Technology Implications for Marine Pilotage

May 2024

About Us

Clear Seas is a Canadian not-for-profit organization that provides independent fact-based information to enable governments, industry, and the public to make informed decisions on marine shipping issues. We work to build awareness and trust so that all people can feel a part of the marine sector. Our vision is a sustainable marine shipping sector that is safe, vibrant, and inclusive, both now and for future generations.

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About this Report

Clear Seas undertook research on the **Technology Implications for Marine Pilotage** to identify and assess emerging technologies and related practices that have the potential to improve the safety and efficiency of how pilotage services are delivered in Canada. This study was conducted from August 2023 to February 2024 by Greenwood Maritime Solutions Ltd. on behalf of Clear Seas.

Clear Seas Board of Directors

Research Team

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Message from the Executive Director

The term *pilot*, long before it was adopted by the aviation industry, has an ancient history of denoting those who navigated ships. Derived from French (*pilotte*) and medieval Greek (*pedotes,* signifying rudder or helmsman) it originally encompassed those skilled in both oceanic and coastal practices. The modern recognized tradition of transferring an experienced mariner, or pilot, with specialised local knowledge onboard a ship to guide it safely to and from port stretches back centuries. This practice of pilotage has delivered a vital risk mitigation to allow the marine shipping industry to continue to safely provide trade and tourism, no matter the weather.

But the pilotage industry is facing a rapidly changing future. The pool of experienced qualified mariners from which pilots are traditionally drawn will diminish as mariners age and are not replaced due to the future predicted shortfall in the maritime workforce. Being a pilot is a challenging job with exacting standards for physical health. Climbing a rope ladder up the side of a heaving ship is not for everyone. Navigational safety is experiencing threats from the environment as well. Climate change is causing sometimes extreme changes to weather patterns and water levels, and altering coastal and estuarine systems. Although pilotage services in Canadian waters have not yet been significantly affected, continued changes to weather patterns and increases in extreme storm events may challenge the traditional wisdom of relying on landmarks and historical practices for safe passage.

The seemingly relentless growth in international trade continues to bring more ships, and the drive for efficiency means that they are becoming larger seemingly every year. At the same time, the expectations for safety and environmental protection have never been higher. Pilots have always been an essential component of the risk mitigation strategy to drive accident rates towards zero and protect the environment from spills or disturbance; how can the industry best respond to these mounting challenges?

The good news is that technology may offer some solutions. The rate of change in navigation safety systems and the equipment available to mariners over the past 50 years has been astounding. Paper charts and sextants have been replaced with electronic chart displays, AIS, and satellite connectivity. Artificial intelligence and low-cost sensors bring new innovations every year. Pilots have often been at the forefront of developing and adopting these technologies.

This research project intends to catalogue and process the technologies that contribute to the safe and efficient delivery of pilotage services. The objective is to identify opportunities to apply emerging technologies to address the challenges faced in providing conditions for safe navigation. We are optimistic that technology presents valuable opportunities for improved pilotage so ships can continue to be safely and economically guided to and from Canadian ports while protecting the coastal and ocean environments and all those who depend on healthy ecosystems.

Acronyms and Abbreviations

AIS	Automatic Identification System
APA	Atlantic Pilotage Authority
ARPA	Automatic Radar Plotting Aid
CASRAS	Canadian Arctic Shipping Risk Assessment System
CCG	Canadian Coast Guard
CHS	Canadian Hydrographic Service
CMA	Canada Marine Act
CMPA	Canadian Marine Pilots Association
COLREGs	International Convention on the Prevention of Collisions at Sea (1972)
CSA	Canada Shipping Act, 2001
DFO	Fisheries and Oceans Canada
ECDIS	Electronic Chart Display and Information System
EMSA	European Maritime Safety Agency
ENC	Electronic Navigational Chart
GIS	Geographic Information Systems
GLPA	Great Lakes Pilotage Authority
GNSS	Global Navigation Satellite System
GPS	Global Positioning System (originally called NAVSTAR)
GSTS	Global Spatial Technology Solutions Ltd.
GT	Gross-tons (a measure of a ship's carrying capacity)
IALA	International Association of Lighthouse Authorities
IHO	International Hydrographic Organization
IMO	International Maritime Organization
IMPA	International Marine Pilots Association
LADAR	Laser Detection and Ranging
LIDAR	Light Detection and Ranging
LNG	Liquefied Natural Gas
LPA	Laurentian Pilotage Authority
MASS	Maritime Autonomous Surface Ships
MMSI	Maritime Mobile Service Identity
NCA	Norwegian Coastal Administration
NCEMP	(Canadian) National Centre of Expertise on Maritime Pilotage
NM	Nautical miles
NOAA	National Oceanic and Atmospheric Administration (of the US)
POLARIS	Polar Operational Limitations and Risk Indexing System
PORTS	Physical Oceanographic Real-Time System (of NOAA)
PPA	Pacific Pilotage Authority
PPU	Portable Pilotage Unit
SBP	Shore-Based Pilotage
SOLAS	Safety of Life at Sea (a fundamental IMO Convention)
STM	Sea Traffic Management
TC	Transport Canada
TSS	Traffic Separation Schemes
UK	United Kingdom

UKC	Under-Keel Clearance
VAtoN	Virtual Aids to Navigation (sometimes Virtual AtoN)
VDR	Voyage Data Recorder
VTS	Vessel Traffic Services (sometimes Vessel Traffic Management Services, VTMS)
VTMS	Vessel Traffic Management Systems (sometimes VTM Information Systems, VTMIS)

Executive Summary

This research provided a scan of technology applicable to the practice of marine pilotage, with the objective of identifying emerging or non-standard technologies that may be available to enhance the effectiveness (safety) and efficiency of pilotage in Canadian waters.

Background research provides an overview of the history and practical functions of marine pilotage; the study traces the evolution of pilotage in Canada and highlights the significant advances in navigational technology that have occurred over the last 50 years. Canadian practice is related to the foreign pilotage regimes of Australia, United States, Chile, Denmark and Norway.

A functional concept of pilotage was developed as a framework for the detailed research, focused on technologies addressing the aspects of (1) position/movement; (2) environment; (3) ship control; and (4) risk assessment/management. A related set of comparison criteria were developed, through which baseline, enhancing and emerging technologies were assessed to identify what technologies may have the greatest potential for improving pilotage.

Within this functional framework, the research examined 54 discrete technologies applicable to marine pilotage: 23 of these are deemed "baseline" technologies, being in common usage among almost all modern pilotage authorities; 17 are "enhancing" technologies which are commercially available and in use with leading pilotage organizations. The remaining 14 technologies are "emerging" in different states of maturity, from conceptual/prototype (e.g.: heads-up bridge displays) to practical demonstration but are not in regular use for pilotage. The "leading edge" of emerging technologies for pilotage includes Virtual Reality Technology for situation appreciation, and the use of Artificial Intelligence for ship scheduling, risk prioritization, and decision-making. The marriage of multiple enhancing and emerging technologies is currently being used to enable limited demonstrations of Shore-based Pilotage (SBP) and Marine Autonomous Surface Ships (MASS).

From the limited comparison available, we concluded that Canada's Pilotage Authorities already employ most commonly available technologies; in this regard they are as advanced as many international comparatives. The exception is with respect to SBP and preparation for MASS, in which Finland, Denmark and Japan appear more advanced, both technologically and with respect to enabling legislation.

Many concerns remain with identified gaps in the feasibility and benefits of remote-piloted or autonomous ships. Nonetheless, experiments with SBP and MASS are pushing the boundaries in ways that may provide benefit to pilotage generally, in the form of display, risk assessment and decision-making technologies. In the meantime, some more "ordinary" enhancements are available, which may address current pilotage concerns such as: safer pilot transfers; increased Vessel Traffic Services situational awareness and management; advanced real-time data availability to pilots; local monitoring and deconfliction with sea-life; and improved coastal connectivity with internet-based sources of information.

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Technology Implications for Marine Pilotage

1.0 Background

Over history, the provision of marine pilotage services has evolved in different areas to suit specific local needs. Generally, this rested on the premise that adequate, detailed and current knowledge required to keep arriving ships safe (i.e., position, hydrography, meteorology, and traffic) could only be provided by those having frequent, localized experience. This situation was affirmed by the fact that faults in early navigation systems could only be detected and corrected "by eye." This resulted in the qualifying standards for marine pilots resting on long personal experience in the pilotage area, memorization, and the ability to continue navigating the ship under extreme conditions of technological failure or deprivation. This tradition of placing an experienced mariner or pilot on ships as they approach and leave a port has continued to this day.

1.1 Responsibilities and Challenges of the Marine Pilot

The pilot is responsible for position and movement of the ship. They have to take into consideration all fixed and mobile hazards in the surrounding environment. A pilot therefore needs skills in navigation, experience in ship-handling, knowledge of the hazards, and wisdom to manage risks. The pilot will usually exercise control of the ship's navigation, issuing either direct helm orders ("conning") or directive instructions to the ship's crew.

Some of these responsibilities call for the application of skill using technology fitted in the ship or embarked with the pilot. The term "technology" here means applied technologies in the form of devices, installations or applications that aid the pilot's (and ship's officers') work. Some technologies will be resident in the port and accessed from onboard the ship. Others may be a function of overarching technical/administrative services established at a national or supra-national level. The pilot must be skilled in the use of all of these, so far as they are relevant to the task at hand.

In Canada, the *Pilotage Act* clearly sets out the role and responsibility of pilots. The *Act* states that no person other than a licensed pilot (or the holder of a pilotage certificate) may have conduct of a ship in a compulsory pilotage area. Canadian pilotage practice is for the pilot to exercise "conduct" of the ship through direct helm orders.[1] The person in command of a vessel, referred to as the master or the "captain of the ship", always retains command and full responsibility for their ship and crew. However, the <u>only</u> situation where a master could legally take conduct away from a pilot is if they have reasonable grounds to believe that the pilot's actions are endangering the safety of the ship. In this extremely rare instance, the master must file a report with the Minister of Transport within three days to set out the reasons.

[1] This is not universally the case as it is possible sometimes for the pilot to exercise their role through the Officer of the Watch. For example, on a ship with complex manoeuvring controls (dynamic positioning and/or azipods) the master may execute the alongside berthing with pilot assistance (as in handling tugs, if any). Such arrangements are the result of a detailed master-pilot exchange.

1.2 The Role of the Pilot

The role of the marine pilot is to cover the critical transitionary phase of the voyage which brings the ship from independent oceanic navigation through complex coastal and river environments and port approaches all the way to the berth. In Canada, delivery of pilotage service is performed locally by regional federal pilotage authorities. Pilots are licensed for specific pilotage areas by the Minister of Transport following rigorous training programs. Pilots in a region decide whether they want to be employed directly by the pilotage authorities or form local corporations that contract their services to authorities. Depending on the model that is chosen, pilotage authorities and local pilot corporations are responsible for: the recruitment and training of pilots, including periodic validation and upgrading; the timely assignment of pilots to meet a ship's requirements; the delivery of pilots onboard ships either by boat or helicopter, or at the berth; self-monitoring for identification and rectification of faults; and execution of risk management processes for evaluation of prospective changes to pilotage practices or regulation. Accordingly, authorities and pilots interface with many elements of the marine industry at local to national levels and sometimes beyond.

At the individual pilot/assignment level, the pilot's task involves three elements: planning, execution, and follow-up. In preparation for employment the licensed pilot must, of course, undergo apprenticeship, training and periodic refresher activity. The specific planning starts when an assignment is given for a particular ship and route. The pilot will collect information on the ship's characteristics, examine forecasts for weather and other environmental/hydrographic factors, and check for any Notices to Mariners regarding temporary hazards or obstructions to the passage. In the execution phase, pilots will use their expert knowledge of local waters and employ their own aids, such portable pilot units, as well as the available bridge resources (technological and human) to achieve a safe passage from boarding to disembarkation. And finally, as follow-up, the pilot will note and report on any aspects of the passage that yield lessons for other pilots or require Transport Canada or pilotage authority engagement with the local port or marine administration.

1.3 Developments in Navigational Technology Application

By the time the comprehensive 1968 Royal Commission on Pilotage was conducted, ship navigation technology had seen some key advances since the days of paper charts, magnetic compass and the sextant. The increasing accuracy and reliability of gyro-compasses had made error-prone magnetic compasses obsolete except as a backup. The widespread use of radar onboard ships, starting from the 1940s, enabled safer navigation in conditions of restricted visibility. Later, automatic radar plotting aid was added to help make sense of complex traffic situations by keeping track of objects the radar had picked up. VHF radio was in widespread use to allow ship-to-ship and ship-to-shore communication. To fix the ship's position, radio direction finding (RDF) and hyperbolic radio-fixing systems such as LORAN-A and DECCA were still considered the state-of-the-art in navigational technology. By triangulating the bearing of radio signal transmitters at known locations, the ship's navigator was able to fix the ship's position to an accuracy of approximately 1 nautical mile (nm), even in the open ocean. These radio-fixing aids simplified the navigator's problem of determining how far from land the ship was, but the accuracy of such systems was not adequate for precise coastal pilotage. The pilot's ability to direct the ship using landmarks and knowledge of local currents and hazards remained critically required skills.

The 1970s and 1980s saw rapid developments in safety regulations (International Convention on the Prevention of Collisions at Sea in 1972, amended in 1977) and in ship- and shore-based technology. Global attention was focused on the environmental consequences of shipping accidents by a number of high-profile and severely damaging groundings and oils spills. Notable examples among these were the 1967 SS Torrey Canyon grounding and spill of more than 100 million litres of oil on the south coast of the UK, and the 1978 Amoco Cadiz spill of 256 million litres of oil on the beaches of Brittany. In Canada, the groundings and spills of the SS Arrow (1970, 10 million litres) and SS Kurdistan (1979, 6 million litres) drew attention to shipping risks in Chedabucto Bay and Cabot Strait.

In response, Traffic Separation Schemes (TSS) were established worldwide, commencing in 1967 with the Dover Straits (mandatory in 1971) and now extending to all areas of major marine traffic confluence. TSS comprise one-way traffic lanes, separation zones, inshore traffic areas, deep-water routes, and meeting points (roundabouts). The routes established through the International Maritime Organization (IMO) and implemented through national regulation help to streamline traffic flow while reduce crossing and heads-on meeting situations, thus significantly reducing the risk of collision. The value of TSS continue to be recognized with new TSS being added each year to the list sanctioned by the IMO. The IMO established the TSS in the Strait of Juan de Fuca in 1981; Canada now has 5 mandatory and 7 recommended routing systems.[2]

In conjunction with TSS, Vessel Traffic Services (VTS) were established to provide oversight of vessel movements. This was pioneered in Liverpool and Rotterdam in 1949 and 1956, respectively, and was implemented in the busy Dover Straits in 1973. VTS were initially rudimentary, comprising manual radar surveillance and radio call-in points for ships to self-report position. In recent years VTS have been augmented by digital ship tracking and sophisticated computer algorithms for highlighting collision and grounding risks. Trained VTS operators aid safety of navigation by alerting ships to dangers and providing a critical interface with search and rescue and pollution response agencies.

[2] CCG, Annual Notices to Mariners 2023. https://www.notmar.gc.ca/publications/annual/annual-notices-to-mariners-eng.pdf

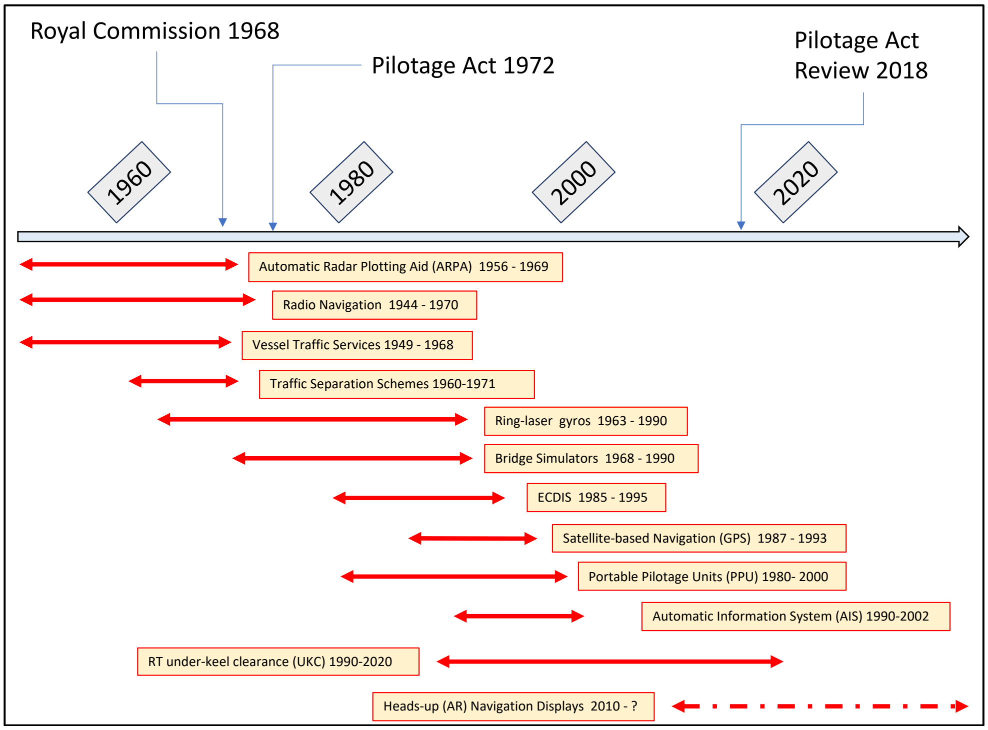

Figure 1: Representative timeline of navigation technology implementation[3]

Onboard the ship saw revolutionary changes in technology in this same period, starting with the development of satellite navigation systems in the 1970s. The US Navy's TRANSIT navigation system, capable of determining terrestrial positions by cross-fixing obtained from radio doppler-shifts, was made available for civilian use and then superseded in the 1980s by the more accurate Global Positioning System (GPS), which determines distance by precise time-differences. In the year 2000, all users were given access to the highest accuracy service when the military disabled a system they had been using to degrade accuracy for civilian users called Selective Availability. The increased accuracy led to the explosion of geographic information systems (GIS) and geo-referenced applications in all aspects of civilian life. Modern navigation systems now have access to American, European, Russian and Chinese[4] satellite constellations simultaneously which allows them to accurately fix positions to within less than 1 m. The combined constellation of technologies is referred to as Global Navigation Satellite Systems (GNSS).

The high degree of navigational precision provided by GNSS was complemented by the digitization of paper charts through electronic navigational charts. The combination creates the ability for mariners to precisely view their position in space on the chart through an Electronic Chart Display and Information System (ECDIS). The result is highly accurate, fully automatic electronic navigation available both commercially and recreationally.

[3] The red arrows signify initial introduction to common acceptance; in many cases (e.g., TSS) implementation continues as required.

[4] These systems of the European Union, Soviet Union/Russia, and People's Republic of China are known respectively as Galileo, GLONASS, and Bei-Dou.

Ships still had to rely on radar, radio communication or visual observations to detect other ships until the advent of Automatic Identification Systems (AIS). AIS is a system of automated VHF radio transmissions that exchanges key identification and navigational data between ships, such as ship name, IMO number, type of ship, destination, activity/status (underway, anchored, fishing, etc.) position, course, and speed. The information is displayed on the ship's navigation system (radar and/or ECDIS) as symbols with leaders to indicate true and relative movement. In this way the navigator is able to correlate ships with radar contacts, and to immediately identify them for bridge-to-bridge radio communications for collision avoidance. This same technology has also increased marine safety with the use of Virtual Aids to Navigation (VAtoN) to highlight navigational hazards or temporary exclusion zones. These are navigational warnings/dangers transmitted to ship's radar/chart plotters as symbols, showing apparent contacts through AIS technology without the need for a physical object like a warning buoy.

The cross-referencing of radar and geographic (charted) information on both radars and ECDIS, combined with AIS, gives navigators the ability to make risk assessments and decisions based on relatively accurate[5] and complete information, even in low visibility conditions. It is even possible for ships to follow planned tracks through the use of autopilots. Such autopilots can operate in three modes: course maintaining, track-following, and route-following. Most ships use the first, with the bridge watchkeeper making adjustments for track following, maintaining personal awareness of the ship's set and drift. Almost always in situations of critical pilotage or complex traffic, and in heavy seas, ship operators will revert to hand-steering for greater control and quicker response.

Communication technology also advanced significantly in the last few decades of the 20th century. Increasing prevalence of mobile phone data connections has created the opportunity for real-time acquisition of weather, wind, bathymetry, water-level and air-gap data through localized networks. Satellite communication initially opened the door to voice communication even when outside of the range of VHF radio. Increasingly, satellite communication is used for data. Lower-cost satellite internet brought about by low-earth orbit satellite technology (e.g. Starlink) means that modern ships can now have access to real-time data sources over extended ranges, subject to satellite coverage and service subscription.

The "baseline" of navigational equipment, what is considered standard in ocean-going ships, varies by tonnage. Table 1 summarizes required navigational equipment in accordance with Canada's Navigational Safety Regulations (NSR) 2020, which mirror the IMO's Safety of Life at Sea (SOLAS) Chapter V requirements.

[5] Note that both AIS and GPS may be subject to inaccuracies and spoofing (deliberate falsification), so prudent navigation and collision avoidance needs to consider all sources of information.

