsion system
Corvus Energy	Norway (formerly BC, Canada)	Energy storage systems

The propulsion may be conventional but, as with the case of the European demonstration projects, the practice has been to simultaneously adopt greener options. These may be battery-based power or hybrid systems, which employ power sources from both conventional and battery sources. If conventional power systems are employed on autonomous ships, the systems are required to have a greater degree of reliability than that normally applied on conventional ships. This is because the opportunity for monitoring, maintenance and repair is reduced if there is no crew or a reduced crew.

4.2.4 Underwater Autonomous, Remotely Operated Vehicles, Robotics Companies

Table 5. Underwater autonomous, remotely operated vehicles, robotics companies

Name	Location of HQ (in Canada)	Scope of services/products
SEAMOR Marine Ltd.	Nanaimo, BC	Research, develop and build Remotely Operated Vehicles (ROVs)
International Submarine Engineering (ISE)	Port Coquitlam, BC	Design and integration of autonomous and remotely operated robotic vehicles and terrestrial robotics
Cellula Robotics	Burnaby, BC	Turnkey design and production of subsea robotic systems.
MarineNav	Panmure Island, PEI	Underwater ROVs
GeoSpectrum Technologies	Dartmouth, NS	Manufacturer of underwater acoustics primarily for navy applications
GRI Simulations	St. John's, NL	Simulators for ROV applications
Clear Path Robotics	Kitchener, ON	Robotics

This category is closely related to autonomous surface ships as illustrated in the chart in Figure 15. As noted earlier, Canada has long-standing in-depth capabilities in this category (see the boxes in the figure coloured in orange). It is reasonable to suppose that this capability can be adapted to address several aspects of the operation of autonomous surface ships, including communications and control systems.

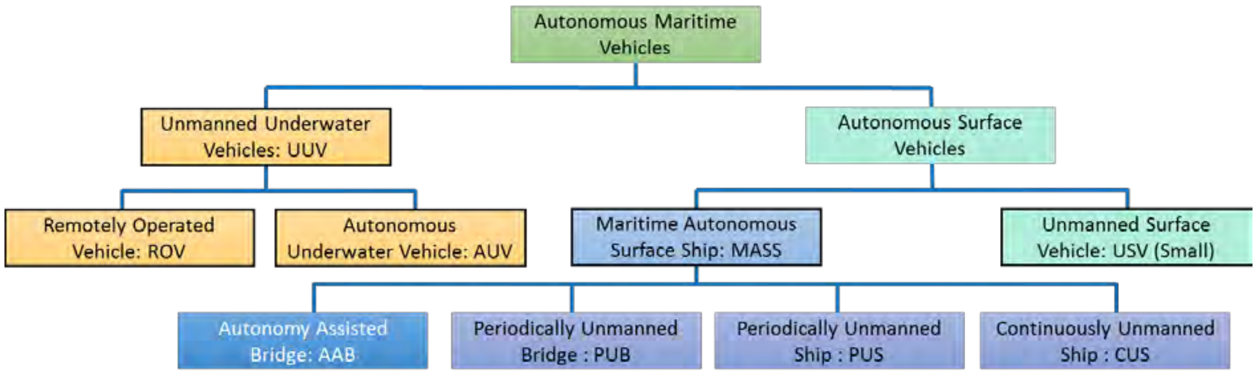

Figure 15. Classification of autonomous maritime systems and autonomous ship types (Norwegian Forum for Autonomous Ships, 2017)

4.2.5 Communications Companies

Table 6. Communications Companies

Name	**Location of HQ (in Canada)**	**Scope of services/products**
Metocean Telematics	Dartmouth, NS	Iridium satellite hardware and airtime plans. Sister company, MetOcean systems, undertake design and production of meteorological and oceanographic technology
Sky Hawk Telematics	St. John's, NL	Internet-based GPS tracking and monitoring solutions
Nova Communications	Dartmouth, NS	Motorola two-way radio dealer and communications systems integrator
MDA	Richmond, BC	Advanced systems in surveillance, intelligence solutions, defence and maritime systems, robotics, satellite antennas, and communication subsystems

With autonomous ship operation, more advanced, sophisticated and reliable communications are needed in comparison with a traditionally operated ship. In generic terms, communications are required for monitoring, supervisory control and direct control of the vessel.