Table 1: Summary of Navigation Equipment (Source: NSR 2020)

Tonnage	<150 GT	>150 GT	>300 GT	>500 GT	>3000 GT	>10,000 GT	>50,000 GT
Steering magnetic compass	x	x	x	x	x	x	x
Gyrocompass		x	x	x	x	x	x
GNSS receiver		x	x	x	x	x	x
Pelorus		x	x	x	x	x	x
Spare magnetic compass		x	x	x	x	x	x
Daylight signalling lamp		x	x	x	x	x	x
Echo sounder			x	x	x	x	x
9 GHz radar			x	x	x	x	x
Speed log			x	x	x	x	x
Automatic radar plotting aid			x	x	x	x	x
Helm and engine repeaters				x	x	x	x
Second radar (3 or 9 GHz)					x	x	x
Autopilot						x	x
Rate of turn indicator							x
Voyage data recorder				Passenger	x	x	x
ECDIS				Passenger	x	x	x
AIS	Note 1	x	x	x	x	x	x
Two-way voice (radio)			x	x	x	x	x
Corrected charts and publications	Note 2	x	x	x	x	x	x
Notes	1	Vessels >20 m other than pleasure craft, and vessels with >50 passengers, towboats >8m, and vessels with hazardous cargoes					
	2	All vessels, but <100 GT may be exempt if master has local knowledge; may be electronic nautical charts					

The standard set of technologies varies depending on the tonnage of the ship. In some cases, pilots may be required to assist relatively small vessels, meaning the pilot may encounter a wide range of fitted navigational equipment. In BC for example the compulsory pilotage threshold of 350 GT of combined tonnage captures almost all coastal traffic including small tugs with large barges.[6] What is common today in even small ships – GPS, ECDIS, automatic radar plotting aid, AIS, autopilot, satellite communications and Internet connectivity – is a very significant step up from the mid-1960s, at which time even large ships were being navigated using paper charts with rudimentary radio navigation aids and hand-plotted collision-avoidance on simple radars.

[6] Subject to frequent local traders being able to obtain Pilotage Certificates or otherwise being able to "waive" mandatory pilotage requirements.

The trend in digitalization and connected technology seen in ships has also been mirrored in the technology deployed by the pilots themselves. Portable Pilotage Units (PPU) are personal tablet computers carried by the pilot; they do not replace traditional methods of pilotage but add an additional, real-time source of navigational precision. Pilots continue to use the ship's fitted equipment (gyros, radars, echo sounders, paper charts, etc.), augmented by visual navigation enabled by memorization of courses, leading marks, clearing bearings and other traditional pilotage methods. The key benefit of PPUs is the availability to the pilot of highly accurate position and navigation information that enables precise navigation independent of any possible faults or failures in the ship's fitted systems. With cellular telephone data connection or ship Wi-Fi, integrated live sources of current local hydrographic information such as water levels are possible.

In the remainder of this report, the following questions will be considered:

1. How to balance the required levels of personal, experiential or even traditional knowledge, and the highly objective, accurate, reliable and current information that is available through modern technology?
2. How this knowledge interfaces with the skills required to recognize and correct for faults or ineffective system responses or extreme conditions?
3. Under what conditions does safe navigation demand actual human execution of this function (or at least onboard monitoring and supervision) rather than automation or remote execution?

2.0 Pilotage Context in Canada

This section of the report presents the historical development and current situation of pilotage services in Canada. It is intended to provide context for the Section 3 discussion of comparable international pilotage jurisdictions and their adoption of technology.

2.1 Evolution of Pilotage in Canada

Prior to Canadian confederation in 1867, marine pilotage varied greatly across the country and was largely the responsibility of the provinces. Post confederation, marine pilotage became a federal responsibility. The first federal legislation was the *Pilotage Act* of 1873 and had its origins in the *1854 Merchant Shipping Act* of the United Kingdom.

This Act survived with small amendments until the 1968 Royal Commission on Pilotage. Between 1873 and the Royal Commission in 1968, pilotage was governed by various local commissions and in some cases by Transport Canada (TC). Even though pilotage services had changed dramatically since the inception of the original Pilotage Act, there were no major amendments during this time.

The 1968 Royal Commission was chaired by the Honourable Mr. Justice Yves Bernier and was an in-depth review of pilotage in Canada. The report from the Commission resulted in 38 recommendations and the findings were published in six volumes. The result was the *Pilotage Act* of 1972 which set up four federal crown corporations to act as regulators and administrators of the four pilotage areas in Canada.

Under the *Pilotage Act* of 1972, the areas of responsibility for the four Pilotage Authorities were established as follows:

- **Pacific Pilotage Authority** (PPA): area of responsibility includes all Canadian waters in and around the Province of British Columbia;

- **Great Lakes Pilotage Authority** (GLPA): encompasses all Canadian waters in the Province of Quebec, south of the northern entrance to St. Lambert Lock, and all Canadian waters in and around the Provinces of Ontario and Manitoba;

- **Laurentian Pilotage Authority** (LPA): covers all Canadian waters in and around the Province of Quebec, north of the northern entrance to St. Lambert Lock, except the waters of Chaleur Bay, south of Cap d'Espoir; and

- **Atlantic Pilotage Authority** (APA): includes all Canadian waters in and around the Provinces of Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland, including the waters of Chaleur Bay in the Province of Quebec, south of Cap d'Espoir in latitude 48 degrees 25 minutes 08 seconds N., longitude 64 degrees 19 minutes 06 seconds W.

It should be noted that since the inception of the first Pilotage Act in 1873, and up to and including the Pilotage Act of 1972, there was no mention of pilotage requirements in northern Canada. There was to this point very little traffic in the Canadian Arctic to justify such national oversight, with only 17 recorded transits of the Northwest Passage up to that year.[7] However, the common use of experienced Ice Navigators to enable such voyages constituted a *de facto* unregulated form of pilotage.[8]

Following the publication of the 1972 *Pilotage Act,* some of the formerly private pilotage groups moved to employee status while other groups chose to remain as private companies. The current breakdown of private and employee status is as follows:

- **Pacific Pilotage Authority**: there are two groups in this area, namely the BC Coast Pilots Ltd., a private company contracting their services to the Authority, and a group of employee pilots covering the Fraser River from Sand Heads to Silverdale near Mission, who work directly for the PPA;

- **Great Lakes Pilotage Authority**: all the pilots are employees of the GLPA;

- **Laurentian Pilotage Authority**: initially LPA had one group of employee pilots covering the Port of Montreal and two private organizations, namely the Corporation of Lower St. Lawrence Pilots and the Mid St-Lawrence Pilots Corporation. This changed to the present two groups in 2011 when the employee pilots opted to join the Mid St-Lawrence Corporation, with the result that all LPA pilots are contract pilots; and

- **Atlantic Pilotage Authority**: all of the pilots are employees working for the APA, except pilots serving Halifax harbour. In 2023 the Halifax Harbour Pilots elected to change their status and form a body corporate to contract their service to the regional authority.

Pilotage in Canada's four established Pilotage Regions has evolved differently to address localized risks of navigation. These differences are a function of marine traffic density, coastal navigation difficulty, state of hydrography, proximity of ports, availability of local knowledge/experience, local environmental hazards, and the differing challenges of coastal versus port, riverine/canal, or ice-infested navigation.

2.2 Pilotage Regulation in Canada

Pilotage in Canada is regulated at a national level by a number of legal statutes. At the highest level is the *Canada Shipping Act, 2001* (CSA), which governs safety of marine transportation and recreational boating, as well as protection of the marine environment. Like the *Pilotage Act* of 1873 the original CSA was based on the United Kingdom *Merchant Shipping Act*. While the CSA largely deals with ships and crewing and does not directly address pilots and piloting, the pilots nevertheless are subject to

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[7] Details compiled from Scott Polar Research Institute (SPRI, https://www.spri.cam.ac.uk) and TC/NORDREG stats. NORDREG is the ship reporting system covering Canada's polar waters.

[8] Until the implementation of the IMO Polar Code in 2017, this was loosely regulated through the requirement for certain ships to carry Ice Navigators who were recognized by Transport Canada as having in-ice experience. The Polar Code requirement for experience in Polar Waters (or TC's requirement for equivalent experience in ice) is incorporated in TC's adoption of IMO requirements for ship's officers to hold Certificates of Proficiency in Polar Waters.

parts of the CSA and the regulations that flow from the Act. The *Collision Regulations* (Canadian enactment of the IMO's *Convention on the International Regulations for Preventing Collisions at Sea*,1972 (COLREGs)) is one such example.

Separate from the CSA is the *Pilotage Act*. This provides the legislative framework for pilotage services in Canada by establishing the four Pilotage Authorities as Crown corporations and allowing for the possibility of pilots forming local pilot corporations.

In the most recent amendments, as a result of 2018 Pilotage Act Review recommendations, an important addition was Section 2, detailing the Purpose and Principles of pilotage services. As this section is such an integral part of pilotage services, it is reproduced here in full:

> *The purpose of this Act is to set out a framework for the provision of pilotage services in accordance with the following principles:*
>
> *(a) that pilotage services be provided in a manner that promotes and contributes to the safety of navigation, including the safety of the public and marine personnel, and that protects human health, property and the environment;*
> *(b) that pilotage services be provided in an efficient and cost-effective manner;*
> *(c) that risk management tools be used effectively and that evolving technologies be taken into consideration; and*
> *(d) that an Authority's pilotage charges be set at levels that allow the Authority to be financially self-sufficient*.

One of the most significant changes implemented following the 2018 Pilotage Act Review was the passing of the regulatory authority from the four Pilotage Authorities to the Minister of Transport. The Minister is also now responsible for the licensing of pilots, and ensuring compliance with the *Act*. TC has therefore assumed the oversight of the *Pilotage Act* and Regulations. The roles and responsibilities of the Authorities now focus essentially on service delivery.

TC is thus responsible for the establishment of regulations governing these aspects of pilotage:

a) establishing compulsory pilotage areas;
b) respecting which ships or classes of ships are subject to compulsory pilotage;
c) respecting waivers of compulsory pilotage;
d) respecting master-pilot exchanges;
e) respecting the classes of licences and classes of pilotage certificates;
f) respecting the qualifications and prerequisites that are required of an applicant for a licence;
g) respecting the examination of pilots;
h) respecting the conditions of a licence or pilotage certificate;
i) limiting the number of licences or classes of licences that may be issued;
j) respecting the information to be provided and the procedures and practices to be followed by a ship that is about to enter, leave or proceed within a compulsory pilotage area;
k) respecting the minimum number of licensed pilots or pilotage certificate holders that are required to be on board a ship;

l) respecting additional training and periodic medical examinations for licensed pilots and pilotage certificate holders;
m) respecting risk assessments;
n) respecting the development and implementation of management system; and
o) respecting fees and charges to be paid.

Due in large part to the significant differences in the local geography and levels of associated risk, there remain significant differences in the licensing and training programs in each Region. Nonetheless, they all have common elements of:

a) Basic prerequisite marine certification (Certificate of Competency);
b) Qualifying sea time experience (in area);
c) Entry written and oral examination; and
d) Apprenticeship training (including observer trips, crewed model training, simulator training and bridge resource management courses.

Responsibility for the matters above is shared between the pilotage authority and, where applicable, local pilot corporations. TC is now in the process of implementing new requirements for both entities to develop and implement formal initial and ongoing training programs and also to develop and maintain quality assurance systems. These responsibilities include advising TC, from time to time, regarding recommended changes to the *Pilotage Act* or Pilotage Regulations. In the case of necessary changes being identified (or of significant changes to operational pilotage practices), TC or the pilotage authority undertake a risk assessment to determine if this engenders any adverse impacts on safety. The process, guided by TC's Pilotage Risk Management Methodology (PRMM – TP13741 05/2010), involves all responsible parties and stakeholders in a subjective and/or numerical analysis of all relevant factors.

Port Authorities depend on the provision of pilotage services. The seventeen Canada Port Authorities, established under the Canada Marine Act (CMA) of 1998, operate at arm's length from the federal government. Like the Pilotage Authorities, they must be financially self-sufficient. The CMA governs Canadian ports so that they remain competitive, efficient and commercially oriented. In particular, the CMA establishes policies and regulation regarding:

a) provision of port infrastructure;
b) harmonization with international standards and practices;
c) provision of marine services at reasonable cost to users;
d) maintenance of a high level of safety and environmental protection;
e) provision of a high degree of autonomy to meet local needs and priorities;
f) management of infrastructure and services that incorporates input from the local community; and
g) coordination of marine activities with surface and air transportation systems.

Thus, although the provision of pilotage services is under the national oversight of TC, the guiding regulation for pilotage has evolved to meet the differing requirements of pilotage in different regions of Canada. Accordingly, the requirements for pilot licencing and the thresholds for mandatory pilotage vary region by region.

2.3 Regional Summaries of Pilotage Service Provision in Canada

This section of the report provides more details on vessel traffic and pilotage service delivery in the Pacific, Great Lakes, Saint Lawrence, Atlantic and Arctic regions of Canada.

Canada's ten largest ports handled 318 million tonnes of cargo in 2022 and are the major driver of large commercial vessels requiring pilotage services. These ports are ranked by volume of cargo handled in Table 2. Vancouver is the largest of these ports, accounting for 141.4 million tonnes in 2022, as much as all the top-ten east coast ports together.

Table 2: Top Ten Ports in Canada 2022 (Source: Ports' Annual Reports)

#	Port	Region	2022 (million tonnes)	2022 (%)
1	Vancouver, BC	Pacific	141.4	44.42%
2	Montreal, QC	St Lawrence	36	11.31%
3	Sept-Îles, QC	St Lawrence	33.4	10.49%
4	Quebec, QC	St Lawrence	27.7	8.70%
5	Saint John, NB	Atlantic	27.4	8.61%
6	Prince Rupert, BC	Pacific	24.6	7.73%
7	Hamilton, ON	Great Lakes	9.9	3.11%
8	Thunder Bay, ON	Great Lakes	8.2	2.58%
9	Halifax, NS	Atlantic	5.4	1.70%
10	Trois-Rivieres, QC	St Lawrence	4.3	1.35%
		Total (top 10)	318.3	100.00%

The four Canadian pilotage authorities together make up a $292.7 million enterprise. Pilotage authorities directly employ approximately 125 pilots while 325 pilots work for local pilot corporations that have service agreements with authorities. They manage some 52,400 ship movements a year – with a ship movement constituting a single point-to-point pilot assignment. The success rate, defined as movements where no incident was reported while under pilotage, was 99.92% for all pilotage authorities in 2022. Table 3 sets out the key statistics for each pilotage authority and the traffic that they manage. The most common vessel types are bulk carriers, oil/chemical tankers, and container ships.

Table 3: Pilotage Activity in Canada 2022 (Source: Pilotage Authorities' Annual Reports)

Pilotage Authority	LPA	PPA	GLPA	APA	Total	
Ship movements	22,115	12,896	9,315	8,079	52,405	
No. of incidents	18	8	14	2	42	
Success rate	99.92%	99.94%	99.85%	99.98%	99.92%	
Pilots on roll	204	130	67 (FTE)	49	450	
Revenue ('000s)	$108,177	$105,632	$46,000	$32,868	$292,677	
Vessel Type	LPA	PPA	GLPA	APA	Total #	%
Bulk	7,161	3,095	3,756	953	14,965	28.51%
Tankers	7,077	258	2,546	2,861	12,742	24.27%
Container	5,086	1,934	97	1,626	8,744	16.66%
General cargo	1,548	903	1,998	663	5,112	9.74%
Passenger	663	1,290	709	842	3,504	6.68%
Anchorage movements	0	3,095	0	0	3,095	5.90%
Other	221	1,676	111	361	2,370	4.51%
Ro-Ro & car carrier	442	645	0	201	1,288	2.45%
Tug and barge	0	0	98	306	404	0.77%
Supply ships	0	0	0	266	266	0.51%
Total	42.20%	24.61%	17.78%	15.42%	52,489	100.00%

Pacific Region

The Pacific region includes the first and sixth largest of Canada's ports (Vancouver and Prince Rupert). Nanaimo, Kitimat, Port Alberni, Victoria, and Stewart are also important ports within this region. The Pacific Pilotage Authority (PPA) is the pilotage authority.

The PPA has established a mandatory pilotage zone that extends from 5-30 NM of the coast, depending on location. The main pilot boarding stations are Victoria, Pine Island (north-end Vancouver Island), Cape Beale (for Port Alberni) and Triple Island (for Prince Rupert). The threshold for compulsory pilotage within this zone is 350 GT for commercial vessels or 500 GT for pleasure craft. In BC, this threshold applies to the combined tonnage of tugs with tows.[9]

Certain exceptions allow ships to be excused from pilotage. Vessels that are by statute "exempt" include warships and government ships (including US government ships <10,000 GT), and ferries. Compulsory pilotage may also be "waived" for ships in distress; medevacs; rescue and salvage operations; ships seeking a place of refuge (i.e.: for weather or damage); or ships proceeding to the pilot station. Ships may also be excused from taking a pilot if the master and/or mates hold a Pilotage Certificate.[10] A Pilotage Certificate is different from a Pilot License but requires a similar level of experience, training and examination. Pilotage Certificates are only available to Canadian citizens and permanent residents.

[9] These sections on compulsory pilotage thresholds are a paraphrase of the regulations for the purpose of general comparison and do not include all complexities and nuances of the Act and Regulations.

[10] Sometimes called a Pilot Exemption Certificate (PEC) in other jurisdictions.

Because of the number of US-flagged vessels regularly operating in the region and the restriction of the Pilotage Certificates to Canadians, the PPA instead usually makes use of a waiver system. This distinct "Waiver of Compulsory Pilotage" is provided to ships less than 10,000 GT in certain areas if the ship's officers meet general criteria of currency (generally 150 days at sea in the previous 18 months or 365 days in the previous 60 months), as well as experience in the geographic area for which the waiver is being sought, specified as a number of runs through the area. These are detailed in the GPR[11] and elaborated in PPA's "Waiver Standard of Care",[12] which establishes additional experiential, equipment and operational requirements for the six areas of PPA's region.

Shipping volumes on the west coast of Canada are expected to grow over the next five years with the addition of two major projects, namely: the Trans Mountain Expansion (TMX) project beginning operations in 2024 and the LNG Canada project likely beginning operations in 2025. Both of these projects will require two pilots to be on the bridge through a number of areas along the transit route. In the south the requirement is for two pilots to be on the bridge of tankers while transiting through the Port of Vancouver and then through Haro Strait and Boundary Pass. For the LNG project in Kitimat, ships could require up to four pilots due to length of passage as well as the requirement for two pilots to be on the bridge through many portions of the transit.

The overall expectation in the Pacific region is that vessel size will continue to grow. At present the largest container vessels being handled are 367 m but with the approval of the Roberts Bank Terminal 2 project, ships could increase to over 400 m in length.

The PPA 2023 – 2027 Corporate Plan notes, "The Authority remains involved in the Enhancing Cetacean Habitat and Observation (ECHO) Program, led by the Vancouver Fraser Port Authority since its inception in 2014." This program instituted a voluntary slowdown (11 knots maximum speed over ground) through Haro Strait and Boundary Pass during the months that the Southern Resident Killer Whales are present in the region.[13] The additional pilotage cost to shipowners from the slowdown (occasionally extending a 7-hour passage to more than 8 hours and requiring a two-pilot assignment) has been reimbursed through funding provided by TC.

Another recent technology-related initiative in the region is the Active Vessel Traffic Management[14] which began in 2021. This system interfaces with the Canadian Coast Guard's VTS by providing comprehensive scheduling to streamline ship movements through the port. It currently operates in the Second Narrows area of Vancouver harbour but in future could include management of the Gulf Islands anchorage areas, movements in the Fraser River, and authorized passage through the key chokepoint of First Narrows in Vancouver Harbour.

Great Lakes Region

The Great Lakes region incorporates the Canadian waters of the Saint Lawrence Seaway south of the St Lambert lock, and all Canadian waters in and around the provinces of Ontario and Manitoba, including

[11] GPR, Art 25.10(3)

[12] PPA Waivers "Standard of Care", https://www.ppa.gc.ca/pacific-pilotage-authority-ppa-waiver-standard-care

[13] Vancouver Fraser Port Authority, ECHO Programme, https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/

[14] Vancouver Fraser Port Authority, Active Vessel Traffic Management Program, https://www.portvancouver.com/marine-operations/avtm/

the port of Churchill. The responsible pilotage authority is the Great Lakes Pilotage Authority (GLPA). The GLPA area covers shared US and Canadian waters and includes two of Canada's top ten ports: Hamilton Oshawa (seventh largest) and Thunder Bay (eighth largest).

The pilotage region is divided into five districts, with pilot boarding stations associated with the locks dividing the districts at St Lambert Lock, Snell Lock (Massena, NY), Cape Vincent NY (Kingston, ON), Port Weller/Port Colborne, ON, and Sarnia, ON.

The threshold for compulsory pilotage in the Great Lakes area is 1500 GT for Canadian ships or 35 m for foreign ships. Tugs are exempt if under 1500 GT and not handling a tow greater than 80 m. Otherwise, standard conditions for waiving compulsory pilotage apply.

A particular aspect of the Great Lakes area is the cross-border nature of shipping routes. The Canadian regulations allow that an individual authorized to pilot a ship in the US waters of the Great Lakes may do so in the Canadian waters as far east as St Regis, PQ (near Cornwall),[15] and a reciprocal authorization is provided in US regulations.[16] An MOU between the US Coast Guard and GLPA[17] governs the sharing of pilotage dispatching, pilot boats and billing in three districts. In two of these, Canadian pilots mostly serve even-numbered ships while US pilots serve odd-numbered ships. In the third, the work is divided roughly 19% (Canada) and 81% (US). For vessels stopping in District 2, pilots serve the vessels bound for their own ports; for vessels proceeding between Canadian and US Great Lakes ports, pilots serve the ships departing their own ports and the handover to opposite pilots is managed by Detroit pilot boat.

Requirements for obtaining a Pilot Licence in the Great Lakes are similar to other regions (12 months as master or 24 months as deck officer), with 50 trips in the area. At this point, two options are offered to candidates. The first one is to challenge an examination in front of a board of examiners and the second is to complete a training program and pass a practical exam under the supervision of an approved evaluator. This program is currently being reviewed by Transport Canada.

Many GLPA customers have been recently using a Draft Information System (DIS) as a tool to provide their ships with better information about under-keel clearances. This program, which under the supervision of the St. Lawrence Seaway Management Corporation, is designed to safely enable increases in the vessel's draft when transiting in the St. Lawrence Seaway, which means a greater cargo carrying capacity thereby maximizing efficiency and profitability.

Vessel traffic management in the St Lawrence Seaway and Great Lakes is variously handled by the Great Lakes/St Lawrence Seaway System (GLSLSS) (St Lambert lock to Lake Erie), the CCG (Sarnia) and the USCG (St Mary River). The GLSLSS publishes the Seaway Handbook with all necessary instructions for transiting this portion, including communications and call-in points. The prioritization of ships through the locks is a function of Seaway internal protocols, where it is first-come-first-serve or Seaway Controllers designate the order of ships at the locks. Nonetheless, this occasionally results in congestion when traffic is heavy.

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[15] GPR Art 24.9

[16] Great Lakes Pilotage Regulations, Art 401.120, https://www.ecfr.gov/current/title-46/chapter-III/part-401/subpart-A

[17] https://www.dco.uscg.mil/Portals/9/DCO%20Documents/Office%20of%20Waterways%20and%20Ocean%20Policy/CG-WWM-2/2013%20MOU%20English.PDF?ver=2019-11-19-120352-133

Saint Lawrence Region

The Saint Lawrence region includes the second, third, fourth, and tenth largest ports in Canada (Montreal, Sept-Iles, Quebec and Trois-Rivieres). The pilotage authority is the Laurentian Pilotage Authority (LPA).

The LPA pilotage area extends from the Strait of Belle Isle to St Lambert lock in the St Lawrence Seaway, including the Magdalen Islands and Anticosti in the Gulf of St Lawrence as well as the Saguenay River. Apart from the nine key ports in this area, compulsory pilotage starts at Les Escoumins and extends to St Lambert lock. The compulsory pilotage area is covered by two pilotage corporations (service providers) with pilot exchange being managed by boat at Quebec for up-river traffic.

Compulsory pilotage in LPA's region is dictated by tonnage/length or cargo: Canadian ships greater than 70 m or 2400 GT in Districts 1 and 1.1 (upriver from Quebec) and 80 m or 3300 GT in District 2 (Les Escoumins to Quebec), or foreign ships greater than 35 m, as well as any barge or scow carrying polluting cargoes. Exceptions to pilotage are similar to the Pacific region, but also include fishing vessels and tugs if not towing/pushing barges. The LPA similarly allows pilotage to be waived for ships in distress and seeking refuge.

LPA has a system of four classes of Pilot License; entry is class D, with upwards promotion to class A with accumulated experience. Minimum qualification is specified in terms of experience as master/deck officer (2 years as master or 1+3 years as master/deck officer) which equates to a Master Near Coastal certificate. The *Pilotage Act* states that pilotage certificate applicants must have a similar level of knowledge of local waters as applicants for a pilot license. Transport Canada is reviewing the process with the objective of developing a program that is more aligned nationally.

The LPA 2023 – 2027 Corporate Plan states: "Over time, merchant vessels have become larger and traffic volumes tended to increase for many vessel types, even though there was a decline in 2020 and 2021. Because of this, the Authority has had to adapt its service delivery to be effective, efficient and safe. This adaptive process includes developing systems to improve the management of pilotage services, managing assignments to optimize transit under the conduct of a pilot, and implementing protocols or applications to help coordinate certain tasks." The Contrecoeur Container Terminal, 70 km south of Montreal, will boost the Port of Montreal's container capacity by 55% and is expected to contribute to the growth of traffic in this region.

With regard to technology, the LPA Corporate Plan states that the "LPA closely monitors technological changes in commercial navigation and is positioning itself to play a leadership role on pilotage related aspects. The LPA is examining how technologies and software currently being developed or already available would allow pilotage services and ship transits to be more efficient. Accordingly, the LPA is leading a development project to optimize ship transits under the conduct of a pilot. This project will also position the Authority to play a role in remote pilotage projects and the potential arrival of Marine Autonomous Surface Ships (MASS)." The Optimized Pilotage Services project, predicted for delivery in 2024, will seek to align pilot taskings and ship speeds with berth and anchorage availability to avoid congestion and unnecessary waits.[18] A related technological initiative is the LPA and Port of Montreal's

[18] Etienne Landry, (2023) LPA Brief to Shipping Federation's Mariners' Workshop

project in partnership with Global Spatial Technology Solutions Ltd. (GSTS) to create an AI-enabled tracking and optimization of oceanic transits for just-in-time ship arrivals based on berth availability.

Atlantic Region

The Atlantic Pilotage Authority (APA) is responsible for pilotage in all of Atlantic Canada which includes the fifth and nineth largest of Canada's ports: Saint John, NB and Halifax, NS. The area consists of 20 "compulsory pilotage areas", largely associated with ports and areas of navigational constraint such as Strait of Canso and Confederation Bridge. Pilot stations are specified accordingly.[19]

The specific ports and pilot boarding areas for the APA are as follows:

- Labrador: Voisey's Bay
- Newfoundland: Bay of Exploits, Humber Arm, Stephenville, Placentia Bay, Holyrood, St. John's
- Nova Scotia: Sydney, Bras d'Or Lakes, Strait of Canso, Sheet Harbour, Halifax
- New Brunswick: St. John, Miramichi, Belledune, Pugwash, Restigouche
- PEI: Charlottetown, Summerside, Confederation Bridge

In the APA region, compulsory pilotage is established for all foreign ships and Canadian ships over 1,500 GT or pleasure craft over 500 GT. The tonnage threshold applies to combined tonnage or tugs and tows, except in the case of more than one tow, in which case the threshold is 500 GT. Exemptions are similar to other pilotage regions but also include offshore supply vessels of 5,000 GT or less that are based in the region, fishing vessels, foreign pleasure craft of 500 GT or less, and foreign tugs of less than 500 GT if crewed by deck officers with Canadian licenses. APA also allows pilotage to be waived in the usual circumstances of urgent need, and provides for "Extended Waivers" of up to a year for vessels engaged in dredging, marine works or salvage.[20]

APA operates a system of graded licenses in three levels: Class A – over 40,000 GT; Class B – not over 40,000 GT; and Class C – not over 10,000 GT. Applicants for a pilot license or pilotage certificate must prove experience as master for 18 months or deck officer for 36 months, or one year each of such experience, or 20-60 trips in the pilotage area depending on role. APA provides that, on a case-by-case basis, a familiarization program may substitute for this prerequisite experience. Applicants for Pilotage Certificates must prove, in the 2 years before application, at least 12 one-way trips for major ports or 4 trips in other ports of the APA area. APA also requires a minimum number of trips over a two-year period as a condition of maintaining a licence or pilotage certificate. In all other ways, APA requirements for qualification and examination are similar to the other pilotage authorities.

Arctic

There is no pilotage authority responsible for Arctic pilotage, nor is there compulsory pilotage in the Canadian Arctic. The most northerly compulsory pilotage areas are Voisey's Bay, NL within the APA area, and the Port of Churchill, MB in the GLPA area. While neither Voisey's Bay nor Churchill are within the area defined by IMO as "polar waters" (above 60 degrees north in this area), they both are reached through waters that are ice-infested for most of the year.

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[19] See details in the APA website https://www.atlanticpilotage.com/operations/compulsory-areas/

[20] GPR Art 22.10

The Canadian Arctic has seen an increase in traffic over the past 20 years.[21] This is evident both in numbers of ship and numbers of voyages in Canadian polar waters. A record 11 passenger ships and 13 commercial vessels completed the full transit of the Northwest Passage in 2023. Though not in the top ten Canadian ports managed by Canada Port Authorities, the port at Milne Inlet has seen significant traffic growth due to the export of iron ore from Baffinland Iron Mines' Mary River Mine. In 2023, the mine produced a record 6.075 million tonnes of iron ore requiring 75 ships sailing to and from northern Baffin Island.[22]

In the latest Pilotage Act review,[23] 3 of the 38 recommendations directly address the issue of safety of navigation in northern Canada's Arctic region. Principal among these is:

> 27. *That Transport Canada, the Canadian Coast Guard, and the Canadian Hydrographic Services place a priority on an accelerated timeline to develop and implement the Low Impact Corridors management structure and assess the need for pilotage services as a possible mitigating measure identified by a robust Navigation Risk Assessment Methodology.*

It is significant that navigation in the North is not supported by formal pilotage requirements but only by Canada's adoption of the Polar Code requirements for advanced Polar Waters Certificates. The Polar Code requirement as adopted in Canada requires time in Polar Waters or equivalent time in ice-covered waters (which could be the Gulf of St Lawrence or the Great Lakes). Those gaining this experience in polar waters as Ice Navigators are in the best position to develop the knowledge of local geography and conditions that is at the heart of traditional pilotage.

Navigation in the North presents certain unique challenges. Communication is incomplete due to limited radio reception and satellite coverage. Hydrographic surveys for charts are incomplete. Although the Canadian Hydrographic Service is proceeding with a multi-year plan to complete higher resolution surveys with improved fidelity for primary and secondary corridors, several sources suggest that only a small percentage of Canadian Arctic waters are presently surveyed to modern standards. Crowd-sourced bathymetry may present a technology solution to improve this situation more rapidly.

The Northern Canada Vessel Traffic Services Zone Regulations (NORDREG) establishes protocols for VTS in the Arctic. It is configured primarily for safety and sovereignty monitoring rather than precise navigation oversight. Nothing in the Arctic is "real time", not the weather, the ice forecasts, or the ship tracking. Canadian Ice Service charts are often held up as definitive representations of ice conditions. However, an ice chart may be 12 hours out of date before it is available for shipboard use. A certain level of conservatism in interpretation is applied; real-time conditions may be more or less onerous than predicted as ice may have moved a considerable distance due to wind and current by the time charts are received.

Until hydrography is improved and reliable comprehensive satellite communication coverage is established for the Arctic, ships in the North have to be largely self-reliant. Ship-based technologies for detection of hazards like forward-looking echo sounders, high-definition radars, electro-optical detection of ice, radar image overlays for verification of position, and effective searchlights are the best

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[21] Scott Polar Research Institute, https://www.spri.cam.ac.uk/resources/infosheets/northwestpassage.pdf , and NORDREG stats to 2016.
[22] Baffinland Instagram, https://www.instagram.com/p/CzHVJexOrOD/
[23] Gregoire, 2018, S.6.4

measures for risk mitigation. High resolution synthetic aperture radar imagery from satellites, if available, can mitigate the latency in ice forecasts because they can visualise ice conditions independent of cloud cover. AI- and database-enabled prediction and assessment of risks also present emerging technology opportunities. Within the Arctic region, another emerging technology trend is the use of stand-alone, but compatible, Ice Navigation Systems that can link to and exchange voyage waypoint information with an ECDIS display. This allows for simultaneous viewing of high-resolution geo-referenced ice imagery and charts on a separate display to the chart information required for safe navigation.

3.0 International Comparable Pilotage Systems

The countries and states surveyed in this section of the report were selected because they have some aspects of pilotage in common with one or more of Canada's pilotage regions, or are representative of some leading innovations in the field. They may not be the highest volume comparators with Canada's pilotage regions, but they represent a variety of geographic types that include indented coasts, unique climatic conditions, remote areas or wide areas of compulsory pilotage.

3.1 Norway

The Norwegian Coastal Administration (NCA, "Kystverket", a government agency) is responsible for the Norwegian state pilotage service. All Norwegian state pilots are recruited, trained, certified and employed by the NCA.

Norway has a deeply indented coast that shares many similarities with the BC coast under the PPA. Norway enforces mandatory pilotage within its coastal baselines, which enclose large bodies of open water such as Vestfjord. This vast pilotage area (950 NM from SW to NE points) is serviced by 300 active pilots at dozens of pilot stations. Generally, all vessels of 70 m or more in length, or 20 m or more in breadth, are subject to compulsory pilotage, with inclusions of smaller vessels of certain categories such as passenger vessels, tugs, and certain hazardous cargoes, in which the vessel's length is 50 m or more (combined length for tugs and tows).[24] There are some exemptions for ships proceeding between pilot stations within the baselines, as well as military vessels, and harbour moves for smaller vessels.[25]

Norway operates a system of "Pilot Exemption Certificates" (PEC) which excuses ships from carrying a pilot so long as a PEC holder is on the bridge at all times. These certificates are applicable to all ships except nuclear-powered vessels and (generally) vessels of 150 m or more. There are three classes of PEC applying to ships less than 100 m, other ships, and (exceptionally, for Class 1 PEC) vessels 150 m or more in length. Each class of PEC requires qualifying time (for Class 2, this is one year as deck officer, with 12 voyages each way in the fairways for which the PEC is applicable, two of which are at night). Class 3 PEC requires the applicant's company to conduct a PEC training plan, while the requirement is more formalized for Class 2 PEC. In all cases the applicant must pass an exam. Notwithstanding the scope of the PEC system, it does not apply to certain classes and sizes of vessel (e.g., tows 100 m or more, and ships of 110 m or more carrying hazardous liquid cargoes).[26]

Norway operates a comprehensive traffic monitoring system within its exclusive economic zone (out to 200 NM from the coast) called NOR Vessel Traffic Service (NOR VTS). All tankers, vessels over 5,000 GT and ocean-going tugs outside of the territorial sea (12 nm) limit are requested to report to NOR VTS.[27]

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[24] https://www.kystverket.no/globalassets/ohm-regelverk/engelsk/02.2021_compulsory-pilotage-regulations.pdf

[25] https://www.kystverket.no/en/pilotage-service-and-pilotage-exemption-certificate/pilotage/compulsory-pilotage/ See also page 9 Map 2 in https://www.state.gov/wp-content/uploads/2020/08/LIS148-Norway.pdf, accessed 14 Feb 2024.

[26] https://www.kystverket.no/globalassets/ohm-regelverk/engelsk/02.2021_compulsory-pilotage-regulations.pdf; Annex 3 provides a detailed table of PEC restrictions by individual fairway.

[27] PB 182, Sailing Directions North and West Coasts of Norway. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwj9ltXU_cGEAxVxODQIHflcACYQFnoECBUQAQ&url=https%3A%2F%2Fmsi.nga.mil%2Fapi%2Fpublications%2Fdownload%3Fkey%3D16694491%2FSFH00000%2F

In addition, five distinct VTS areas are established with traffic separation schemes in the approaches to significant ports and terminals, which require compulsory participation of all ships greater than 24 m in length. Within these VTS areas, very detailed restrictions are defined by ship size and cargo for specific fairways.[28]

Norway has also been strongly engaged in future electronic nautical chart development, conducting S-102 demonstrations to advance charting technologies suitable for future pilotage needs.[29] Norway has some experience in remote pilotage, both in the common sense of providing guidance when the pilot is unable to board and in the more intentional situation of shore-based pilotage (SBP). As early as 2001 Det Norsk Veritas (DNV) outlined the prerequisites for SBP, subsequent to a test conducted from the Kvitsoy VTS station.[30] Recently, more traditional off-board direction was exercised during the pandemic to limit exposure of pilots.[31] A Norwegian company, Kongsberg, is a world leader in marine simulation and has been at the forefront in developing the visualization and control technologies to permit not only SBP but also remote control of ships. They have developed a video that is illustrative of what is imagined for the future of SBP.[32] The Norwegian company Massterly, in conjunction with Kongsberg, recently opened a Remote Operations Centre to monitor operations of its 80 m autonomous container vessel Yara Birkeland.[33] This is not, however, technology that is demonstrated or implemented in full-sized commercial vessels, nor is it technology that can be easily retrofitted in existing vessels.

3.2 Finland

Marine pilotage has been practiced officially in Finland for 320 years, with the aim of providing navigational safety within the tight channels and public fairways of the Finnish archipelago. Marine pilotage in Finland is provided by Finnpilot Pilotage Ltd, a state-owned special assignment company.

Pilotage in Finland is divided in these regions:

- Gulf of Finland, including the approaches to the ports of Helsinki, Kotka and Porvoo.
- Archipelago Sea Area covering the fairways along the southwestern coast of Finland.
- Bothnian Sea and Bay of Bothnia is an extensive area covering the northern and western coasts of Finland. It includes the Bothnian Sea, the Quark and the Bay of Bothnia as well as the ports within this zone.

In 2022, Finnpilot conducted 20,315 assignments with 132 pilots deployed from 11 pilot stations, in a pilotage region that stretches 370 NM south to north and 230 NM west to east.[34] Compulsory pilotage applies to all ships of 50 m in length and greater, as well as ships carrying specified hazardous cargoes. Exemptions are allowed for certain categories of ships and those whose officers hold Pilotage

Pub182bk.pdf&usg=AOvVaw1OxEF6UO-5sO1WLhpOm335&opi=89978449 , also NCA VTS, https://www.kystverket.no/en/navigation-and-monitoring/vts---vessel-traffic-service/sailing-rules/

[28] Norwegian Coastal Administration, https://kystinfo.no/share/7922ea57a15b

[29] S-102 Demonstrator Project, https://s102.no/operational-tests-results/kvitsoy-vts-operational-test/

[30] Hovda, 2021, 14

[31] https://marlog.no/en/making-history-with-remote-pilotage/

[32] Kongsberg Remote Operations Center, https://www.youtube.com/watch?v=UPtdgiIrlJI

[33] Autonomous Shipping Company Massterly Opens Operations Center in Norway, https://www.marinelink.com/news/autonomous-shipping-company-massterly-512079

[34] FinnPilot, https://finnpilot.fi/wp-content/uploads/2023/03/Finnpilot_annualreport_2022.pdf

Exemption Certificates.[35] Finnpilot's annual report for 2022 indicated 35% of ships in Finnish waters employed pilots.

Pilots require a pilot license granted by the Finnish Transport and Communications Agency (Traficom) to perform pilotage in specific fairways. While specific qualifications may vary, mariners holding the certificate of competency/service as master of a foreign-going vessel are eligible for this job. First Mates (foreign-going) or Dredge Mates Grade-I with at least two years of experience can also apply.

Finland is a leader in the continuing development of remote pilotage, largely due to government direction and changes to regulation in 2019 that facilitate permit-based remote pilotage. Finland is also participating in the development and testing of autonomous ships, employing similar oversight technologies that may enable remote pilotage. Notwithstanding this progress, the Pilotage Director of Finnpilot in 2022 concluded "Although various autonomous vessels have been tested in Finland and around the world for a few years now and we are at the international forefront in the development of remote pilotage, the implementation of remote pilotage itself is still years ahead."[36] More detail is provided in section 4.5.

Finland operates six VTS areas surrounding its coast. All ships of 24 m length and more are required to participate. Finland also cooperates with Estonia and Russia in GOFREP (Gulf of Finland Reporting system) which monitors traffic (all vessels 300 GT or more) in international waters; Helsinki Traffic covers Finnish, Tallinn Traffic covers Estonian and St Petersburg Traffic covers Russian areas of marine traffic. Finland has also implemented this system in territorial waters outside VTS jurisdiction.[37]

3.3 Denmark

DanPilot is the governmental pilotage service provider, conducting more than 20,000 assignments annually.[38] The "Act on DanPilot" was passed by the Danish Parliament in May 2013 to transform the pilotage service provider to an independent public enterprise with its own Board of Directors and independent economy. All pilots are approved and certified by the Danish Maritime Authority and all possess qualifications and experience earned while serving in the merchant marine service.

There are thirteen areas identified in the DanPilot guidelines on pilotage; the waters surrounding Greenland are in addition to that. The fundamental requirement for compulsory pilotage is related to carriage of hazardous cargoes, of which the basic threshold is 5 tons of bunker fuel. For cruise ships in Greenland waters, the threshold for compulsory pilotage is 250 passengers, but many smaller ships opt to take pilots as a matter of due diligence.

The waters between Denmark and Sweden are non-compulsory pilotage areas as a result of a centuries-old decree between the respective countries. This changed in 1985 with the issue of IMO

[35] Marine Regulations: https://www.marineregulations.news/finland-ministry-of-transport-and-communications-has-published-the-pilotage-act/

[36] Remote piloting test undertaken in Finland: https://smartmaritimenetwork.com/2022/05/20/remote-piloting-test-undertaken-in-finland/

[37] Fintraffic: https://www.fintraffic.fi/en/vts/masters-guide

[38] Information in this section comes from DanPilot and Danish Maritime Authority websites (https://www.danpilot.dk, https://dma.dk/safety-at-sea/safety-of-navigation/pilotage/rules-and-regulations) as well as interviews with senior DanPilot management.

Resolution A.579 (14) recommending that certain oil tankers, all chemical carriers and gas carriers, and ships carrying radioactive material using the sound that separates Sweden and Denmark should use pilotage services. The resolution also recommended pilotage for all vessels of more than 7 or 11 m draft, depending on route.

The pilots are equipped with PPUs, current electronic charts, and aids to ensure the best possible guidance. The pilots are online during the operation and can receive information from local authorities and DanPilot's service centre (staffed 24 hours a day) on navigational warnings and any other factors that might influence the safe passage of the vessel. Once the pilot embarks the vessel, the operation is planned in cooperation with the crew of the vessel so all demands and expectations by the customer are fulfilled, while simultaneously choosing the safest and most optimal route. The pilots also offer advice in cases where alternative shorter or safer routes exist.

DanPilot and the pilot service providers are jointly working on a project to introduce shore-based pilotage to the region. In the test phase at present, they put a pilot on board as well as a pilot in the "control centre" when conducting remote piloting on a vessel. The test project is taking place in the non-compulsory area of the waters between Denmark and Sweden and into the Baltic.

The present requirements for a vessel to participate in the remote piloting program are as follows:

- An area-specific risk assessment is conducted;
- The vessel has proven proficiency in English;
- The ship has an ECDIS with AIS;
- The vessel is able to stream its telemetry, including the onboard radar picture, to the control centre;
- The telemetry is taken from the voyage data recorder (VDR) and downloaded every few seconds or any period set up by the pilot engaged in the remote piloting operation. All the data accessed by the ship's VDR is sent to the SBP control centre; and
- The hardware that attaches to the VDR uses satellite communication to transmit the information to the shore-based piloting control centre and is one-way communication from the ship to the control centre. This one-way communication reduces the risk of cyber security issues. The cost of this hardware is about US $10,000.

The SBP control centre itself requires the following:

- A completed risk assessment;
- Access to the ship's telemetry, including the onboard radar picture;
- Clear and constant communication with the ship; and
- An ECDIS system with AIS.