4.2.6 Navigation Systems Companies

Table 7. Navigation Systems Companies

Name	Location of HQ (in Canada)	Scope of services/products
OSI Maritime Systems	Burnaby, BC	Integrated navigation and tactical solutions (naval)
NavSim Technology	St. John's, NL	Software and hardware R&D firm, focusing on electronic navigation solutions for both land and marine applications
CNS Systems Canada	Sweden (St. John's, NL)	System solutions for communication, navigation and surveillance of traffic, both marine and aviation

The comments made for **Communications Companies** also apply for navigation systems, perhaps even more so.

4.2.7 Sensor Technology Companies

Table 8. Sensor Technology Companies

Name	Location of HQ (in Canada)	Scope of services/products
Kraken Robotics	Mount Pearl, NL	Design and development of sensors for unmanned underwater vehicles
Think Sensor Research	Burnaby, BC	Underwater and above water marine sensor systems
PanGeo Subsea	St. John's, NL	High resolution 3D acoustic imaging solutions

CartNav Solutions (A subsidiary of PAL Aerospace, an Exchange Income Corporation Company)	Halifax, NS	Mission system software that enhances situational awareness and improves mission effectiveness in airborne, land-based, and maritime platforms.
RBR Limited	Ottawa, ON	Oceanographic sensors, loggers and associated hardware
Rutter Inc.	St. John's, NL	Specialist signal processing technologies for radar systems for marine security, safety and environmental monitoring
SubC Imaging	Clarenville, NL	Technology for ROV inspection tasks
MTE Instruments	Rimouski, QC	Design and manufacture of oceanographic equipment such recorders, buoys etc.

While all ships rely on systems to provide a degree of situational awareness, e.g., GPS, AIS, ECDIS, sonar, radar, etc., enhanced capability is required to interpret what is being observed, sensed and measured using techniques, such as pattern recognition.

4.2.8 Information Technology Companies

Table 9. Information Technology Companies

Name	**Location of HQ (in Canada)**	**Scope of services/products**
Element AI	Montreal, PQ	Implementation of AI and ML solutions (Montreal Port Authority)
Maya HTT	Montreal, PQ	Implementation of advanced IT solutions for ship operations
Computer Research Institute of Montreal	Montreal, PQ	Advanced software modeling and development, emerging technologies and data science, speech and text, vision and imaging

Canada has considerable strength in digitalization or information technology. There are numerous enterprises, centred in Montreal and Toronto and elsewhere, working in this broad area. Apart from a very few exceptions, none appears to be active in marine fields, and therefore, this list is relatively short. Those in the list are Canadian companies who have some involvement in Canada's marine sector (including ports) in terms of technology areas mentioned in the previous paragraphs.

A general sense of capabilities in this broad area in Canada can be obtained from the current membership of the Scale.AI Supercluster[19].

4.3 Assessment of Capabilities

To assess Canada's current capabilities in autonomous ships, it is necessary to be aware of the environment within which the assessment is made. The environment concerned is the marine ecosystem that prevails in Canada today. Key characteristics of this ecosystem are the current state of Canada's marine industry, the demand in Canada for marine-related products and services, and the availability of the technology to support the construction and operation of autonomous ships in Canada. These are considered in Sections 4.3.1 and 4.3.2. An overall assessment follows in Section 4.3.3.

As discussed earlier, there exists considerable expertise in Canada related to the technology pertinent to autonomous surface ships. From Section 4.2, it was observed that apart from one exception, none of the Canadian companies listed in the tables appear to have direct experience with autonomous surface ships. Nevertheless, they all work in technologies that could be adapted for application to autonomous surface ships.

4.3.1 Canada's Maritime Industry and Investment in R&D

In this section, a qualitative comparison is made between Canada and countries that have been active in developing autonomous surface ships. In this assessment, Finland and Norway are used as benchmarks. Both countries are investing heavily in autonomous shipping through projects, either nationally or through EU projects. Both countries are building and trialing purpose-built ships to explore many issues, still to be resolved, to render autonomous ships feasible. Both countries are also home to technology companies that are regarded as world leaders in technologies relevant to autonomous ships and indeed other conventional ship systems.