At present the SBP control centre does not have access to a video on board the vessel being remotely piloted, but this will likely be coming. For now, it is as if the pilot is piloting in fog. Collision avoidance remains a responsibility of the onboard crew, with advice from the remote pilot, rather than the remote pilots maneuvering the ship. Given these limitations in the scheme, and the fact that the pilot does not exercise full "conduct" of the ship, it could be argued that this experiment in SBP only amounts to "navigational assistance."

DanPilots are specifically trained to provide remote navigational assistance from the SBP control centre. In addition to the usual pilotage requirements, they have to be clear communicators to give direction to the ship's crew by voice only; there are no visual clues such as body language. The remote pilot needs to communicate the plan so that the crew on board has the same mental picture of the transit and the vessel's progress. The program seems designed to enhance both the pilots' knowledge and skills (with the need for more effective communication) and that of the ship's crew as they learn the pilot's local knowledge and expertise to safely maneuver the vessel through the passage. In the Danish experience with remote pilotage, pilot costs remain the same, but anticipated savings could come from reduced travel, including pilot boat costs, and the increased pilot safety by not having to board in all weather conditions. This, however, is hypothetical as the test phase still has a "fail-safe" pilot embarked on the ship.

The Danpilots Professional Footprint Guide (2020)[39] indicates that the technologies they were considering at that time included Real Time Under-Keel Clearance, drone-assisted pilotage for better visibility, and remote-controlled tugs.

3.4 Chile

Marine pilotage in Chile covers three areas of a heavily indented coastline of 4300 km covering more than 800 NM of latitude, including the complex tidal channels of the Magellan Strait and Patagonia.[40] Pilots are dispatched from 8 pilot stations ranging from Chacao Channel (41 48S latitude) to Cape Horn (55 57S latitude).

The three pilotage areas are:

- Chiloé and Aysén Area: From latitude 41°45' South (Chacao Channel/Ancud) to 47°00' South (Golfo de Penas).
- Patagonian Area: From 47°00' South (Golfo de Penas) to the Strait of Magellan.
- Fuegian Area: From the Strait of Magellan to Cape Horn, including Isla Tierra del Fuego and the Fuegian channels. This last sheltered region is the most used passage to reach Antarctica.

Pilotage is compulsory for all foreign vessels navigating the inland waters of Chile south of the Chacao Channel. Certain vessels are not required to carry a pilot in the western part of Strait of Magellan. There are some specific draft and size restrictions for some of the routes.

In Chile, marine pilotage is regulated by the Chilean National Maritime Authority (also known as the Directorate General of the Maritime Territory and Merchant Marine, or Directemar). Chilean pilots are mariners with command experience, drawn from both naval and merchant marine backgrounds.

3.5 Australia

Australia has vast areas of oceanic responsibility surrounding a continental coastline of 34,000 km and dozens of ports, of which at least 10 may be considered major ports. Much of this area is considered

[39] https://danpilot.dk/media/1295/danpilot_professional_footprint.pdf
[40] Information in this section is taken from the Directemar Chile website, https://www.directemar.cl/directemar/site/edic/base/port/estrechodemagallanes_en.html#:~:text=Pilotage%20policy,Chacao%20Channel%20and%20Cape%20Horn, and https://www.findaport.com/country/chile. The more detailed reports are not available in English.

either ecologically sensitive or has particular navigational hazards (especially the shallow waters of the Great Barrier Reef and Torres Strait). Australia's top 10 ports aggregated 1,516 million tons of international freight in 2020-21.[41] In 1997, a lesser international trade of 478 million tons was managed in over 60,000 ship movements by 272 licensed pilots.[42]

Pilotage in Australia is mainly confined to ports and their approaches. In addition, compulsory coastal pilotage is required in five areas, namely:

- The Inner Route (from Cape York to Cairns)
- The Great Northeast Channel
- Hydrographers Passage
- Whitsundays (Whitsunday Passage, Whitsunday Group and Lindeman Group)
- The Torres Strait

Under the *Navigation Act of 2012*, ships over 70 m in length, loaded oil tankers, loaded chemical carriers, and loaded liquefied gas carriers (irrespective of length) are required to embark a licensed coastal pilot when transiting these areas.

The five coastal pilotage areas are regulated by the Australian Maritime Safety Authority while port pilots are licensed and regulated by state governments. Marine-Pilots.com lists 24 pilotage service providers in Australia. The Australasian Marine Pilots Institute (formerly the Australian MPI) was formed in 1989 to serve as a collective voice for these disparate organizations.[43]

All pilots are required to be able to work in Australia, hold the relevant qualifications and be medically fit. To be eligible to become a coastal pilot, a candidate is required to attend induction training, including approved courses such as approved pilot training and a bridge resource management course. As coastal pilots work in particularly sensitive areas, they need to have a high level of local knowledge to guide vessels of any size safely through these areas. For port pilots, the requirements vary across Australia but in general they will be required to hold a relevant marine certificate of competency, demonstrate their navigational expertise, and undergo the required training for that specific area.

In September 2023 the Australian Maritime Safety Authority announced it would undertake a comprehensive review of coastal pilotage.[44]

3.6 US (Alaska)

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[41] Australian Government: https://www.bitre.gov.au/sites/default/files/documents/Australian%20Sea%20Freight%202020-21.pdf

[42] AMPA: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjO2pvfsceDAxWMweYEHe4NBIsQFnoECBMQAQ&url=https%3A%2F%2Fwww.aph.gov.au%2Fparliamentary_business%2Fcommittees%2Fhouse_of_representatives_committees%3Furl%3Dcita%2Fmanfatigue%2Fsubmissions%2Fmfsub37.pdf&usg=AOvVaw0fFeHvfZWcCesH1IxebVH9&opi=89978449

[43] AMPI: https://ampi.org.au/about-us/

[44] Shipping Australia: https://www.shippingaustralia.com.au/under-the-microscope-amsa-announces-coastal-pilotage-review/, accessed 5 Jan 2024.

Alaska has a vast oceanic area that includes navigational challenges similar to the BC coast with the added challenge of ice-infested inlets, as well as a considerable polar waters domain that is inaccessible for much of the year and requires special expertise during the navigational season. Pilotage is compulsory for all vessels greater than 20 m (65 ft) length overall, although vessels less than 53 m (175 ft) may qualify for an exemption.

There are three regions in which marine pilots in Alaska can hold a license, namely:

- Area (1) Southeastern Alaska Region: the compulsory pilotage waters of Alaska commencing at the southern border with Canada, then west to and north on 141 degrees west longitude. This area is covered by the Southeast Alaska Pilots' Association.
- Area (2) Southcentral Alaska Region: the compulsory pilotage waters of Alaska commencing at the western boundary of the Southeastern Alaska pilotage region, then generally west to 156 degrees west longitude. This area is covered by the Southwest Alaska Pilots' Association.
- Area (3) Western Alaska Region: the compulsory pilotage waters of Alaska commencing at the western boundary of the Southcentral pilotage region, then west, north, and east to the northern border with Canada. This area is covered by the Alaska Marine Pilots, LLC.

Pilotage in Alaska is overseen by the State of Alaska through a Board of Marine Pilots. The Board of Marine Pilots is staffed by the Division of Corporations, Business, and Professional Licensing. The Board adopts regulations to carry out its mission to provide efficient and competent pilotage service for the protection of shipping, the safety of human life and property, and the protection of the marine environment.

To qualify to sit the pilotage exam, a candidate must hold a valid U.S. Coast Guard license as a master or mate of vessels of appropriate tonnage, have substantial experience in navigating Alaskan waters, and pass written and oral examinations conducted by the Board to test knowledge of Alaskan waters, navigation, and safety procedures.

Upon passing the exams, the candidate will serve as an apprentice pilot working alongside experienced pilots to gain further knowledge and practical experience. This includes completing a training program approved by the Board and undergoing regular assessments to ensure competence. After successful completion of the apprenticeship and training, the apprentice will receive an Alaska Marine Pilot License. Once licensed, the pilot must stay updated on regulations, technology, and safety practice, and attend workshops, seminars, and refresher courses. There is also ongoing evaluation, with the Board periodically evaluating pilots to maintain high standards.

The research conducted for this project indicates that the technology used by Alaskan pilots is consistent with common practice in Canada.

3.7 Summary of Comparative Pilotage Authorities and Operations

The scope and size of compulsory marine pilotage areas varies widely by jurisdiction. The fundamental commonality is harbour pilotage; with some variation of tonnage and hazardous cargo thresholds, this requirement is almost universal for ships flagged to countries other than the coastal state. Harbour pilotage usually applies to limited areas.

Thresholds for compulsory pilotage generally fall in the range of 500-1,500 GT, or 35-70 m in length. Military and government ships (and sometimes fishing vessels) are commonly exempted from pilotage, and certain situations of extremis (distress, rescue, seeking refuge) may allow pilotage to be "waived".

All jurisdictions have criteria and schemes for the licensing of pilots, usually based on an expectation of several years of command experience in the geographic area with examination, training and apprentice programs following. Almost all jurisdictions also have schemes for the issue of Pilotage (Exemption) Certificates to mariners who satisfy certain conditions of qualifications and local experience.

Apart from harbour areas, coastal pilotage can be and is frequently mandated for extended navigational approaches to ports. Usually the scope of these areas aligns with waters under the exclusive control of the state, referred to as "territorial sea", up to 12 NM from shore. This is basis on which extensive coastal pilotage requirements are established in BC, Alaska, Chile and Norway. Some of these areas cover large open-water straits and sounds. A further category of non-compulsory pilotage is "deep sea pilotage", in which non-state enterprises offer experienced mariners to assist with passage planning and conduct in busy areas such as the English Channel.

In some cases (Denmark and Turkey being prime examples), the right to impose compulsory pilotage is limited by the right of "innocent passage" which permits ships to conduct without impediment "continuous and expeditious" transits of territorial waters connecting two regions of the high seas. In such cases, pilotage may be strongly advised or recommended by the coastal state and the International Maritime Organization but not enforced except in limited cases of hazardous cargoes.

This right of innocent passage contends with opposing value of environmental protection in several instances. The Torres Strait is such a case in which Australia's imposition of compulsory pilotage supported the stewardship requirements of a designated Particularly Sensitive Sea Area at the expense of freedom of navigation and was thus controversial. The extension of compulsory pilotage to large areas of the Canadian Arctic would engender similar objectives and opposition, not least of which because the status of areas Canada regards as "internal waters" is disputed by other maritime nations.

In terms of technological innovation in pilotage, it appears that Denmark and Finland are leading among the countries surveyed for this study.[45] Both are heavily involved in preparing for discretionary shore-based piloting, and Finland is actively engaged in preparing for autonomous shipping. Sweden, while not explicitly researched for this study, is similarly involved in cooperative EU/Baltic structures of information exchange and traffic monitoring. Sea Traffic Management (STM) and the related Mona Lisa 2.0 project are exemplary initiatives of the Swedish Maritime Administration in this domain, but these now seem mainly related to exchange of passage (sailing) plans.[46]

There are several reasons why these Baltic countries may be more advanced than Canada in SBP/MASS: ecological concern for the Baltic has provided multi-national collaboration for improvement, and the

[45] Japan also appears to be leading in marine innovation, particularly MASS, but was not part of our comparison of pilotage regimes.
[46] STM: https://www.seatrafficmanagement.info/projects/monalisa-2/

unified efforts of European states through the European Maritime Safety Agency (EMSA[47]) provides significant political, scientific, and financial support for innovation in this limited geographic area of the Baltic. EMSA released a report in Dec 2023[48] that might constitute the most elaborate attempt yet to describe "the effective functioning of a future remote operations centre". Even so, the report implicitly recognizes through its hypothetical test cases that the practical scaling of technology to commercially viable size does not presently exist.

Despite innovation in many different countries, neither Denmark, Finland nor the other comparative nations employ technologies for crewed pilotage that are strikingly different from Canada's common practice.

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[47] EMSA: https://www.emsa.europa.eu/about.html

[48] EMSA: Identification of Competences for MASS Operators in Remote Operation Centres https://www.emsa.europa.eu/newsroom/latest-news/item/5089-cmoroc-mass.html

4.0 Technology Catalogue

This section of the report presents the full catalogue of navigational technologies considered as part of this research and is categorised according to the methodology defined below. The technologies are summarised in a matrix in Section 4.2 and the full catalogue is provided in Section 4.3. The technologies will be further analysed for their potential for improving pilotage in Section 5.

4.1 Methodology

A survey of the pilotage regions of Canada and several international comparatives provided insight into the use of technology in each region that contributes to the efficiency and effectiveness (safety) of marine pilotage. The technologies encountered were categorized according to three criteria:

1. What pilotage function does the technology assist?
2. At what organizational level is the technology introduced or implemented?
3. How mature is this technology and how widely accepted is it?

These three criteria are defined in more detail below and provide a way to organize the technologies for presentation in the summary matrix in Section 4.2 and the catalogue in Section 4.3.

4.1.1 Pilotage Functions

The marine pilot must apply a wide variety of information from different sources to accomplish a recognized set of functions. These functions can be divided into four distinct domains:

1. **Position/movement:** meaning the current and predicted future location of the ship;
2. **Environmental:** meaning all the aspects of the surrounding water, air and land environment that comprise the medium in which the ship moves, and includes both fixed and mobile hazards (i.e.: other vessels);
3. **Control:** meaning the functions available to the ship's officers and pilot to change the ship's course, speed, attitude or trim/draft; and
4. **Risk Assessment:** meaning the processes (intellectual or technical) through which the pilot recognizes and prioritizes hazards, then decides upon actions to mitigate risk.

The pilot needs to consider these functions in both planning and execution, which demands technical support/information in both non-real-time, like forecasts or plans, and real time, like instantaneous information on actual conditions at time of execution. Technological supports or tools can assist the pilot in accessing the baseline information/knowledge, helping to visualize a complex situation, providing prompts or warnings of imminent hazards, and streamlining the decision-making process for managing risks. The current state of technology provides such support along a spectrum of automation, from manual operation requiring the pilot to define and positively select actions, to fully automatic functions in which AI-enabled machines evaluate the situation and implement actions subject only to veto by the embarked pilot (or remote operators).

4.1.2 Organizational Level

The technologies considered may be applicable in multiple phases of navigation, from oceanic transits through landfall and coastal navigation to port entry and berthing. The technologies may be fitted in the ship and available to the ship's officers in the absence of the pilot, while others may be specialized equipment, communications and information sources that the pilot brings onboard. Still others require implementation through complex shore-based systems.

The candidate technologies have been categorized according to the organizational level at which technologies can be provided or applied. For example, some technological improvements may be implemented locally (e.g., real-time water-level reporting), while others require national coordination, standardization or services (e.g., improved hydrographic surveys). The organizational levels for implementation of technology organized from simplest to most complex are:

1. **Pilots:** technology that is brought onboard by the pilot, with the approval/support of the Pilotage Authority;
2. **Ships:** technology that is installed by the shipowner/operator, or is an attribute of the ship's design and construction;
3. **Port/Pilotage Authority:** technology that is installed ashore by local authorities for the benefit of ships and pilots in that area;
4. **State:** technology that is implemented at a national level or is the result of national development, standardization or production;
5. **IMO:** technology that is installed due to international convention and standardization.

4.1.3 Technology Maturity

The technologies were further assessed based on the level of development or acceptance. The three categories developed for this purpose were:

1. **Baseline:** technology that by convention or statute is virtually guaranteed to be available;
2. **Enhancing:** technology that is commonly available and will be used by most modern pilotage and port authorities; and
3. **Emerging:** technology that exists in either concept or technical demonstrations, but has not been deployed widely in commercial production or common use.

4.2 Summary of Results

The complete set of baseline, enhancing and emerging technologies collected through this research is presented in Table 4. They were selected for their potential relevance to the safety and efficiency of pilotage service delivery. In this table, technologies in black font are considered "baseline" (BL), those in blue are "enhancing" (EH), and those in red are "emerging" (EM). In Section 4.3, these technologies are all numbered sequentially as shown in Table 4, and annotated BL, EH, EM as appropriate.

The technologies have been categorised by the primary pilotage function (position/movement, environment, control, risk) that they address, and by the organizational level within the pilotage system (pilot, ship, port, state, IMO) they are implemented or provided. The "ship" category contains technologies available to both ship's officers and the marine pilot when embarked. Those in the "ports" category are implemented at a regional level and provide benefit for all ships and pilots operating in that area.

Table 4: Baseline/Enhancing/Emerging Technologies

		Functional Area			
		Pos/Mov	Envir	Control	Risk
Implentation Level	Pilot	2. Portable Pilotage Units		32. Portable Digital VHF	52. GIS for Ice Risk Assessment
		3. Navigation Software			53. Mobile AI App for Ice
		4. Pilot Plug			
		6. ROT Generator			
		7. RTK Positioning			
	Ship	5. ECDIS	12. AIS	36. Autopilots	48. Radar
		8. Indep. Advanced Position	18. Optimum Ship Routing	37. Bridge Dials	49. ARPA
		9. Heads-up/AR Display	24. Wave Analyzer Display	39. Voyage Data Recorder	51. RT UKC
			27. Forward-looking E/S	41. Dynamic Positioning	54. AI Collision Avoidance
			28. 3-D Display of Bathymetry	42. Improved Pilot Ladders	50. Echo Sounders
			29. mm Wave Radar	45. Ergonomic Bridges	
			30. E/O Detection of Hazards	46. Automatic Berthing	
	Port	10. AI Ship Scheduling	13. VAtoN	33. Tractor/Tethered Tugs	
			14. VTS	34. FMB Simulators	
			15. VTMS	35. Manned Model Training	
			16. Internet Connectivity	38. Pilot Assignment Software	
			17. e-Navigation Portals	40. Pier/Fender Systems	
			19. RT Water Levels	43. Helicopter Pilot Delivery	
			20. RT Air Draft	44. VSTOL Pilot Vehicles	
			22. RT Bathymetry	47. Control Ctr for MASS/RP	
			21. RT Tidal Current		
			23. RT Wind and Sea		
			25. RT Marine Mammal Detect		
	State	1. GPS/GNSS (DGPS)	26. Crowd-sourced Bathymetry		55. Comprehensive Risk Assess.
	IMO		11. S-57 ENC		
			31. S-100 Series ENC		

4.3 Catalogue of Technology

4.3.1 Position/Movement

1. GPS/GNSS (BL)

These systems comprise the modern standard of ship position-finding and movement reckoning. While all ships retain the ability to "fix" the ship by astronomical means, cross-bearings of terrestrial marks,[49] and/or radar-range plotting, in practice modern ships rely almost exclusively on GPS/GNSS-determined positions. Future position may be determined by "dead-reckoning" from onboard gyroscopic[50] or magnetic compasses with speed from electro-

[49] This is achieved using the pelorus, which positions an azimuth ring above a gyro- or magnetic compass-repeater for establishing position-lines from horizontal "true" or "compass" bearings.

[50] A more sophisticated device is the ring-laser-gyro (RLG), but their use is usually limited to naval platforms. Note that most gyro systems today are linked to transmitting magnetic compasses and will generate alarms if the gyro wanders from the corresponding corrected compass course (i.e.: magnetic course +/- variation and deviation.) This of course is subject to the stability of the magnetic compass and may therefore alarm uselessly in areas of weak or disturbed magnetic field (such as the polar regions).

magnetic or doppler "logs", but in common practice the ship's progress is determined by GPS/GNSS-derived course-over-ground or speed-over-ground and rate of turn. GPS (single source) is vulnerable to being "spoofed", "jammed", or otherwise corrupted by hostile electronic interference; this vulnerability is reduced with multi-source GNSS. In this report, the term GPS is used to denote a generic satellite-derived position.

2. **Portable Pilotage Unit (BL)**
PPUs are tablet-sized personal computers that combine the key functions of an ECDIS in a portable format. These are provided by pilotage authorities and pilot corporations, as applicable, and carried onboard by the pilots. They enable the pilot to bring their own passage plan and to operate independently of the ship's systems. PPUs can either be bespoke hardware and software, or common platforms such as an iPad. They have independent GPS receivers and contain approved charts for the pilot's licence area. They frequently also provide more refined bathymetric data such as berth surveys, a level of detail not available in standard electronic nautical charts. A PPU combined with precise positioning by GPS is a powerful tool that augments but does not replace the pilot's traditional methods of navigation.

3. **Navigation Software (BL)**
Specialized software is produced to run on PPUs and provide the advanced navigational functions desired by pilots. Some may be bespoke products for certain clients, or it may be more widely available as a commercial software. BC Coast Pilots use a product developed by NAVSIM, while other commonly used systems are produced by Wartsila, TRANSAS, and SEAiq.

4. **Pilot Plug (BL)**
Pilot plugs are WIFI- or Bluetooth-enabled devices that plug into a special port on the ship's navigation console or bridge-front. Through this connection the pilots may receive on their PPUs the ship's data concerning heading, speed, rate of turn, AIS contacts, etc. Note here that the rate of turn may be taken from the ship's system directly or the PPU may differentiate ship's heading changes to derive this.[51] Connections to the ship's systems may not be available in smaller, non-commercial ships. A pilot plug may also provide an independent source of position as described previously in item 1.

5. **Electronic Chart Display and Information Systems (ECDIS) (BL)**
Electronic chart plotters are common in modern vessels, from commercial to recreational. ECS (Electronic Charting Systems) is a general term while ECDIS are formally defined as meeting IMO standards of redundant, fail-safe positional inputs and approved electronic charts (see below). These systems incorporate the significant advantages of being able to save and modify previous routes, adjust range scales to use, seamlessly "quilt" adjoining charts, and provide a host of detailed voyage-planning functions like estimated time of arrival to waypoints or speed required. Ships meeting the requirements for ECDIS and having approved electronic charts for their area of operations may be exempt from the requirement to carry paper equivalents. Many ECDIS are fitted with Radar Image Overlay capability. This is the ability to overlay the radar image on the electronic chart. This serves the purpose of quick verification of the GPS accuracy (by matching of coastlines), and also allows quick correlation of radar contacts with charted objects like an isolated rock or a buoy. As simple and useful as this sounds, it is not a universal

[51] Pilots do not generally rely on Rate of Turn information from the ship's system through the pilot plug as this is too imprecise.

function in ships' ECDIS. Radar Image Overlay is a function limited to ship's systems and does not transfer to pilots' PPUs. ECDIS also incorporates a number of risk or warning functions, such as the display and alarm features of a "grounding cone", an area defined by user in terms of minutes ahead of the ship, allowing enough time to alter or stop the vessel.