[19] https://scaleai.ca/members/

Despite being a G8 country, Canada ranks low as an owner of ships and as a builder of ships. According to the UNCTAD (2019), while Canada generates 2% of the world's GDP, it owns only 0.48% of the world's ships and builds just 0.01% of the world's ships. In contrast, Finland and Norway, both leaders in autonomous ship technology, own 0.11% and 3.11% of the world's ships, and build 0.24% and 0.15% of the world's ships, respectively. This is despite each having populations roughly one-seventh that of Canada's.

The above situation is compounded by the fact that Canada spending on R&D is low. The latest OECD (2019) data indicates that the overall average R&D expenditure in OECD countries in 2015 was 2.4% of GDP and whereas it was 1.7% for Canada. Furthermore, the investment in marine R&D is even lower at about 1.4%. Academic research in Canada on autonomous surface shipping is also very limited.

The story is different for other transport sectors, namely aerospace and land vehicles. Canada is among world leaders at least in terms of production volumes. Canada is the 4th largest exporter of automobiles in the world. It is also the 4th largest exporter of aerospace products. Similarly, there is significant academic research related to these sectors.

While the observations made above are more indicative rather than conclusive, it does suggest that the advantages of "critical mass" enjoyed by the aerospace and land transport sectors are absent in Canada's marine industry. It is possible that some of the shortcomings identified above will be rectified to a degree by the launch of Canada's Supercluster initiative. It is planned that up to $950m will be spent on five supercluster initiatives. Some of the technologies represented by two of them, Scale.AI and Ocean Superclusters, are relevant to autonomous surface ships. It is feasible, therefore, that some of these resources might be employed to further develop technologies directly relevant to autonomous surface ships.

4.3.2 Canada's Activities in Related Fields

This section summarizes Canada's involvement in allied fields, including both marine and non-marine fields.

In the marine field, Canada has an enviable track record in the broad subject of autonomous underwater vehicles. Technologies associated with sensors, communications and control are well developed. It is reasonable to suppose that these technologies could, in principle, be adapted for application to autonomous surface ships. Of course, for this to happen, there needs to be a significant domestic demand for products and services associated with autonomous surface ships. Or, alternatively, vendors in Canada have to determine that there is sufficient international demand, and that they have the capability to compete with already-established companies in this market.

Thus far there is evidence of only a few instances of interest in autonomous ships in Canada. These were identified in Section 3.2. These organizations have chosen to employ technologies developed outside Canada. The reliance on suppliers with an established track record is entirely reasonable in the circumstances as a way of minimizing technical and project risk. One Canadian company, Robert Allan Ltd., has developed a design for the un-crewed RALamander fireboat (Robert Allan Ltd., 2018). In this endeavour, Robert Allan Ltd. have allied themselves with Kongsberg Maritime, a well-established provider of autonomous ship technology.

In non-marine fields such as autonomous road vehicles, Canada also has a track record. Again, in principle at least, it is reasonable to suppose the technologies developed in this sector could be adapted to marine applications, although probably to a lesser extent than applications to underwater autonomous vehicles. But this would be highly unlikely in the absence of significant demand.

4.3.3 Overall Assessment

The concentrated technological capability in autonomous surface ships is limited in Canada. However, there is significant expertise in related fields, including

1. Underwater autonomous vehicles
2. Land vehicles
3. Information technology
4. Naval architecture and marine engineering

Canada has considerable expertise, some of it world class, in underwater autonomous vehicles. Autonomous land vehicles are a well-developed category of technology resident in Canada. In regard to the third category, Canada has world-class expertise and a host of related information technologies upon which autonomous operation relies. These technologies include image and pattern recognition, artificial intelligence, machine learning, etc. With respect to the last category, Canada has significant expertise in naval architecture and marine engineering. There is a lot of room for naval architects and marine engineers to advance the technologies in autonomous surface ships in collaboration with those in the other three fields.