6. **Rate of Turn Generator (EH)**
   A rate of turn generator provides more accurate independent information on how the ship is responding to steering inputs. Instead of the conventional analog gyroscopic device fitted on most ships, advanced rate of turn generators are small devices carried by pilots and use micro-electromechanical systems technology commonly used in smart phones to precisely measure changes in the motion of the ship. The device not only calculates the rate of change in heading, but also provides pitch, roll, heave, sway and surge measurements. This input to the pilot's PPU is preferred over ship-generated rate of turn data.

7. **Real-Time Kinematics Positioning (BL)**
   Real-time kinematics provides even greater accuracy and robustness to GPS/GNSS positioning through positional comparison with reference data. It reduces environmental effects, like passing under a bridge, and protects against spoofing. The real-time kinematics unit is a portable device that the pilot brings to interface wirelessly with their PPU. This technology has largely displaced locally-based differential GPS services. Real-time kinematics generally operates on short baselines and is applicable to limited area, high-precision needs. More widespread reference data can be provided through Wide Area Augmentation Services or Satellite-Based Augmentation Service to provide sub-30 cm accuracy. In the future, such advanced positional corrections may be provided worldwide through satellite-based VHF Data Exchange System (VDES).

8. **Independent Advanced Positioning (EH)**
   Highly accurate positioning systems are available for specialized use such as hydrographic surveying. The Canadian Hydrographic Service's (CHS) system of choice for positional accuracy is the Applanix POS MV, which provides lat./long. to 7 places (cm-level precision) under dynamic conditions with 6 degrees of freedom/orientation.[52] While this does not have direct utility to pilotage, it does speak to the increasing precision of geophysical mapping and positioning.

9. **Heads-up/Augmented Reality Displays (EM)**
   Heads-up displays have been available to the aviation and automotive sectors for some time but have only recently been studied seriously for marine application.[53] This technology has applications in positional, environment and risk-assessment functions so is best addressed here as a platform for these other functions. Approaches to marine heads-up displays to date have been focused on either augmented reality headsets or some manner of fixed display (i.e., projection onto the bridge windows). The first case has the advantage of being something the pilot can bring onboard, while the latter requires prior investment and installation by the shipowner. The second approach consists of three elements: a computer to combine information, a projector to cast the image, and a "combiner" or surface on which the image is

[52] https://www.applanix.com/products/posmv.htm
[53] Holder and Pecota. 2011.

projected. The particular display technology is variously described/defined as: Maritime Augmented Reality or Head-mounted Display Optical Pass Through.[54]

Figure 2. Notional Heads-up Display (Source: Wollebaek[55])

Depending on the approach taken, viewability of the image may be constrained by the pilot's position in the bridge, the field of view, and the contrast (i.e., the pilot must be able to view simultaneously the image — virtual reality — and the actuality beyond the windows.) The simultaneous viewing of augmented or plain reality may be an issue with head-set approaches. In addition, the pilot must be able to access other bridge information (radar, automatic radar plotting aid, helm and position/movement data) which may not be included in the heads-up display.

A key issue for heads-up display in the maritime environment is what and how much data to display. "Cluttering" is a significant issue in situational awareness displays. Is the heads-up display to augment visibility in low light or restricted visibility situations? Is it to highlight safe navigational areas for close coastal pilotage? Should it be used as a decision aid for highlighting or ranking potential manoeuvres to resolve a COLREGs situation?[56] And in each of these, how much information does it need to display: ship position, course and speed, helm and engine orders, identity of surrounding objects/vessels, relative risk warnings, etc.? The challenge is two-fold: what to display, and how to display it.

A different approach is to produce a virtual bridge-window view with the use of a visual camera feed overlaid with information from ECDIS, AIS, radar and collision avoidance apps. Presented on a separate bridge monitor (or even the pilot's PPU), this display would provide an enhanced situational awareness without obscuring the real-world view. This is the approach taken by Furuno's Augmented Reality Navigation System (Figure 3). Implementing such a system either requires the pilot to import the visual sensor or for this to be a standard fitment in ships. The

[54] Laera et al. 2021.
[55] Wollebeck, 2014.
[56] Szlapczynski, 2015.

display itself would have to be an advanced feature of the PPU or an additional fit in the ship, in both cases needing to interface with the ship's AIS/VDR data stream.

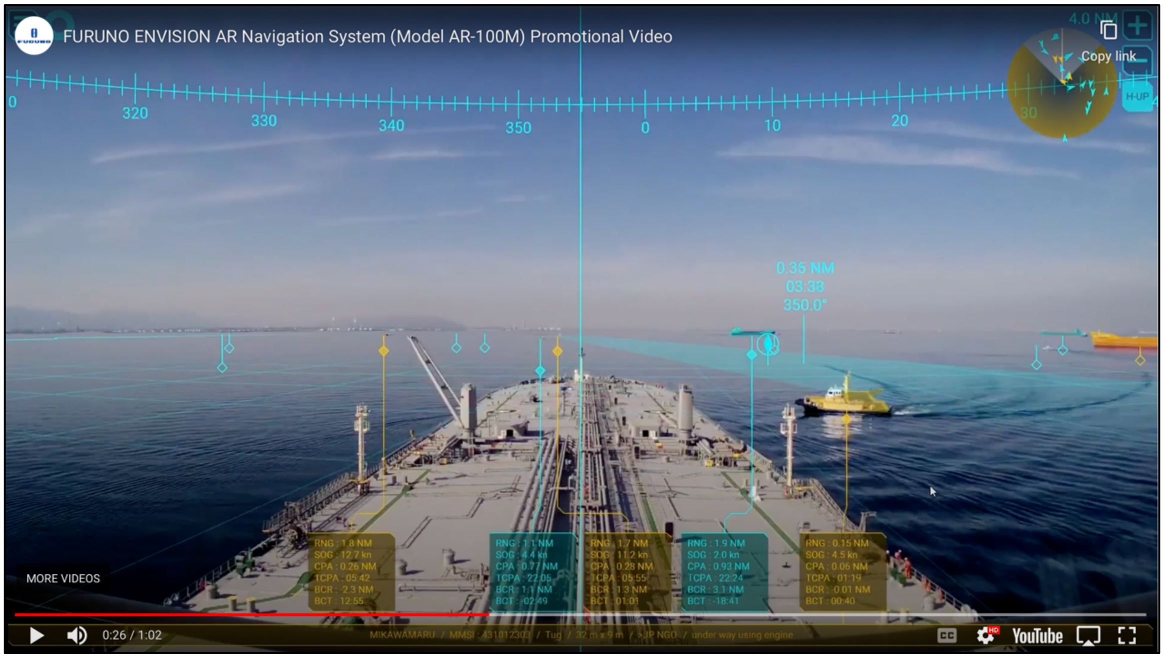

Figure 3: Furuno's Augmented Reality Navigation Concept (Source: Furuno[57])

10. **AI-driven Ship Scheduling (EM)**
Advances in remote sensing of ships, through satellite monitoring of AIS or other electronic emissions, paired with AI analysis of movement and refinements of route optimisation methodologies, provide the opportunity for ports to more precisely forecast ship arrivals and queuing for berth availabilities. This will have the advantage of fuel economies and reduction of greenhouse gases enroute, reduced dwell-time in port anchorages, and more efficient pilot utility in direct sea-to-berth transits, with gains accruing to ports, pilotage authorities and ship operators. In Canada, Global Spatial Technology Solutions (GSTS) in Halifax, NS is pioneering this technology through a platform called Ociana.[58]

4.3.2 Environment

11. **S-57 Electronic Nautical Charts (BL)**
S-57 is the common standard of electronic navigational chart (ENC) data established by the International Hydrographic Organization (IHO) in 1992. These are vector-formatted charts and replace raster images made to the BSB format.[59] Raster charts are simply georeferenced images of paper charts and do not adjust to the user's scale selection. S-57 ENCs are scalable and compiled of standardized layers of information compatible with the Coordinate Reference

[57] https://www.furuno.com/special/en/envision/

[58] GSTS Ociana Port Otimizer, https://gsts.ca/wp-content/uploads/2023/06/GSTS-Port-Optimiser-Brochure.pdf. Disclosure: Nigel Greenwood and Kevin Obermeyer are Board Members of GSTS.

[59] The BSB File Format was developed by Maptech, Inc. to describe and store raster image data and associated textual documentation.

System[60] of the associated GPS. A principal advantage of vector charts is that layers can be selected or deselected to "de-clutter" the plot, and depth-shading and associated alarms can be tailored to the user-ship's draft.

12. **Automatic Identification System (BL)**
AIS is a means of transmitting ship identification, position and movement data between ships, and between ships and shore. It operates in the Very High Frequency (VHF) radio spectrum, which provides line-of-sight communications (effectively horizon range, unless repeated from elevated relay stations or buoy-mounted devices). The transmitted information may include: the ship's unique Maritime Mobile Service Identity (MMSI) number, ship name, position, course, speed, destination, status (e.g., fishing, anchored, underway) among other details. Participating units both transmit and receive; the received information is plotted directly as symbology on radars and ECDIS and is thus helpful both to ships and shore authorities for collision avoidance, security, and environmental monitoring.[61] Full capabilities are provided by Class A AIS equipment; more limited functions are provided by Class B. Some recreational vessels may receive but not transmit on AIS.

AIS signals transmitted by ships can also be picked up on satellite receivers and relayed to ground stations. A significant industry for the analysis of current and historical AIS data aggregated from satellite and terrestrial receivers is developing to serve the needs of maritime security, commercial efficiency and environmental monitoring. Examples include the popular MarineTraffic.com app or the Ociana web app developed by Canada's GSTS.

13. **Virtual Aids to Navigation (EH)**
VAtoN are AIS-generated symbols that convey additional navigation information to AIS-fitted ships. VAtoN may be supplementary to existing physical aids (say, amplifying changeable information on a buoy) or a virtual warning of a temporary danger or exclusion area like marking the location of a sailing race.

14. **Vessel Traffic Management Systems (EH)**
VTMS is the technical enabler for vessel traffic services. What started historically with simple radar displays, radio communications and manual counts of traffic movement through reporting points has evolved to include computer-aided automatic tracking of ships by way of radar, AIS, and electro-optical sensors. This may extend to the use of simulation technology to enable the VTS operator to visualize the movement of ships either from external or onboard perspectives. Systems by Wartsila and Kongsberg are exemplary of this leading capability at the coastal or port level.[62]

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[60] Coordinate Reference Systems (CRS) are based on different geodetic datums that define the surface of the globe and provide the basis for satellite-to-earth relative positioning. The use of a chart CRS different from the GPS receiver can result in an error of position of 100 m or more. The CRS transformation can usually be selected on the ECDIS, and thus needs to be verified. This is more of an issue with BSB charts, whose CRS may be dated, or even obsolete, than with ENCs.

[62] Wartsila, Vessel traffic management systems, https://www.wartsila.com/marine/products/port-optimisation/vtms; Kongsberg, The future of Vessel Traffic Management in Europe, https://www.kongsberg.com/globalassets/norcontrol/files/thefutureofvtmineu.pdf

15. **Internet Connectivity (BL)**

Internet connections are a common feature of ships' and pilots' technological support. Ships may have the near-continuous benefit of satellite communications providing this service, while pilots rely on local cellular networks. Both are critical elements of receiving new ENCs, navigational warnings and corrections to charts, weather forecasts, live data streams for real-time wind and water levels, coordinating information for port arrival procedures, and pilot tasking orders. Previously, navigation warnings or weather updates were received through fax/teletype, VHF and high frequency radio broadcasts or NAVTEX, but these did not offer the data transmission rates or connectivity with other ships systems like the ECDIS that Internet connectivity offers. The continuity, reliability and bandwidth of cellular networks is still dependent on the distribution and situation of local repeating towers. Increasingly, high-speed service through satellites, such as Starlink, are providing high-speed global connectivity without reliance on local cellular services.

16. **e-Navigation Portals (BL)**

As more information becomes available in digital form, and with the increase in timeliness requirements (up to and including real time), maritime administrations and port authorities are investing in combined websites for "one-stop-shopping" convenience. The Canadian Coast Guard's contribution to this trend is the e-Navigation Portal. Such websites commonly provide real-time environmental data, navigation warnings, regulatory information and port details. A more comprehensive approach is the IMO's Maritime Single Window standard which became mandatory as of 1 January 2024, providing a common framework for exchange of information to facilitate trade, and combined public/private sharing of information relating to port arrivals.[63] The St Lawrence Global Observatory (SLGO)[64] and the Canadian Integrated Ocean Observing System (CIOOS)[65] also provide online GIS-based access to a quantity of geophysical and biological oceanic data.

17. **Optimum Ship Track Routing (BL)**

Optimum Track Ship Routing was a service developed by the US Navy fleet weather centers in the 1970s to facilitate timely, safe transits around oceanic weather systems. Enterprises now provide such services to commercial ships, including not only routing advice but also time-graphed predictions of wind, sea, swell, resulting ship speed, and critical roll periods. This service is more applicable to oceanic than coastal navigation, but is representative of the highly detailed predictive services available today for ships and navigators. The emerging capabilities of AI-driven ship/port scheduling builds on this capability.

18. **Real-Time Water Levels (EH)**

The concept of real-time depth reporting is to move from charted depths to actual water depths. There are two aspects to this:

   a. accurately measuring the bottom of the ocean by more frequent updates to the bathymetric databases particularly in rapidly shifting estuarial areas; and
   b. more accurately measuring the water surface level to make up for shortfalls in tidal predictions due to software limitations and wind-driven variations in water levels.

[63] https://www.imo.org/en/OurWork/Facilitation/Pages/MaritimeSingleWindow-default.aspx
[64] https://ogsl.ca/en/home-slgo/
[65] https://www.cioos.ca

One Canadian example of the first of these is Avadepth, a reporting system to frequently survey and report available depths in the Fraser River.[66] This information is posted on a web-map but is also made available as a Bathymetric Marine Information Overlay for use in ECDIS. Real-time water level measurement is also practiced using either fixed water level measurement installations or smart buoys. The measured water depth is used to calculate a correction to the predicted tidal height in real time and this information is broadcast though AIS or made available on e-Navigation portals. Measurements are usually done at critical reference points in the passage, for example, at the Second Narrows Bridge in Vancouver.

19. **Real-Time Air-Draft (EH)**

Some of the information layers available to pilots extend to real-time reporting of oceanographic conditions and air-gap measurement of bridge clearances. National Oceanic and Atmospheric Administration's (NOAA) Physical Oceanographic Real-Time System (PORTS) is an example of this technology, dating from the early 1990s and now covering 75 US ports comprising 80% of national cargo tonnage.[67] This system covers tide/water levels, air gaps, current profiles, wave observations, salinity and water temperature, wind speed and direction, and visibility, recording changes at 6-minute intervals and posting information to a NOAA website for onward dissemination. In the case of air-gap measurement, this data incorporates not only changing water levels but also temperature-driven expansion or contraction of the bridge structure.[68] PORTS is also used in advanced apps to estimate water levels along a route (say the Columbia River) to recommend best arrival times. Technologies employed for such applications include micro-wave range finders and radar level sensors with ranges of up to 35 m with resolution of ±10 mm,[69] as well as light- and laser-range finders (LIDAR/LADAR). Real time air-draft information is now in place for the First Narrows (Lions Gate Bridge) in Vancouver harbour.

20. **Real-time Currents (EH)**

Real-time current sensors include bottom-mounted or side-looking acoustic doppler current profilers, occasionally situated on aids to navigation with Irridium links (iAtoN) for offshore monitoring. These can measure currents at different depths. Bottom-mounted sensors have been used for real-time monitoring of ice-thickness and movement in the St Lawrence region.[70] Other technologies for surface current measurement include high frequency radar signals for medium to long-range sensing of oceanic currents.[71]

21. **Real-time Bathymetry (EH)**

An example of this technology is Kongsberg's "Berthwatch" real-time berth depth monitoring and reporting system. Using a dual-axis scanning sonar mounted on the berth face, this system

[66] DFO, https://www2.pac.dfo-mpo.gc.ca/index-eng.html
[67] NOAA, https://tidesandcurrents.noaa.gov/ports.html
[68] As of 2017, covering 16 sensors in 10 PORTS systems across the US. This article also provides interesting stats on the dollar value benefits of this system, suggesting savings of US$300M annually if extended to all 175 US ports. See also Miros, https://miros-group.com/blog/air-gap-why-measure-it-at-all/, which notes accuracy of +/- 5mm in their system.
[69] Campbell Scientific, https://www.campbellsci.ca/rls
[70] Chave, 2004. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=913bfd8162ff87f482f302316eeaa58a70b8dd0b
[71] See CODAR Ocean Sensors https://www.google.com/search?client=safari&rls=en&q=CODAR+(Coastal+Ocean+Dynamics+Applications+Radar)&ie=UTF-8&oe=UTF-8, and Ocean Networks Canada, https://data.oceannetworks.ca/PrinceRupertPort?rotatemin=0&refreshsec=0&qpddr=L10

maintains a record of silting and scouring to provide a continuously updated bathymetric profile of the berth approaches, allowing ships to more efficiently use their full cargo capacity. This system has been trialled in Prince Rupert harbour as recently as 2022.[72]

22. **Real-time Wind and Sea State (EH)**

Real-time oceanographic sensing is a function of both technology and organizational collaboration. An example of the latter is NOAA's observation website,[73] which provides a portal to all manner of real-time and near-real-time information, including links to all sensors of the PORTS web. The sensors themselves cover a wide range of specific technologies from high frequency to millimeter wave radar, ultrasonics, electrical-optical sensors in the visible and near-infrared spectrum, magnetics and gravitational devices.

23. **Wave Analyzer Display (EM)**

This is a computer-based system that analyzes radar returns to present a display of sea state and wave spectra.[74] This has implications for safety at sea and also for reporting actual weather conditions to better estimate ship progress to berth, but limited utility for pilots except perhaps for exposed pilot boarding stations such as Triple Island, BC.

24. **Real-time Marine Mammal Detection (EM)**

Detection and avoidance of marine mammals is not strictly a ship-safety issue but is becoming an increasingly important component of environmental protection measures for ships. Examples of active programs include seasonal slow-down areas for the North Atlantic Right Whale and Southern Resident Killer Whale. Recent efforts in Canada to implement real-time systems have employed thermal and visual cameras assisted by AI-detection and discrimination analysis to achieve reliable detection ranges of up to 4,750 m, depending on species.[75] These systems have been tested in land-based and shipboard installations but are not yet widely established. The BC Cetaceans Sighting Network has instituted a crowdsourced reporting system that collates visual sightings and broadcasts this to ships in the area by SMS messaging.[76] Other common approaches involve acoustic monitoring through use of non-invasive vehicles such as Slocum gliders.[77]

25. **Crowdsourced Bathymetry (EH)**

A vast quantity of bathymetric data is collected by depth sounders on commercial and recreational vessels. By combining this with the position of the vessel as measured using GPS, a picture of the bathymetry can be created. Although this is unverified and not rigorous enough for traditional chart creation, the technology can be used to provide navigational confidence in less well surveyed areas. Resources available to hydrographic services like the CHS are constrained, so this technology could be a solution to bridge the gap and Fisheries and Oceans Canada (DFO) has been pursuing this idea on behalf of CHS for application in northern

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[72] Mech,2022, https://aapa.cms-plus.com/files/AAPA_FacEngPPTJun2022.pdf
[73] NOAA, https://marinenavigation.noaa.gov/observations.html
[74] Furuno, https://www.furuno.com/en/merchant/wave-analyzer/
[75] Zitterbart, 2023. Brief to 2023 CMAC, and https://apps.dtic.mil/sti/trecms/pdf/AD1207369.pdf
[76] BC Cetaceans Sighting Network, https://wildwhales.org/category/sightings/
[77] JASCO, 2022/2020; and Kowarski, 2020.

regions.[78] The Canadian initiative in the public sector is called Community Hydrography.[79] The IHO calls their program Crowdsourced Bathymetry and makes soundings available through the Data Centre for Digital Bathymetry. Commercial examples of this approach are produced by OLEX and Orange Force Marine.[80] The first of these provides both hardware and software solutions and depth databases for navigation. The second is a crowdsourced bathymetry system which collects and uploads bathymetric data to the cloud for sharing among subscribers. It is also connected with the IHO's Crowdsourced Bathymetry initiative. British Antarctic Survey's Polar Data Centre also collects spot data from all British Antarctic Survey and Royal Navy vessels operating in Antarctic waters in the same way, also with the caveat that the resulting "charts" are not official and "not to be used for navigation."[81]

26. **Forward-looking Echo Sounders (EH)**

Echo sounders typically sound the depth immediately below the vessel, which does not provide adequate warning in poorly surveyed areas where depths may shallow sharply. Forward-looking echo sounders[82] feature transducers that may be trained in azimuth[83] and elevation to cast the beam ahead of, or to the side of, the ship. The error of the reading is proportionately degraded the further ahead the sensor is looking, but the best devices have a range/depth ratio of 20 (i.e. can see 100 m ahead with 5 m under-keel depth). Some systems claim obstacle avoidance use up to 1,500 m ahead of the ship.[84] These are now common in expedition ships which travel in sparsely-surveyed areas, and transducers can be raised in ice-infested waters, but forward-looking echo sounders are not otherwise in common use.

27. **3D depiction of bathymetry (EM)**

3D depictions of topography have become commonplace in the era of gaming and virtual-reality presentations. Some purveyors of popular navigation software, such as Navionics and Garmin, have made this available to recreational users, for whom the visualization aids orientation. A more comprehensive approach is that of Furuno with their Nav-net 3D, which permits the fusion of chart, radar, satellite imagery, echo-sounder, and vessel control data in striking displays.[85] Insofar as these technologies mirror the intention of heads-up displays, they are helpful to marine navigation, but there is a real risk that inexperienced users will become distracted by gimmicky displays rather than informed and alerted by prioritized data.

28. **Millimeter Wave Radar (EH)**

Millimeter wave (E-band, 60-90 GHz) is short-range, high resolution (600 m, ±7.5 cm) radar used for small-object discrimination and highly accurate positioning.[86] It has applications to

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[78] DFO, https://www.dfo-mpo.gc.ca/science/partnerships-partenariats/research-recherche/its-sit/projects-projets/015-eng.html

[79] DFO, https://www.dfo-mpo.gc.ca/science/hydrography-hydrographie/opp-ppo/index-eng.html

[80] See: OLEX https://www.olex.no/depthcharts_en.html , https://www.olex.no/products/olex_software_en.html; and Orange Force Marine, https://www.orangeforcemarine.com/crowdsourced-bathymetry

[81] British Antarctic Survey, https://www.bas.ac.uk/data/uk-pdc/

[82] See for example: https://daniamant.com/products/echopilot-fls3d/, https://www.farsounder.com/argos-navigation-sonars, https://www.wavefront.systems/vigilant-crewed-surface/

[83] An azimuth is an angular measurement in degrees clockwise from north on an azimuth circle of 360 degrees.

[84] Farsounder claims ranges of 1000 m ahead of the ship at speeds up to 25 kt for its Argos-1000 [which may encourage imprudent navigation?] Another example of advanced echo sounders is https://www.furuno.com/special/en/fishfinder/dff-3d/.

[85] Furuno NAVNet 3D, https://www.furunousa.com/-/media/sites/furuno/document_library/documents/brochures/brochures/navnet_3d_brochure.pdf , accessed 23 Nov 23

[86] Elva-1, https://elva-1.com/blog/e-band-short-range-marine-radar-faq#1

autonomous vessel sensors and also to marine security perimeter monitoring. Much of the development and miniaturization of this technology has been driven by the self-driving vehicle sector.[87] Research has also examined the fusion of mm-wave radar and camera data for object identification.[88] Millimeter wave radars have particular application to Arctic navigation, helping to fill the blind spot that exists for conventional X and S band radars from the side of the ship out to 0.25 NM and successfully picking up small ice targets in all but the heaviest of seas.

29. **Electro-optical Detection of Hazards (EH)**
Distinct from radar but still employing the electro-optical spectrum are technologies in the visible or near-visible domain. Forward-looking infrared and low-light television are two of these. Current Corporation of Port Coquitlam, BC is one Canadian purveyor of such systems, combined with laser rangefinders, which come in ruggedized gyro-stabilized mounts for use in leisure, defence and uncrewed surface vehicle applications. Their offerings include panoramic scanning, detection and alerts.[89] Another representative vendor is Sea.AI, whose products merge thermal and visual imaging with "machine vision" (AI).[90]

30. **S-100 Layers of ENC Detail (EM)**
The S-100 Universal Hydrographic Data Model is a structure of different specifications proposed by the IHO, International Association of Lighthouse Authorities (IALA), World Meteorological Organization and others for special purpose layers to be used with ECDIS. Tier 1 S-100 layers are to be available for use by 1 January 2026.[91] These specifications/standards form the basis of data exchange between onboard systems and the ship's ECDIS, or the compatibility of external data source inputs to ECDIS. The scheme covers everything from chart symbology and standards of competence for hydrographic surveyors, to comprehensive ECDIS design and function, Aids to Navigation, water levels (tides and currents), VTS messages and data exchange, danger and traffic advisories, and met-ocean data overlays.[92] Canada is in the forefront of implementing the S-100 standard in conjunction with Norway and South Korea.[93]

4.3.3 Control

31. **Portable Digital VHF Radio (BL)**
This is the critical link between the pilot in the berthing ship and the ship-assist tugs. Such systems over the years have become small, reliable, clear and cheap. The pilot brings onboard their own, with agreed frequencies (channels) for communication to the ship-assist tug-masters. In the very rare event of failure the ship has other portable VHF units that can be dialled to the pilot-tug channels.

32. **Tractor/tethered Tugs (BL)**
The use of tugs for berthing is an economical alternative to additional control forces (such as

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[87] Utmel, https://www.utmel.com/blog/categories/sensors/millimeter-wave-radar-advantages-types-and-applications
[88] Cheng, 2021.
[89] Current Corp, https://www.currentcorp.com
[90] Sea AI, https://sea.ai.The Sentry system can spot a person in the water at 700 m.
[91] IHO, https://iho.int/en/s-100-universal-hydrographic-data-model
[92] Note the latter aspect does not seem to be advanced; no data on the IHO website
[93] See CHS 2020 video regarding cooperation between CHS, LPA/GLPA pilots, Teledyne-Caris, and PRIMAR for development of S-100 in Canada: https://www.dfo-mpo.gc.ca/videos/s-100-eng.html

bow thrusters) being installed in the ship. Over the years, these have evolved from simple push-pull assists to very powerful "tractor" tugs using a variety of propulsion and control mechanisms (kitchen rudders, shrouded propellors, azimuth thrusters, cycloidal drives) as well as dynamic manoeuvres to provide significant thrust vectors. Typical ship-assist tugs now deliver up to 100 tons of "bollard pull". Tugs provide ship assistance in response to voice commands over VHF radio from the assisted ship's pilot.

33. **Full Mission Bridge Simulators (BL)**

A fundamental requirement for skilled control of ships is practice. This results from many years of actual conduct of navigation, but it is costly in both time and effort to train by observation and onboard mentoring. Since the 1980s, a number of simulator approaches have helped to bridge this gap. Starting with full-motion simulators that emulated the current practice of the aviation industry, these have mostly evolved to fixed-platform simulators in which the movement of the (simulated) horizon mimics the movement of the ship. The visuals are provided by very high-resolution, large-scale monitors that replace the bridge windows. These are fed virtual images by the computer that generates a view corresponding to the position and movement of the ship.

An alternate approach is the optical projection of real images against the window "screens."[94] Simulators commonly use actual or near-real bridge equipment to replicate as closely as possible the functionality of an actual bridge and allow for "full mission" simulations. In many cases, simulators can pair or group several independent bridges for cooperative training such as ship berthing with tethered tugs. The movement of the ship is predicated based on mathematical calculations using data about the simulated sea-state and the ship's own form and power.[95]

One very significant utility of modern bridge simulators is the ability to build digital models of intended structures (harbour infrastructure or notional new ships) and then conduct ship-handling experiments under a range of anticipated environmental conditions. Many companies active in this field offer a range of hardware and software solutions for simulator requirements, ranging from full-motion bridges to full-bridge mock-ups with 180 to 360-degree visibility, to simulation packages that can run on desktop or laptop computers, with or without Virtual Reality/Augmented Reality headset visualizations.

A further innovation in practical simulation in Chile is the construction of a physical boarding ladder mock-up to train pilots in the most hazardous phase of their assignment.[96]

34. **Scaled Manned-Model Training (BL)**

A common approach to training pilots in manoeuvres influenced by environmental factors including shallow water and bank effect is to use scale model boats that trainee pilots manoeuvre on a specially designed lake that mimics real ocean situations. The model's power is carefully scaled to provide realistic effects. Two popular sites for this type of training are Port Revel in France and Timsbury Lake in the UK.[97]

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[94] This approach is taken by the PPA's refresher-simulator.
[95] From experience, the simulated motion is startlingly real! Trainees have gotten seasick using simulators.
[96] Marine Pilots, 2020.
[97] https://www.portrevel.com, https://www.solent.ac.uk/facilities/ship-handling-centre

35. **Autopilots (BL)**

A ship's autopilot eases the burden of hand-steering for the helmsman. All ships have some degree of automatic steering. This can operate in three modes: (i) course following, to maintain a constant heading; (ii) track following, to steer following a single plotted course-line; and (iii) route following, to execute a planned route of several tracks. Typically, autopilots are not sophisticated enough to deal with traffic situations, nor do they anticipate adverse effects of wind and current.

36. **Bridge Dials (BL)**

A modern ship's bridge contains many dials and read-outs to constantly remind the Officer of the Watch of critical movement and control parameters. As a minimum, this includes local time, speed, heading (gyro), engine order/revolutions, helm position, depth, relative wind (speed and direction), and inclination. The most critical of these (heading, helm, engine orders) will be configured to be visible throughout the bridge and also on the bridge wings. A pilot's PPU may include some but not all of these, and also the ship's rate of turn.

37. **Pilot Assignment Software (EH)**

Modern pilot scheduling software enables the most efficient tasking of pilots to minimize travel and optimize duty cycles. Portlink's Port Management Information System[98] is an example of a modern modularized software pack that can be adapted to meet the interfacing demands of pilot, anchorage and berth scheduling, as well as billing. LPA is developing an assignment software solution Optimum Pilot Services. Basic packages are considered baseline technology but more intelligent solutions that optimise assignments to take into account voyage restrictions and other constraints are considered to be an emergent area for continued research and development.

38. **Voyage Data Recorder (VDR) (BL)**

VDRs contribute to safer future navigation by permitting the accurate reconstructing of ship movements to aid in accident analysis. However, VDR's are used increasingly to provide more comprehensive real-time data on ship movements, engineering states and control orders on which to base remote pilotage advice. VDR are required by IMO rules to be carried on passenger ships and ships over 3,000 GT constructed after 2002. The requirement for a simplified VDR (SVDR) was applied to all ships over 3,000 GT effective 2010.

39. **Effective Fender/Pier Systems (BL)**

This is the final element in controlling the ship's approach to the berth. The ship will eventually contact the berth at a finite velocity, and the fender systems have to be able to absorb this without either bending the ship's structure or allowing the ship's momentum to damage the pier. Fender systems are designed relative to: (i) the maximum size of ship expected; (ii) the angle of approach, (iii) the terminal velocity of the ship, and (iv) the local range of tide. Typically, ships contact the berth parallel (ideal) or at an angle of no more than 5 degrees to the line of the pier, with a velocity between 10 and 15 cm/second (equating to no more than 1/3 of a knot). The majority of incidents that occur while a ship is under pilotage take place during the berthing phase, so effective pier design is an important risk mitigation and includes not only effective

[98] https://www.portlinkglobal.com/solutions

fender/pier systems, but also appropriate positioning of cranes or other pier-side infrastructure such as junction-boxes.[99]

40. **Dynamic Positioning/Joystick Controls (EH)**
Dynamic positioning is the ability of ships to hold an ordered position and heading. Different levels of segregated systems and redundancy (DP-1/2/3) are specified requirements depending on the criticality of employment and whether human lives are at stake. Examples of ships equipped with dynamic positioning capability include cruise ships and platform support vessels for oil and gas exploration. The underlying technology for dynamic positioning (positional/attitudinal references, feedback systems, and propulsion elements such as azipods[100] and thrusters) forms the basis for vessels having sufficient precise mobility for automatic berthing.

41. **Improved Pilot Ladders (BL)**
A simple rope ladder with wooden steps is used to allow the pilot to transfer between the smaller pilot boat and the larger vessel. Accidents that occur during this vulnerable act have resulted in severe injury and death, and are a source of major concern. UK MAIB in 2023 reported 400 ladder incidents in 96,000 transfers, and Finnpilot in 2019 reported the problem was getting worse rather than better. Of 124 persons killed in EU maritime accidents 2017-2021, five were pilots. The International Maritime Pilots' Association (IMPA) reported that a survey of 4,664 pilots returned 16.8% experience with non-compliant ladders;[101] the French Maritime Pilots' Association reported 32 deaths over 18 years from IMPA stats (1.8/year).[102] There are few examples of potential technology innovation here, but a major improvement would consist merely of greater compliance with already-existing standards of construction, maintenance and deployment for ship ladders.

42. **Helicopter Delivery of Pilots (EH)**
Transfer of pilots onboard by helicopter (either landing or by hoist) has been used in certain jurisdictions for upwards of 30 years.[103] Long experience with helicopters in the marine environment by navies as well as the offshore oil and gas industry has demonstrated very high safety records. In places where hoist transfer from helicopter has been frequently used, this is seen as safer for pilots and also more efficient for the pilotage service. Helicopter transfers also permit earlier boarding of the ship before it reaches a critical navigational constraint that may present a risk to the transfer, for example the Triple Island boarding station off Prince Rupert, BC.[104]

43. **Vertical and/or Short Take-off and Landing (V/STOL) Pilot Transfer Vehicles: (EM)**
An innovative idea presented in a Johns Hopkins University Master's thesis is to use remotely-

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[99] For a detailed view of the subject of berthing and terminal structures, see: Thoreson, C., *Port Design*, and Greenwood, N., *Berthing Risk Assessment*, 2016, prepared for PPA and VFPA.
[100] Azipods are marine propulsion units which project below the hull and swivel in azimuth to provide directional thrust. They can operate in both push- and pull-mode, and are increasingly popular due to their effectiveness for manoeuvres in ice.
[101] Grundmann, 2023.
[102] Gaillard, 2022.
[103] See Lewin regarding the Columbia River Bar Pilots' experience, in IMPA on Pilotage, Helicopter Use.
[104] Greenwood, 2014.

guided personal V/STOL vehicles.[105] While this particular proposal may be a planning/intellectual exercise rather than a practical project, reality is not too far off. As early as 2021, the UK Royal Marines experimented with jet packs for military boarding operations. Variously reported as "very successful" and "may not be ready for military adoption just now,"[106] the trial has at least demonstrated the feasibility of such systems.

44. **Ergonomic Ship Bridge Design (EM)**
The foundation of safe and efficient pilotage services is standardization of navigational tools, equipment and their physical arrangement. The pilots' use of PPUs and personal equipment mitigates a large measure of this variability, but much still depends on the ship's fit and layout of the navigational space. Modern ship bridges conform to IMO standards of essential equipment[107] but improvements could be made in accessibility and ergonomic arrangement, both of key ship controls and indicators, and also visibility through the bridge windows. As additional advanced technology become available, bridge design needs to evolve to accommodate it.

45. **Automatic berthing systems (EM)**
Automatic berthing systems[108] are under development to support autonomous ships. In 2022 several autonomous voyages of large ships were trialled, including auto-berthing; the autonomous vessels were a 313 m container ship and a 223 m ferry, both part of the MEGURI 2040 Autonomous Ship Project of the Nippon Foundation.[109] The technologies required to enable such accomplishments include infrared cameras, target image analysis, LIDAR range finders, AI control of manoeuvres, ultrasonic sensors, and the associated propulsors that give the necessary thrust vectors.

46. **Remote Pilotage Control Centres (EM)**
To enable remote pilotage, three connected elements are required: (1) the ship in which the pilot's directions are received, interpreted and actioned; (2) the shore control centre in which the pilot observes the ship's movement and issues directions; and (3) the no-fail communication system which connects the two. The pilotage control centre must attempt to provide the remote pilot with the same situational awareness of the ship's position, orientation, surrounding environment and control functions as they would have had on board the ship. In experiments to date, this has resulted in a combination of simulation and VTMS oversight technologies so that the pilot can retain a "feel" for the actual progress of the ship. The degree to which this needs to be fully "immersive" or real depends on the criticality or difficulty of the navigation passage. The relay of instructions to the ship will also need to meet high standards of fail-safe continuity, clarity and unambiguous interpretation, low latency, and protection against cybersecurity threat.

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[105] Bijani, 2020

[106] Royal Navy, https://www.royalnavy.mod.uk/news-and-latest-activity/news/2021/may/05/050521-boarding-trials#:~:text=Royal%20Marines%20have%20tested%20the,military%20operations%20in%20the%20future. The Royal Navy was experimenting with devices produced by Gravity Industries, https://gravity.co.

[107] In Canada, this is given force by the Navigation Safety Regulations 2020.

[108] Note this is distinct from an "automatic mooring system" which addresses the handling and tensioning of berthing lines or ship-shore connectors. See Trelleborg website and Gravendeel 2017 for more on this subject. Automatic mooring, however, is likely to be an element of automatic berthing.

[109] Yukinori, 2022; The Maritime Executive, 2022.

4.3.4 Risk

48. **Radar (BL)**

Apart from its value as a fixing aid (now increasingly redundant), radar is a key risk-assessment tool. It is the one independent shipboard source of info on mobile hazards. Most commercial ships carry two independent radar systems: one is S-band (3 GHz, 10 cm wavelength) for mid- to long-range detections, and the other X-band (9 GHz, 3 cm wavelength) for higher resolution, shorter-range detection and tracking. In modern systems the distinction is moot as even the X-band has significant range, and S-band is capable of picking up objects as small as seabirds. All modern radars are digital and have advanced auto-tune functions, as well as multiple-sweep discrimination and timed "trails" to highlight persistent contacts. Nonetheless, radar systems are subject to degradation by higher sea-states (sea clutter) and if officers of the watch are manually adjusting suppression filters, they must be careful not to filter out valid targets. Specialized high definition "ice radars" employ advanced processing to render an image in which the types and boundaries of ice can be more easily discerned.[110]

49. **Automatic Radar Plotting Aid (ARPA) (BL)**

ARPA was introduced in the 1970s to alleviate the burden of having to plot relative tracks by hand, usually with grease pencils on Perspex overlays of radar screens. ARPA quickly became indispensable and is now a universal, embedded feature of modern radar systems. Its functions include: (i) automatic detection and tracking of contacts; (ii) generation of collision-related risk parameters such as target bearing, range, course, speed, closest point of approach, time to closest point of approach, bow-crossing range, and bow-crossing time; and (iii) audible alarms at danger ranges selected by the user. ARPAs also provide both relative and true-motion leaders[111] to help visualize future positions, and a "trial manoeuvre" function that allows different manoeuvring solutions to be previewed. Contacts (symbology) generated by ARPA can be transferred to ECDIS, to give an appreciation of mobile dangers' positions relative to fixed hazards and thus more clearly delimit mitigation options.

50. **Echosounders (BL)**

Echosounders are fundamental navigational tools, once used to confirm the proximity of land in reduced visibility but now relegated to secondary utility. Modern systems have advanced depth ranges and sensitivity that sometimes mistake organic or thermal layers for bottom. These are required equipment but of limited use as most commonly fitted systems use a narrow sonic beam that only sounds the depth directly below the ship.

51. **Real-time Under-keel Clearance (UKC) Prediction (EM)**

UKC is a function of the position and movement-sensitive combination of charted depth, height of tide, and ship's draft. All three of these are subject to errors and changes: depth can be imprecise or variable (e.g., silting/scouring); predicted tidal heights are subject to harmonic or environmental influences; and the ship's draft may be varied by hydrostatic (sinkage due to salinity changes) or hydrodynamic (squat due to shallow-water) effects. This calculation is

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[110] https://www.furuno.fi/eng/merchant_marine/navigation_products/ice_radar/

[111] These are lines that represent a target vessel's future true or relative position according to a selected time period, say 6 or 12 minutes or one hour, depending on scale and the preferences of the officer of the watch.

complicated by manoeuvres, in which a ship under helm will heel and generate an effective draft deeper on the outboard side commensurate with the angle of heel and breadth of the ship. In some cases, this may be a substantial portion of the available safety margins. The resolution of these factors for accurate dynamic UKC requires action by the port to establish current real-time water levels, action by the ship to accurately calculate or measure static draft under known conditions, and action by naval architects to determine the ship's sinkage and squat under various conditions of speed and hypothetical UKC. Technologies addressing real-time water levels, bathymetry, and sea state are also important and have been covered elsewhere. Prediction of squat is commonly available to ships as a computer-generated tabular output based on speed and draft. The fundamental parameter of static draft is usually visually inspected against the ship's draft marks upon loading and then adjusted for changes of salinity and load (consumption of fuel) enroute, but this is subject to human errors of draft and salinity measurement. More technical solutions include direct (i.e. real-time) remote monitoring of draft through ultrasonic or pressure sensors. The ultimate aspiration of dynamic UKC systems is to provide an overlay on the pilot's PPU which depicts the port entry in terms of residual UKC, compensated for all factors together. This subject is a project under the IHO's S-100 scheme for integration of nautical data sources.[112]

52. Risk-assessment Tools for Ice Navigation (EH)

Fednav's ENFOTEC[113] continues to evolve its highly successful IceNav program developed in the 1990s. The latest versions of the IceNav system utilize a stand-alone computer that plugs into ships' sensors, utilizing position, heading, speed and radar data superimposed over high-resolution satellite ice imagery and geo-referenced ice charts. Such imagery can be directly and automatically downloaded to the IceNav when connected to the ship's satellite internet. The Polar Operational Limitations and Risk Indexing System (POLARIS) Risk Index Outcomes[114] are displayed when mousing over individual SIGRID-3 formatted digital ice charts, providing immediate risk assessment. Mariners are able to select ice routing based on the displayed imagery/charts, overlaid with real-time radar imagery and ship position data. Routing may be uploaded to ECDIS for verification of bathymetric safety, corrected there, and then returned to the ice navigation platform if required. The system is capable of generating POLARIS or Arctic Ice Regime Shipping System[115] routing reports as required by NORDREG in Canada's north.

IcySea, a Danish app developed by satellite ice-imagery specialists Drift + Noise, is another such example.[116] This simple app can be used on PC and iOS computers, tablets and smartphones. It can either manually or automatically connect to download small-area high-resolution imagery "packets", thus building a grid of ice information in manageable transmission sizes (often less than 100 kb per grid square). The ability to select specific small-area grids and receive higher resolution imagery for only the areas specifically required, rather than the large areas (and subsequently much larger data packet sizes, often above 30 MB), allows for not only cheaper data acquisition and transfer but more focused view and representation of the data.

[112] See IHO: https://s-100.no/operational-test-s-129-under-keel-clearance-management-tested-in-tjeldsundet-norway/

[113] Formerly Enfotec Technical Services Inc., this subsidiary enterprise has been reorganized as Fednav's Ice Services Group. https://www.fednav.com/en/icenav-forefront-ice-navigation-technology

[114] Risk Index Operator is a sum of partial concentrations of different ice-types weighted by multipliers according to a vessel's Ice-Class, which yields a number (positive or negative) reflecting the ship's suitability to pass through a particular ice regime.