All these related technologies and expertise can be adapted and applied to autonomous ships. But in the absence of domestic demand, the development of autonomous surface ships is in question. On the other hand, there are opportunities for companies in related fields to collaborate with national and international players and develop products and services for the wider worldwide market. Note that Canada is relatively a late starter in the area of autonomous surface ships without concentrated effort and investment. Therefore, it is anticipated that the competition in the global stage with well-established and experienced companies would be fierce. As discussed in previous chapters, there are such companies in

Europe, some smaller ones in USA. Companies in Asia are also making investments in this technology area.

5 The Next Steps

This section addresses three levels of actions that have the potential to raise the level of Canada's involvement in autonomous surface ships:

1. High-level actions that can contribute positively to the effort towards making Canada a player in autonomous surface ships.
2. Specific projects, identified at the recent CISMaRT Workshop[20], should be undertaken to address a range of issues important to autonomous ships.
3. A demonstrator project designed to highlight Canadian technology and promote autonomous shipping in Canada.

5.1 High-Level Actions

The general features of Canada's marine industry and the technologies related to autonomous ships are reiterated below:

- Canada's marine industry is small in terms of both ship ownership and ship building.
- Investment in RD&D is lower than average in Canada compared with its peers.
- Current activities are limited in designing and operating autonomous ships. Where there is involvement in autonomous ships, reliance has been on technology from non-Canadian sources.
- Nevertheless, there is considerable related technology in related fields, which potentially could be adapted for application to autonomous ships.

In the absence of substantial Canadian demand, it appears unlikely that a domestic industry dedicated to autonomous ship products or services will develop to any great extent. In order to encourage greater activities in autonomous ships in Canada, at least some of the following actions should be considered:

- Undertake studies to identify the types of ship operations in Canadian waters that are suitable for autonomous operation with a focus on operations that do not appear to have been investigated elsewhere. Operations in the Arctic might be one example.
- Establish which operators of ships in Canada are amenable to introducing elements of autonomy in their operations.

[20] CISMaRT Workshop on Autonomous Surface Ships in Québec City on November 27-28, 2019 as outlined in Chapter 1.

- Subsidise collaborative work involving ship operator, technology provider and appropriate government agencies. This would typically involve introducing autonomy to well-established existing operations.
- Consider supporting a demonstrator project in which a small vessel is built from scratch and outfitted with autonomous systems designed and built by Canadian companies. An outline of such a project process is presented in Section 5.3.

5.2 Other Projects

The following are mostly smaller-scale projects identified during the CISMaRT Workshop. These are presented in categories. Many of these projects could be integrated into larger-scale projects of the type mentioned above.

5.2.1 General High-Level Projects

- Increase awareness of autonomous shipping with shipowners, builders and designers
- Assessment study of Canadian capability to produce small/intermediate-sized maritime autonomous surface ships (MASS)
- Assessment of the readiness of Canadian ports for autonomous shipping
- Canadian technologies that can be adapted for the marine environment
- Approach Canada's Transport Minister to set up a DND IDEaS-type program for autonomous ships

5.2.2 Arctic Projects

- Evaluation of MASS 3 and MASS 4 in ice-covered waters[21]
- Identify operations in the Arctic that autonomous ships could support
- Operations in ice

5.2.3 Operation Centre and Related

- Identify, build and test shore-based infrastructure
- Development of operations centre

5.2.4 Testing

- Promote small-scale test beds
- Testbed project (pilot project)

[21] "MASS 3" and "MASS 4" refer to the level of autonomy according the four-level scale introduced by IMO. MASS 4 is the highest level of autonomy.

5.2.5 Miscellaneous

- Demonstrate inter-operabilities
- Interactions with non-conforming traffic, i.e., fishing fleets
- Develop ability to collect and analyze data – get talent in Canada around that topic
- Bring AI, sensor companies, etc., into the discussion
- Training for new mariners
- Investigate autonomous ships to provide offshore support functions to oil and gas rigs

5.3 Outline of a Demonstrator Project for Developing a Platform to Explore the Application of Canadian Technology to Autonomous Ships

Canada needs a means to enhance the profile and utility of autonomous platforms to the marine industry and the general public. An attractive approach for promoting autonomous shipping in Canada and showcasing Canada's expertise in relevant technology is through a demonstrator project. This basic approach has been used by many leaders in autonomous surface ships, such as those in US, Northern European countries and the Far East.

As identified in the asset map, there is world class expertise resident in Canada in technologies related to autonomous shipping. A vehicle is required to develop and demonstrate this capability and further develop it for application to autonomous ship operations. A demonstrator project in which a purpose-built vessel can provide a platform for these technologies has many attractions. An alternative approach that potentially has some advantages is to rely on an existing vessel that can be converted to provide a suitable platform.

It is suggested that the most successful projects are likely to be initiatives that align with operators that already have some inclination to at least explore the use of some level of autonomy. This process can be encouraged, and perhaps accelerated, by putting in place the right incentives and by initiating a pilot project to demonstrate the benefits of automation for a specific application that addresses a unique situation in Canada. A possible approach to such a pilot project is outlined below. This is presented in terms of four major phases.

CISMaRT is well positioned to act as the lead in such a project. It has many leading companies in Canada as members concerned with marine research, development and design. It is proposed that a team is formed of members with the requisite skills and experience to undertake the project in four phases outlined below. Note that the descriptions for each phase are highly condensed. It is designed to give a very high-level view of the basic process that would be followed.

The next section, Section 5.3.1, summarizes the key benefits that could potentially be realized by undertaking a project of the type introduced above. The following section, Section 5.3.2, provides a high-level description of the project in four phases. A phased approach is considered prudent in a project with several innovative and non-traditional features.

5.3.1 An Autonomous Ship Project for Canada

The key benefits to Canada of a demonstrator project include:

- Showcase Canadian technology relevant to autonomous ships.
- Act as a catalyst in the development of autonomous surface ships in Canada.
- Interact on an equal footing with international companies and other organizations already established in autonomous ships.
- Provide an opportunity for exploring the infrastructure needs (e.g. control centre) of autonomous operations using existing Canadian companies and organizations.
- Allow the exploration of regulatory, legal and other requirements necessary to allow safe and orderly autonomous operations in Canadian waters.
- Encourage cooperation between many companies and organizations that form the Canadian marine ecosystem.
- Assist in the development of academic and research programs related to autonomous shipping in Canadian universities, colleges and research institutions and potentially become a world centre in this subject area.

It is recommended that a collaborative multi-phase project is undertaken in which a ship is built and operated. An outline of a proposed project for the design and construction of a ship with autonomous features is presented below in four phases. The project will be designed to maximize the benefits listed above. The three main attributes of the project are:

- General support of the broad Canadian marine ecosystem and direct engagement of elements of the ecosystem with relevant expertise and committed to the success of the project.
- The selection of a ship type that makes sense for Canadian waters and thus having the maximum opportunity for Canadian stakeholder buy-in.
- Ideally the ship type selected will be distinct from the ship types already addressed by other countries that have already committed significant resources to the development of autonomous ships.

Regardless of the mission specific ship type that is chosen for a demonstrator project, it should be developed to draw upon Canada's world leading capability in areas including underwater autonomous vehicles, autonomous terrestrial vehicles, ocean and naval architectural engineering, ocean mapping, underwater remote sensing (such as acoustic and radar), and key areas of IT (such as image and pattern recognition, AI, machine learning, cybersecurity, etc.). The first step in identifying this ship type is to consult with the leading adopters of maritime autonomous ship technology as referenced in this report and identify an application that could utilize Canadian expertise to develop a specific market niche of an end product where Canada could potentially be a global leader.

5.3.2 A Phased Approach to the Project

Phase 1: Development of mission requirements

- **Objective:** To develop mission requirements.
- **Approach:** Requirements will depend on the ship type and service envisaged. In this regard, it would be advantageous to have an operator as part of the team who has an interest in autonomous operations. The operator may be a government operator, for example of, buoy tender, icebreaker, Arctic supply vessel, and survey vessel, etc., or a commercial operator, for example of, ferries, bulk carriers in the Arctic or Great Lakes/St Lawrence Seaway service. A set of mission requirements consistent with the anticipated operations of the vessel will be drafted. Based on the anticipated operations a decision will be made in regard to whether the platform will be based on a new vessel or whether it would be more cost effective to convert and use an existing vessel as a platform.