[115] The Arctic Ice Regime Shipping System was a Canadian ice risk assessment system that preceded the introduction of the IMO POLARIS system but operates on similar principles.

[116] Drift + Noise, https://driftnoise.com/icysea/

53. **AI App for Real-time Ice Assessment (EM)**

American Bureau of Shipping has developed an Android app to assist in identifying and categorizing ice conditions via AI. Upon taking a photo of nearby ice conditions, the app attempts to break down the ice in the photograph into the elements required to make POLARIS risk management calculations. At present in "learning stage", several units are in the field where experienced Ice Navigators are taking photos of ice conditions, noting the AI's interpretation, then correcting the result with ground-truth actual conditions – in effect "teaching" the AI. Many years of in-situ ground truthing and training are needed to build photo libraries to teach the app; operational utility is not expected for the next ten years.[117]

54. **AI-driven Collision Avoidance (EM)**

This system includes a number of the technologies already mentioned, for the purpose of automated obstruction detection and alerts ("proximity alerting" or "automated lookout" systems). Many of these are oriented toward minimally crewed oceanic yachts. Others, such as OrcaAI, include elements of heads-up displays and have been adopted for commercial use.[118] More significant is the decision aid and execution technology being developed for autonomous ships. This includes the use of AI, not just for recognition and classification of surface objects, but to determine, rank, and provide the best options for avoiding other ships for compliance with COLREGs in complex traffic situations. Several systems have been developed and trialled; Wartsila/TRANSAS's Advanced Intelligent Manoeuvring (AIM) system is one of these in which experienced mariners appreciated the visualization of the problem and confirmation of their own solutions but expressed skepticism about accepting machine-based decisions at face-value.[119] Other systems employ simplified rules that suit simple meeting and crossing situations but fail under complex multi-ship avoidance challenges, especially in confined waters.

55. **Comprehensive Risk Assessment (EH)**

A significant part of prudent risk management is passage planning. Pilotage organizations conduct passage planning based on familiarity developed through experience, amended as required by consideration of short-forecast environmental conditions. The availability of multiple long-series databases creates an opportunity to assess anticipated conditions filtered by area, route or date. The National Research Council's Canadian Arctic Shipping Risk Assessment System (CASRAS)[120] is one such example which has special applicability to northern navigation by incorporating the long-term climatic record of ice coverage with POLARIS analysis. The system is being adapted for web access and now provides short-term (two-day) forecasts of ridging and pressure fields to augment the daily reporting of ice conditions by the Canadian Ice Service.

4.4 Advanced Vessel Traffic Management Services

Vessel Traffic Services (VTS) are operational services established under national security and maritime safety mandates to monitor, coordinate, and manage marine traffic. Formerly called simply VTS, they

[117] Personal communication to Captain Snider.
[118] Riviera, 2023.
[119] Aylward, 2021.
[120] NRC, https://nrc.canada.ca/en/research-development/products-services/technical-advisory-services/canadian-arctic-shipping-risk-assessment-system-casras. See also Sudom, 2023.

are taking on greater scope and authority following calls for increased oversight for safe shipping, and are therefore sometimes referred to as Vessel Traffic Management (VTM or VTMS). This trend is evident in the evolution of the term "proactive vessel management" which extends to the protection of environmental or culturally sensitive areas. Intelligent, predictive technologies are being used to optimize ship scheduling and port services in projects such as the Vancouver Fraser Port Authority's Active Vessel Traffic Management scheme.

VTS commonly relies on IMO or locally approved traffic separation schemes or restricted movement areas to establish rules for traffic separation. A control room gives operators access to shore-based radar and AIS surveillance. Communications is via VHF voice-radio reports at designated call-in points. Operators provide clearance authority for harbour entrance and passage through restricted movement areas. Beyond territorial waters, national maritime administrations or border services may require daily position reports for monitoring traffic within the country's exclusive economic zone. In the precincts of a port, VTS functions may be partially or wholly devolved to the port, or the VTS center may exercise control on behalf of the port. Otherwise, VTS is usually established and staffed by the Coast Guard under national authorities.

VTS does not yet match air traffic control in the degree of authority in providing direction, but the trend is in this direction.

4.5 Remote Pilotage

Remote pilotage is not a technology per se but the combined application of a number of technologies, with the intended result of providing pilotage advice from offboard the vessel. It is distinct from remote control, which supposes the distant command and control of an uncrewed vessel. In the case of remote pilotage, a physical human presence remains on the ship.

In a basic sense, remote pilotage is not new; it is practiced in Canada, but only in exceptional circumstances and only for short distances, when conditions preclude the pilot boarding via the ship's ladder, so the pilot can provide lead-through advice from the pilot boat to calmer waters inside the pilot station where the boarding can be accomplished safely. Experimental approaches to remote pilotage attempt to do the same thing, but more deliberately and at a greater distance, through the use of advanced surveillance, monitoring and fail-safe communications from shore stations. For clarity, in this study we will consider remote pilotage as "shore-based pilotage" (SBP) rather than pilotage from the pilot boat (a "lead-through.") A 2012 report from the European Union on pilotage exemptions indicated that SBP was exercised (exceptionally) by 12 of 24 member countries, and 10 only allowed advice from the pilot boat.[121] Italy was the only country using SBP regularly in 2021.[122] In many of these cases, what is described as SBP is in fact "navigational assistance" as the pilot does not assume "conduct" of the vessel.

SBP has been studied for more than 20 years, and in the past 10 it has been acknowledged as technically feasible.[123] The incentives for this have included the difficulty of recruiting sufficiently trained individuals, the anticipated economies and efficiencies of increasing the number of vessels one

[121] EU, 2012.
[122] Hovda, 2021.
[123] Bruno, 2009; COWI, 2014; Brooks, 2016.

pilot can assist within a single shift, and safety gains of avoiding pilot ladder boardings. The COWI report of 2014 anticipated savings of up to 50-60% for modest decrements of ship safety.[124] Others have proposed that SBP may increase safety, lowering pilotage error rates from 1 in 15,543 vessel moves to 1 in 95,000 over a five-year period. This latter report assessed the potential benefit of SBP would fall 25% to navigational safety, 10% to pilot safety, 20% to pilot utilization and 45% to pilot support efficiencies.[125] Other reports are more skeptical that any improvement in navigational safety is possible with SBP. Much of the focus is on "intelligent fairways" that rely on established infrastructure to ensure a shared situational awareness between the ship's command and the VTS (SBP) operators.[126]

Initial studies focused on the essential technical/operational enablers (see Table 5) and supposed some operational limitations such as "no SBP in harbour" or "no SBP for vessels carrying dangerous cargoes in confined waters". Additional limitations or caveats proposed include confined waters, prior certification of ships, prior onboard experience of the pilot in the ship, fairway navigation with limited traffic, pre-approval of passage plans, restriction of SBP to frequent visitors, and two officers on the bridge.[127]

A significant concern (of pilots) with SBP is the loss of "touch" with the ship, meaning a loss of intuitive situational awareness. One proposal for bridging this gap is to provide situational awareness cameras or auto-following drones to provide a "bird's eye" view of the ship's progress as an adjunct to sharing of radar and ECDIS pictures.[128] A very large measure of SBP feasibility depends on the investment in a shore-side control center. Initial work by Rolls-Royce, now Kongsberg, demonstrates that this is an area for the combination of multiple advanced technologies from communications and navigation to simulation visualizations.[129] Finland is pursuing a similar approach with Finnpilots' Intelligent Shipping Technology Test Laboratory (ISTLab), which aims to build a simulator environment to enable remote pilotage in Finland by 2025.[130]

Table 5: Technical Requirements for SBP (Source: COWI)

The following must be available on shore	**The following must be available at sea**
A system similar to that of ECDIS/VTS	Two functional radars
Radar image as interface overlay	Approved ECDIS system with current navigation charts
AIS data system integrated to computer	At least two independent VHF systems
Stable and direct communication line/channel (VHF) with back-up	Technical equipment and steering mechanisms must not be defective
Access to meteorological data in sailing area – primarily current, wind and visibility	The crew on the bridge must have situational awareness and preferably be experienced
Line of communication (e-mail) to exchange information on the vessel (Pilot card) and intended course	The crew on the bridge must be able to communicate in English

[124] COWI, 2014, p. 7-8.
[125] Brooks, 2016.
[126] Lahtinen, 2019. Such "smart fairways" could also include pilot-controlled buoys whose characteristics/power could be adjusted to current environmental conditions (Lindborg, 2021).
[127] Hovda, 2021.
[128] Lindborg, 2021.
[129] See the Youtube video: https://www.youtube.com/watch?v=UPtdgiIrlJI
[130] https://istlab.samk.fi

In some ways, Finland is leading the world in SBP. A number of high-level consortia and associations have combined the research strength and innovation of a large number of partners. Finland passed legislation enabling remote pilotage (SBP) in 2019 and has been steadily working towards operationalizing the concept.[131] This resulted in a live test of SBP in the pilotage centre of Turku in May 2022. This test, a collaboration of the Finnish consortium Safe for Value Fairway (S4VF) and Brighthouse, featured data from the ship's VDR and onboard 360-degree video cameras streamed through a diode-isolated "Smartbox" (to preclude attacks by inbound signals) to the shore station. Here the data was assembled in a virtual environment for the benefit of the operator (pilot) and the resulting instructions were conveyed back to the ship by resilient communications by voice (VOIP) and virtual reality headsets.[132]

Some of the continuing concerns with the viability (reliability) of SBP remain those of communication — both technical and verbal. The increasing prevalence of seafarers who are not native-English speakers means that mere continuity of communications will not always guarantee perfect comprehension. Single-channel data streams may not be enough to replicate in-situ awareness of bridge team competence, cohesion or comprehension of pilot's orders. In practice, this will require more completely formalized communication protocols to make up for loss of body-language, interpersonal cues, and other means of interaction onboard that establish mutual rapport and confidence between master and pilot.

4.6 Autonomous Ships

The subject of autonomous ships, more formally referred to as Marine Autonomous Surface Ships (MASS), is largely beyond the scope of this study. However, since it relies on many of the technologies presented earlier in this section of the report, it is helpful to discuss the advances being made and the challenges encountered.[133]

The technology of MASS is being rigorously pursued, with recent successful demonstration voyages of ships from 15-220 m in sometimes busy maritime traffic situations.[134] Alongside this is a well-established discussion of the definitional and legal aspects of operating ships without crews.[135] In both the technical and legal discussions there is acknowledgement that the subject spans a spectrum of operational modes from current "fully crewed with pilots onboard" through Remote Pilotage to Remote Control, thence to a graduated spectrum of "hybrid" solutions before arriving at fully autonomous ships (i.e. from "berth to berth"). Much of the required technology to achieve such automation is being pioneered in automotive[136] and other industries such as offshore oil and gas and defence. The implications for liability (insurance) are a significant part of this discussion in the civil

[131] Rinkinen, 2022.
[132] Grundmann, 2023.
[133] Particularly good overviews of technical, legal/regulatory, and human issues of MASS are provided by Olcer, 2023 and Fenton, 2023.
[134] These include: 2021 *American Courage,* 190 m, in Cleveland (Wartsila); 2021 *Sunflower Shiretoko,* 190 m, in Japan (Mitsui); 2021 *Mikage,* 95 m ,in Japan (Mitsui); 2022 *Suzaku,* 95 m, in Japan (MEGURI2040), achieving 97.4 to 99.7% autonomous operation; 2022 *Soleil*, 220 m, in Japan; 2022 *Zhi Fei*, 120 m, in China; 2021 *Yara Birkland*, 95 m, in Norway (Kongsberg); 2018 *Falco*, 54 m, in Finland (Rolls Royce); 2021 *Mayflower 400,* 15 m, in US (Promare/IBM); others by Wartsila and ABB in Finland and Singapore. At least three of these are in active service. (Sources: various websites.)
[135] Carey, 2017.
[136] Even here, the technology is not yet mature and fail-safe: see https://www.caranddriver.com/news/a44185487/report-tesla-autopilot-crashes-since-2019/

domain.[137] In fact, it may be that the legal and regulatory issues are more substantial and difficult to solve than the technical enablers of MASS.[138]

At the highest level, a secure and reliable MASS system requires:[139]

- Fail-safe ship-shore communications (including cyber security);
- Advanced sensors and autonomous navigation;
- Autonomous engine monitoring and controls; and
- A shore-based control centre.

Different levels of automation are defined for each of these functions. These sometimes refer to a Level of Automation Taxonomy, which lists five to eight levels of automation under four categories:

1. Information Acquisition
2. Information Analysis
3. Decision and Action Selection
4. Action Implementation

Some of these are intelligence tasks (i.e., digital) and some require a cyber-physical interface for actuation of control functions of the ship. What they all share, however, is the requirement for reversion to lower levels of control. The IMO has defined four such degrees:

- Degree 1: ships with human crews aboard, but with some automated systems;
- Degree 2: remotely controlled ships with human crew aboard;
- Degree 3: remotely controlled ships with no human crew aboard;
- Degree 4: ships that are able to operate autonomously with no human controller, either on board or at a remote location.[140]

The sophistication of the related decision-making and functional circuits will determine the degree of autonomy any particular vehicle will enjoy and under what conditions it will revert to or request operator input.

Most writers on the subject of MASS suppose that (at least in the medium term) there may be restrictions on what level of automation is permitted in what areas. This may impose practical and technological challenges: while the ship is optimized for autonomous, uncrewed operations, what provision will be made for occasional crew on board to support legal or practical concerns of port arrival? There is also the issue of different ship types and different operational profiles: how will uncrewed vessels cover the duties previously executed on voyage (e.g., preventative maintenance, cargo hold cleaning/preparation for cargoes while transiting "in ballast"), without imposing delays and labour costs in port approaches?

The companies currently leading the development of MASS are: Rolls-Royce, Kongsberg, Wartsila, ProMare, DNV GL, and ABB.[141] Rolls-Royce sees the timeline of development resulting in autonomous

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[137] Rylander 2016.
[138] Soyer 2022.
[139] Rylander 2016.
[140] Fenton 2023. Degree 4 may nonetheless be subject to a level of monitoring or oversight if not active control.
[141] Nishant 2023.

ocean-going ships by 2035,[142] whereas the Nippon Foundation sees their MEGURI2040 project delivering "practical implementation" by 2025.[143] One Sea Association has been established as an industry group to represent manufacturers, integrators and operators in the maritime autonomous field; its 2021 White Paper deals mainly with safety, cyber security and various legal/regulatory hurdles.[144]

Notwithstanding this apparent progress, there are many who are frankly skeptical of the feasibility, acceptability or economic incentives of converting this technological development to full-scale commercial implementation of MASS. Some assert that implementation must be accompanied by an equitable distribution of costs, risks and benefits.[145] EMSA's 2023 report on Identification of Competences for MASS Operators indicates that "the introduction of MASS is becoming increasingly realistic …[but] the human operator retains an important role."[146] IALA, in a 2024 assessment, reckons the widespread realisation of large autonomous ships is 20 years away, and "while there is recognition that human error contributes to accidents, and MASS could help in reducing human error, not everyone is convinced that autonomy is the solution." IALA identifies six areas of incentives and challenges to realising the vision of MASS. The Canadian National Centre of Expertise on Maritime Pilotage (NCEMP) identifies 21 specific gaps (requirements that cannot currently be met), under these headings: technological, operational, legal, cost and investment, and public perception/acceptance.[147]

The IMO is working on a Code for Autonomous Ships but this is not expected to become mandatory before 2028.[148] In the interim, the IMO's Interim Guidelines for MASS Trials advise that "trials should be conducted in a manner that provides at least the same degree of safety, security and protection of the environment as provided by the relevant instruments [existing regulations]".[149]

[142] Rolls Royce, 2023. Note: the Rolls-Royce marine division was acquired by Kongsberg in 2019 for US$525 million (https://www.rivieramm.com/news-content-hub/kongsbergrolls-royce-deal-completed-for-estimated-us525m-54057).
[143] Nippon Foundation
[144] Lehtovaara, 2021.
[145] Negenborn, 2023
[146] EMSA, 2023
[147] NCEMP, 2024 letter to Clear Seas.
[148] IMO, 2024. Autonomous Shipping. https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx
[149] https://www.imorules.com/GUID-57E8476A-5512-4BE5-9E68-C095B2BDE239.html

5.0 Technology Opportunity Analysis

5.1 Methodology

The catalogue of pilotage technologies compiled in Section 4 is now analyzed to assess their potential for improvement to the safety and efficiency of pilotage service delivery. Assessment started with assignment of a "Use Index" — a 5-point scale running from 5 (universal) to 1 (rare). Technologies with a low current Use Index may present a greater opportunity for improvement. A series of subjective measures for technology cost/benefit analysis were developed and the research team scored each technology using the 5-point scale to try to discern which technologies present the greatest opportunity.

It must be cautioned that the scoring performed was subjective and relative, based on a limited number of perspectives, and often lacking in hard evidence (especially regarding cost). In cases lacking hard facts, the researchers exercised professional judgement to choose a probable rather than absolute score. The results below must therefore be accepted as generally indicative but not authoritative. The scoring resulting from these criteria represents the appreciation of the research team and is mainly a tool for sorting and examining the research rather than an authoritative judgement of existing and emerging technologies.

5.1.1 Desired Attributes of Pilotage Technology

In consideration of what benefits technology can offer pilots, we looked first at practical attributes. These include:

1. **User-friendly ergonomics:** The degree to which the technology is intuitive, easy to use, and renders the intended effect with the least effort;
2. **Timely, effective and efficient information exchange:** The degree to which the technology clearly delivers pertinent and current information at the right time;
3. **Uninterruptable power supply:** A fail-safe mode of operation that endures independent of ship's power supply; and
4. **Fall-back or fail-safe modes of operation:** The facility to revert seamlessly to lower (manual or non-automatic) modes of operation.

These aspects were not scored explicitly but informed the approach to the formal evaluation process that follows.

5.1.2 Criteria of Comparison

The particular criteria of comparison employed were:

1. **Maturity:** the degree to which the technology is ready for implementation;
2. **Use Index:** the degree to which the technology may be considered common;
3. **Cost:** an order-of-magnitude figure for cost of the system;
4. **Benefit:** a subjective measure of potential utility;
5. **Effect/Cost:** a calculated figure that expresses the trade-off of (3) and (4);

6. **Ease of Use:** a subjective figure for facility of use; and
7. **Implementation Risk:** a subjective figure that expresses the difficulty of implementation and the certainty of expected benefits.

The associated scales of categorization and comparison are shown in Table 6. The five-point scales of comparison are consistent from Very Low (1) to Very High (5). This allows for consistent colour coding corresponding to desirability: green (high score) is best and red (low score) is worst.[150]

Table 6: Criteria of Technological Comparison

Score	Short	Maturity	Use Index	Cost	Benefit to safe pilotage	Efficiency (Effect/Cost)	Ease of Use	Implementation Risk
1	VL	Basic Principles - Tech Concept	Rare	>$10M	Marginal benefit	0.2	Difficult, complex	Major change, difficult, indeterminate, doubtful
2	L	Proof of Concept - Validation	Occasional	>$1M	Some improvement	0.6	Significant training reqd	Involved, complex, lengthy, uncertain
3	M	Laboratory Protoype Demo	Frequent	>$100K	Modest improvement	1	Moderate training reqd	Progressive, careful, medium, confident
4	H	Operational Prototype Demo	Common	>$10k	Significant improvement	3	Some training reqd	Incremental, natural, quick, likely
5	VH	Technology Deployed	Universal	<$10k	Key technological improvement	5	Intuitive, natural	Straight forward, easy, immediate, certain

5.2 Results of the Analysis

This report examined 54 pilotage-related technologies as catalogued in Section 4. The greatest number of identified technologies (23) required implementation at the ship level, with 5 more being directed at the State or international level as set out in the table below. This leaves 26 technologies that are managed at the individual pilot or port/pilotage authority level – these are the technologies within the innovation scope of individual pilotage authorities or pilot groups. Of these 26, 20 (14 + 6) were assessed to be at the fully mature state.

Table 7: Technologies by Maturity

Maturity	Pilots	Ships	Ports/PAuth	State	IMO	Grand Total
1		2				2
2					1	1
3		2				2
4	2	5	4	1		12
5	6	14	14	2	1	37
Grand Total	8	23	18	3	2	54

The technologies are also assessed through a lens of how widespread their usage is, shown in the Use Index in Table 8. Focusing again on the technologies within the sphere of influence of pilotage authorities, it can be observed that seven of the technologies capable of implementation at the pilot/port or pilotage authority level are "universal" with a score of 5, while seven more are "common" with a score of 4.

[150] This required an inversion of the preferred criteria of Cost and Implementation Risk for columns 5 and 9 on this table.

Table 8: Technologies by Use Index

Use Index	Pilots	Ships	Ports/PAuth	State	IMO	Grand Total
1	2	3	2	1	1	9
2		8	2	1		11
3		1	6			7
4	2	3	5			10
5	4	8	3	1	1	17
Grand Total	8	23	18	3	2	54

5.3 Opportunities for Improvement

Looking for opportunities to improve pilotage service through technology, the data in Table 9 shows the number of technologies that have high prospective benefit paired with lower Use Index (current implementation).

Table 9: Technologies by Benefit/Use Index

Use Index	Benefit					Grand Total
	1	2	3	4	5	
1	1	4	3	1		9
2	2	2	5	1	1	11
3			1	1	5	7
4	1		3	4	2	10
5	1		1	3	12	17
Grand Total	5	6	13	10	20	54

Many of the items at the Benefit level of 4-5 are already implemented and have Use Indexes of 4 or more, corresponding to the orange shading in Table 9 with 21 technologies. These are not considered to be opportunities for improvement.