  Early in this process, aspects associated with autonomy will be considered. This will include, among many other aspects, the required degree of autonomy since this will determine the systems required to support autonomous operations. In this regard, it will be necessary to have experts as part of the team that can address this aspect. Using the asset map described in the aforementioned CISMaRT report, candidate organizations will be identified for possible participation in the project.
- Phase 1 is anticipated to take 6 months.
- **Output:** Mission requirements

Phase 2: Design development

- **Objective:** To develop a design of an autonomous ship.
- **Approach:** The vessel will be designed, and major features will be determined based on the mission requirements. A general arrangement will be prepared indicating the arrangement of spaces and major equipment. To be included at this stage is provision for equipment required to support autonomous operations.

Standard design calculations will be made to establish the hull form, stability, resistance, propulsion, seakeeping, and structural strength, etc. This will be an iterative process to ensure that the final design will meet the mission requirements established in Phase 1. Studies will be particularly undertaken to consider aspects of autonomous operation and how they should be incorporated in the design.

- Phase 2 is anticipated to take 6 months.
- **Output:** A design in sufficient detail to allow shipyard to develop estimates and prepare a plan for construction

Phase 3: Construction of ship

- **Objective:** To construct the autonomous surface ship.
- **Approach:** The vessel will be built during this phase. If the project is based on an existing vessel, this phase will be a conversion project. The overall process is essentially similar. Apart from acquiring the usual mechanical, electrical and other systems, the hardware and software to drive and support autonomous operation will also be acquired taking due account of lead times.

  Depending on the design of the autonomous elements of the ship, it may be necessary also to set up a control centre.
- Phase 3 is anticipated to take 12 months.
- **Output:** A vessel able to perform autonomous operations as per the mission requirement.

Phase 4: Sea trials

- **Objective**: To undertake acceptance trials and take delivery of the vessel
- **Approach:** Apart from the usual sea trials to evaluate the performance of the vessel in regard to speed, manoeuvrability, equipment performance, etc., it will be necessary to establish that the autonomous operation functions are performing satisfactorily.
- Phase 4 is anticipated to take 6 months.

6 Concluding Remarks

The subject of this report is autonomous surface ships in Canadian waters. Related activities in Canada and other parts of the world were reviewed.

Northern European countries are the most active in this technology. They have performed a number of high value projects and studies and continue to do so. These include demonstrator projects, which involve the building of ships for research and demonstration purposes, including feeder containerships for short-sea shipping as a means of relieving the transport of cargo by road. Another sector that has received attention is ferry traffic typically involving short trips.

East Asia is another region of the world active in autonomous shipping. This region builds the vast majority of the world's largest cargo ships. These countries are interested in the kinds of trade referred to in the previous paragraph, and also have a focus on large ocean-going ships.

There have been a number of applications of autonomy in vessels not engaged in trading. These include specialist functions, such as hydrographic survey, oil spill recovery, firefighting, etc. The first type of operation is the most prominent example of marine autonomous operation in Canada.

Activities in autonomous surface ships in Canada have been limited. Compared with the regions of the world mentioned above, Canada's marine sector is very small, which is at least partly responsible for the low level of activities in autonomous ships. There are a handful Canadian operators using some degree of autonomy in their ships involving foreign vendors. The use of established vendors is consistent with minimizing project and financial risk.

On the other hand, Canada does have expertise, some of it world class, in related technologies. Principal among these are underwater autonomous vehicles and land autonomous vehicles. The expertise possessed by these organizations could, in principle, be adapted to surface ships if sufficient demand existed. Whether such demand will develop is unknown at this point. In constructing an "asset map" of capabilities, companies active in the marine field, and especially those working in autonomous systems, have been identified.

Steps that could be taken to encourage the development of a higher level of activities in Canada in this sector were outlined.

As for the next steps, a pilot project is outlined, which aims to develop a platform to explore the application of Canadian technology to autonomous ships.

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