Those with a high degree of opportunity for improvement were selected based on having a 3 for Use Index (i.e., frequent, but not common or universal) but scored 3 or better for Benefit (i.e., modest or greater). These seven items are (with Implementation Level in brackets):

1. Real-time air draft (Port/Pilot Authorities)
2. Real-time tidal current information (Port/Pilot Authorities)
3. Real-time wind and sea data (Port/Pilot Authorities)
4. Real-time water levels (Port/Pilot Authorities)
5. Dynamic positioning, joystick control (Ships)
6. Helicopter pilot delivery (Port/Pilot Authorities)
7. Improved pier/fender systems (Port/Pilot Authorities)

The next tier is those technologies scoring 2 for Use Index (i.e., occasional) while scoring 3 or better for Benefit. These eight items are (with Implementation Level in brackets):

1. Forward-looking echosounder (Ships)
2. Ergonomic bridge design (Ships)
3. Independent advanced positioning (Ships)
4. Millimeter wave radar (Ships)
5. Automatic electro-optical detection of hazards (Ships)
6. Real-time bathymetry (Port/Pilot Authority)
7. Differential GPS (State)
8. Automatic berthing systems (Ships)

Reviewing these two groups of prospective improvements, it is evident that the first group is mostly the responsibility of the Port and Pilotage Authorities or pilot groups, while the second group are mostly under the purview of ships.

6.0 Conclusion

6.1 Current Assessment

Pilotage across Canada is established in a varied manner, adapted to the geography, traffic patterns and local conditions of the different regions. Across these pilotage regions, Canada is leading in many aspects of modern pilotage:

- Robust prerequisites, selection and examination of pilotage candidates;
- Advanced apprenticeship training and mentoring;
- High degree of independent technical support while on board (PPU, etc.);
- Well-established hydrographic and environmental agencies;
- Deep reserves of polar/ice-navigation expertise; and
- A highly innovative private maritime technology sector.

In its four pilotage regions, Canada already uses many of the leading technologies applicable to pilotage, thus underpinning a very satisfactory safety record:

- Use of PPUs, combined with highly accurate positioning and rate-of-turn generators;
- Reliable hydrography (except for the Arctic), supplemented by real-time sensors for water level, currents and air gaps;
- A well-established network of e-Navigation portals, both local and national; and
- Robust and modern VTS centres.

6.2 Recommendations

Many of the leading technological innovations are being developed or standardized at the level of corporations or international organizations. Implementation at the local or regional level will follow, but efforts by local pilotage or port authorities to improve pilotage safety and efficiency through implementing technology are limited to their sphere of influence.

Changes are happening in the traditionally conservative global shipping industry, but given the long lifecycle of ships, it is a lengthy process to implement a new technology in all ships. In addition to requiring a robust business case to invest in a new technology for a new ship (or retrofit an existing ship), shipowners will need confidence that the new technology will be beneficial, supported and reliable. Improvements must be demand driven.

This report attempts to highlight those technologies that are most achievable through application of local or regional resources, with focus on the following priorities:

- Safety of pilots
- Safety of ships
- Safety of the environment
- Safety of the public

From this high-level assessment of the subject, the most prominent opportunities for improvement include:

1. Pilot transfer arrangements;
2. VTS effectiveness/efficiency (surveillance/prediction/communications/training);
3. Advancing real-time data inputs to pilots (to increase precision but not reduce safety margins unduly);
4. Local/regional monitoring (including real-time marine mammal spotting);
5. Advanced communications and connectivity in coastal areas.

In many quarters of the marine industry, technology is seen as a two-edged sword: an opportunity to simplify and streamline the performance of routine onboard work; but, conversely, a threat to the livelihood of mariners. A survey of 1,000 marine professionals in 2018 revealed that "84% of maritime professionals consider automation to be a threat to seafaring jobs, and 85% believe that uncrewed remotely controlled ships pose a threat to safety at sea."[151] These views are encouraged by the failure of technology to thus far ease the burden of shipboard work — a key example is the fact that "digitization" so far still requires watchkeepers to make hourly hand-written records!

At the same time, there is a critical dearth of manpower in sea-going employment, which in part is driving a desire for automation, and the rapidly advancing technology of automation has already made experimental MASS a reality. But this is not necessarily a threat to job security. "The higher skill levels required for vessels that are becoming ever more technically complex means that operators need to be more, rather than less, skilled in order to successfully cope with these atypical conditions."[152]

There remains considerable skepticism regarding the ultimate benefit of automation: "The results from the STM (Sea Traffic Management) project [in Sweden] indicate that, although several of the STM services were useful, they caused changes to existing work practices which could impact communication structures, workload, and situational awareness;"[153] and "assuming that, overall, autonomous maritime systems are involved in fewer accidents than non-autonomous systems is also problematic."[154] The salient caution from this last report was that "Technology is not destiny."

Nonetheless, it predicted that such changes to the shipping industry are inevitable, most notably:

- Pilotage for transit in coastal waters (and possibly into the port and onto a berth) being provided from shore;
- Congested water-space being actively managed through the maritime equivalent of air traffic control; and
- International fleet control centres developed to monitor and manage fleets of digitally-connected ships throughout the world.

These changes are already feasible with currently available technologies. How much more common such practices become will be constrained not by technical advances, but by the pace of regulatory and legal changes that enable these as common practice. This in turn will be governed by the buy-in of the maritime industry, the rate of turnover in the global shipping fleet, and public acceptance.

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[151] Aylward, 2022.
[152] University of Southampton, 2017.
[153] Aylward, 2023.
[154] University of Southampton, 2017.

7.0 References

Allianz. 2023. Shipping and Safety Review: Report & Insights. https://commercial.allianz.com/news-and-insights/reports/shipping-safety.html, accessed 11 Jan 2024.

Australian Marine Pilots Association. (undated). Inquiry into managing fatigue in transport (submission to the House of Representatives Standing Committee on Communications, Transport and the Arts). https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjO2pvfsceDAxWMweYEHe4NBIsQFnoECBMQAQ&url=https%3A%2F%2Fwww.aph.gov.au%2Fparliamentary_business%2Fcommittees%2Fhouse_of_representatives_committees%3Furl%3Dcita%2Fmanfatigue%2Fsubmissions%2Fmfsub37.pdf&usg=AOvVaw0fFeHvfZWcCesH1IxebVH9&opi=89978449, accessed 12 Jan 2024.

Australasian Marine Pilots Institute (website). https://ampi.org.au/about-us/, accessed 12 Jan 2024.

Atlantic Pilotage Authority (website). Compulsory Areas. https://www.atlanticpilotage.com/operations/compulsory-areas/, accessed 10 Jan 2024.

Australian Government (website). 2023. Australian sea freight 2020–21 (Bureau of Infrastructure and Transport Research Economics Statistical Report). https://www.bitre.gov.au/sites/default/files/documents/Australian%20Sea%20Freight%202020-21.pdf, accessed 12 Jan 2024.

Aylward, Katie et al. 2022. Navigators' views of a collision avoidance decision support system for maritime navigation. https://www.cambridge.org/core/journals/journal-of-navigation/article/navigators-views-of-a-collision-avoidance-decision-support-system-for-maritime-navigation/077D42D9C3589DE03F941E635D175748, accessed 11 Jan 2024.

Baffinland Iron Mines. 2023. Instagram announcement, Baffinland Instagram, https://www.instagram.com/p/CzHVJexOrOD/, accessed 10 Jan 2024.

British Antarctic Survey (website). UK Polar Data Centre. https://www.bas.ac.uk/data/uk-pdc/, accessed 12 Jan 2024.

Bawlf, Samuel. 2004. The Secret Voyage of Sir Francis Drake. Penguin.

BC Cetaceans Sighting Network (website). Send a Sighting. Save a Whale! https://wildwhales.org/category/sightings/, accessed 11 Jan 2024.

Bijani, Amir. 2020. Remote-Guided Pickup Drop Off System (RGPDOS). https://ep.jhu.edu/wp-content/uploads/2020/09/se-seminar-series-a-bijandi.pdf, accessed 11 Jan 2024.

Brooks, Ben et al. 2016. Technological innovation in the maritime industry: The case of remote pilotage and enhanced navigational assistance. https://www.cambridge.org/core/journals/journal-of-navigation/article/technological-innovation-in-the-maritime-industry-the-case-of-remote-pilotage-and-enhanced-navigational-assistance/5B17E903DBA7D610872A40A49852BC0D, accessed 11 Jan 2024.

Bruno, Karl and Lutzhoft, Margareta. 2009. Shore-Based Pilotage: Pilot or Autopilot? Piloting as a Control Problem. http://us.lodstilsyn.dk/files/links/rapporter/shore-based%20pilotage_karl%20bruno_and_margareta_ltzhoft.pdf, accessed 11 Jan 2024.

Campbell Scientific (website). Radar Level Sensor. https://www.campbellsci.ca/rls, accessed 12 Jan 2024.

Carey, Luci. 2017. All Hands Off Deck? The Legal Barriers to Autonomous Ships. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3025882, accessed 11 Jan 2024.

Council of Canadian Academies. 2016. Commercial Marine Shipping Accidents: Understanding the Risks in Canada. Prepared for Clear Seas. https://cca-reports.ca/wp-content/uploads/2018/10/cca_marine_shipping_risks_en_fullreport.pdf, accessed 11 Jan 2024.

Canadian Coast Guard. e-Navigation Portal. https://e-navigation.canada.ca/index-en, accessed 11 Jan 2024.

Chave, R.A.J., Lemon, D.D. and D.B. Fissel. 2004. Real-Time Measurements of Ice Draft and Velocity in the St. Lawrence River. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=913bfd8162ff87f482f302316eeaa58a70b8dd0b, accessed 12 Jan 2024.

Cheng, Yuwei et al. 2021. Robust Small Object Detection on the Water Surface through Fusion of Camera and Millimeter Wave Radar. https://ieeexplore.ieee.org/document/9710582, accessed 11 Jan 2024.

Clear Seas. 2022. Demystifying Maritime Governance. https://clearseas.org/wp-content/uploads/2022/11/2022-Clear-Seas-Demystifying-Maritime-Governance.pdf, accessed 11 Jan 2024.

CMPA brief. (Undated). New Technologies and Canadian Pilotage. https://docs2.cer-rec.gc.ca/ll-eng/llisapi.dll/fetch/2000/90464/90552/548311/956726/2392873/3614457/3615225/3635252/3717037/A96323%2D9_New_technologies_and_Canadian_Pilotage_%2D_A6L3K1.pdf?nodeid=3717146&vernum=-2, accessed 11 Jan 2024.

CODAR Ocean Sensors (website). Supporting Critical Coastal Operations with Real-time Surface Current Data. https://codar.com, accessed 12 Jan 2024.

COWI (Danish Maritime Authority). 2014. Technological Assessment on the Possibility of Shore Based Pilotage in Danish Waters. http://www.balticpilotage.org/files/bpac%20-%20report%20-%20shore%20based%20pilotage%20-%2028.05.2015.pdf, accessed 11 Jan 2024.

Current Corp (website). The Science of Seeing. https://www.currentcorp.com, accessed 11 Jan 2024.

Daniamant (website). 3D Forward-looking Sonar. https://daniamant.com/products/echopilot-fls3d/, accessed 11 Jan 2024.

Danish Maritime Authority (website). Rules and Regulations. https://dma.dk/safety-at-sea/safety-of-navigation/pilotage/rules-and-regulations, accessed 12 Jan 2024.

Danpilot (website). https://www.danpilot.dk, accessed 12 Jan 2024.

DFO (website). Avadepth. https://www2.pac.dfo-mpo.gc.ca/index-eng.html, accessed 11 Jan 2024.

DFO (website). Community Hydrography. https://www.dfo-mpo.gc.ca/science/hydrography-hydrographie/opp-ppo/index-eng.html, accessed 11 Jan 2024.

DFO (website). Crowd-Sourced Bathymetry in the Northern Canada Area. https://www.dfo-mpo.gc.ca/science/partnerships-partenariats/research-recherche/its-sit/projects-projets/015-eng.html, accessed 11 Jan 2024.

DFO (website). S-100 Services for Safe and Optimized e-Navigation. https://www.dfo-mpo.gc.ca/videos/s-100-eng.html, accessed 11 Jan 2024.

Directemar Armada de Chile (website). Provisions, Regulations and General Information on Pilotage in Chile. https://www.directemar.cl/directemar/site/edic/base/port/estrechodemagallanes_en.html#:~:text=Pilotage%20policy,Chacao%20Channel%20and%20Cape%20Horn, accessed 12 Jan 2024.

Drewery Maritime Advisors. 2020. VFPA Long Term Container Forecast: 2020-2060 Final Report. https://www.portvancouver.com/wp-content/uploads/2021/03/Drewry-container-forecast-report-final.pdf, accessed 10 Jan 2024.

Drift + Noise (website). IcySea: An ice information app for navigation in polar regions. https://driftnoise.com/icysea/, accessed 11 Jan 2024.

Elva-1 (website). mm-Wave E-band Marine Radar. https://elva-1.com/blog/e-band-short-range-marine-radar-faq#1, accessed 11 Jan 2024.

European Maritime Safety Agency (website). https://www.emsa.europa.eu/about.html, accessed 12 Jan 2024.

European Maritime Safety Agency. 2023. Identification of Competences for MASS Operators in Remote Operations Centres. https://www.emsa.europa.eu/publications/reports/item/5089-cmoroc-mass.html, accessed 26 Mar 2024.

Etymology Online (website), https://www.etymonline.com/word/pilot, accessed 10 Jan 2024.

European Union. 2012. Study on Pilotage Exemption Certificates. https://transport.ec.europa.eu/system/files/2016-09/2012-09-18-pec.pdf, accessed 11 Jan 2024.

Farsounder (website). Argos Navigation Sonars. https://www.farsounder.com/argos-navigation-sonars, accessed 11 Jan 2024.

Fednav (website). ICENAV: At the Forefront of Ice Navigation Technology. https://www.fednav.com/en/icenav-forefront-ice-navigation-technology, accessed 11 Jan 2024.

Fenton, Adam James and Chapsos, Ioannis. 2023. Ships Without Crews: IMO and UK responses to cybersecurity, technology, law and regulation of maritime autonomous surface ships (MASS). https://www.frontiersin.org/articles/10.3389/fcomp.2023.1151188/full, accessed 11 Jan 2024.

Findaport (website). Chile. https://www.findaport.com/country/chile, accessed 12 Jan 2024.

Finnpilot (website). Annual Report 2022. https://finnpilot.fi/wp-content/uploads/2023/03/Finnpilot_annualreport_2022.pdf, accessed 12 Jan 2024.

Furuno Finland (website). Ice Radar FICE-100. https://www.furuno.fi/eng/merchant_marine/navigation_products/ice_radar/, accessed 11 Jan 2024.

Furuno (website). 1st Watch Wireless Radar. https://www.furuno.com/en/products/radar/drs4w, accessed 11 Jan 2024.

Furuno (website). Augmented Reality Navigational Concept. https://www.furuno.com/special/en/envision/, accessed 12 Jan 2024.

Furuno (website). NAVNet 3D. https://www.furunousa.com/-/media/sites/furuno/document_library/documents/brochures/brochures/navnet_3d_brochure.pdf, accessed 11 Jan 2024.

Furuno (website). Network Multi-Beam Sonar. https://www.furuno.com/special/en/fishfinder/dff-3d/, accessed 11 Jan 2024.

Furuno (website). Wave Analyzer. https://www.furuno.com/en/merchant/wave-analyzer/, accessed 11 Jan 2024.

Galliard, Andre. Accidentology of the Past 20 Years Within the French Maritime Pilotage. https://www.impahq.org/sites/default/files/content-files/Capt.%20André%20Gaillard.pdf, accessed 11 Jan 2024.

Global Newswire. 2023. Dry Bulk Shipping Market is Anticipated to Grow at a CAGR of 4% by 2030. https://www.globenewswire.com/en/news-release/2023/04/26/2655215/0/en/Dry-Bulk-Shipping-Market-is-Anticipated-to-Grow-at-a-CAGR-of-4-by-2030-Report-by-Market-Research-Future-MRFR.html, accessed 10 Jan 2024.

Great Lakes Pilotage Authority (website). Compulsory Pilotage in the Great Lakes Region. https://www.glpa-apgl.com/passage-plan/great-lakes-region-passage-plan/, accessed 10 Jan 2024.

Gravendeel, A. et al. 2017. Automatic Berthing. http://www.maritimesymposium-rotterdam.nl/uploads/Route/Automatic%20berthing.pdf, accessed 11 Jan 2024.

Gravity Industries (website). Flight Club. https://gravity.co, accessed 11 Jan 2024.

Greenwood, Nigel S. 2014. LNG Helicopter Risk Assessment (Report Prepared for PPA).

Greenwood, Nigel S. 2016. Berthing Risk Assessment (Report for PPA and VFPA).

Greenwood, Nigel S. 2018. Proactive Vessel Management (Report for Transport Canada).

Gregoire, Marc. 2018. Pilotage Act Review Final Report. https://tc.canada.ca/en/legislative-reviews/pilotage-act-bill-c-97/pilotage-act-review-final-report-april-2018, accessed 12 Jan 2024.

Grundman, Robert, et al. 2023. Use Case Remote Pilotage – Technology Overview. https://iopscience.iop.org/article/10.1088/1742-6596/2618/1/012007/pdf, accessed 11 Jan 2024.

Holder, E., & Pecota, S. 2011. Maritime Head-Up Display: A Preliminary Evaluation. *The Journal of Navigation, 64*(4), 573-594. doi:10.1017/S0373463311000191. https://www.cambridge.org/core/journals/journal-of-navigation/article/abs/maritime-headup-display-a-preliminary-evaluation/F61E84D3D543E5BB15CAD3C2C46B7B29, accessed 11 Jan 2024.

Hovda, Knut. 2021. Pilotage Methods (Master's Thesis). https://hvlopen.brage.unit.no/hvlopen-xmlui/handle/11250/2765799, accessed 11 Jan 2024.

IALA. 2024. Future Scenarios Regarding the Development and Evolution of MASS. https://www.iala-aism.org/sailing-into-the-future-of-autonomous-ships/, accessed 26 Mar 2024.

IHO (website). S-100 Demonstrator Project. https://s-100.no/operational-test-s-129-under-keel-clearance-management-tested-in-tjeldsundet-norway/, accessed 12 Jan 2024.

IHO (website). S-100 Universal Hydrographic Data Model. https://iho.int/en/s-100-universal-hydrographic-data-model, accessed 11 Jan 2024.

IMO (website). Maritime Single Window. https://www.imo.org/en/OurWork/Facilitation/Pages/MaritimeSingleWindow-default.aspx, accessed 11 Jan 2024.

ISTLAB (website). Intelligent Shipping Technology Test Laboratory (ISTLAB). https://istlab.samk.fi, accessed 11 Jan 2024.

JASCO. 2022. JASCO, BO-MTS and OCIUS demonstrate cutting-edge capabilities in Real-Time Marine Mammal Acoustic Monitoring. https://www.jasco.com/press-releases/2023/real-time-marine-mammal-acoustic-monitoring#:~:text=–In%20September%202023%2C%20JASCO%20Applied,underwater%20vehicles%20(AUVs)%20and%20uncrewed, accessed 11 Jan 2024.

Kongsberg (website). Video: Kongsberg Maritime - Remote operation center. https://www.youtube.com/watch?v=UPtdgiIrlJI, accessed 11 Jan 2024.

Kowarski, Katie et al. 2020. Near real-time marine mammal monitoring from gliders: Practical challenges, system development, and management implications. http://whitelab.biology.dal.ca/hw/Kowarski_et_al_JAE_2020.pdf, accessed 11 Jan 2024.

Laera, F., Fiorentino, M., Evangelista, A., Boccaccio, A., Manghisi, V., Gabbard, J., . . . Foglia, M. (2021). Augmented reality for maritime navigation data visualisation: A systematic review, issues and perspectives. The Journal of Navigation, 74(5), 1073-1090. doi:10.1017/S0373463321000412. https://www.cambridge.org/core/journals/journal-of-navigation/article/abs/augmented-reality-for-maritime-navigation-data-visualisation-a-systematic-review-issues-and-perspectives/934E94814CCD6F89F1F25E4458BC60AB, accessed 11 Jan 2024.

Lahtinen, Janne et al. 2020. Remote piloting in an intelligent fairway – A paradigm for future pilotage. https://www.sciencedirect.com/science/article/abs/pii/S0925753520302861, accessed 11 Jan 2024.

Landry, Etienne (LPA). 2023. Brief: Optimum Pilotage Services Project. (Personal communication from Clear Seas).

Leblanc, Mark (CHS). 2023. Canadian Hydrographic Service Briefing (personal communication).

Lehtovaara, Eero. White Paper: Autonomous Ships and Safety at Sea. https://www.iims.org.uk/wp-content/uploads/2021/07/Autonomous-ships-and-safety-at-sea-whitepaper.pdf, accessed 12 Jan 2024.

Lewin, Gary. Helicopter Use in IMPA on Pilotage. https://docs2.cer-rec.gc.ca/ll-eng/llisapi.dll/fetch/2000/90464/90552/548311/956726/2392873/3614457/3615225/3635252/3717037/A96323%2D14_IMPA_on_Pilotage_%2D_Helicopter_Use_%2D_A6L3K6.pdf?nodeid=3716832&vernum=-2, accessed 11 Jan 2024.

Lindborg, Liro. 2021. S11 – Autonomy Simplified: Conceptual Approach to Remote Pilotage. https://www.linkedin.com/pulse/s11-autonomy-simplified-conceptual-approach-remote-iiro-lindborg, accessed 11 Jan 2024.

Marine Pilots. 2020. Physical Pilot Ladder Simulator (Chile). https://www.marine-pilots.com/videos/157338-physical-pilot-ladder-simulator-chile, accessed 5 Jan 2024.

Marine Regulations (website). Finland: Ministry of Transport and Communications has published the Pilotage Act. https://www.marineregulations.news/finland-ministry-of-transport-and-communications-has-published-the-pilotage-act/, accessed 12 Jan 2024.

Mech, Konrad. 2022. Kongsberg Brief for AAPA, Maritime Civil Engineering Applications and Solutions. https://aapa.cms-plus.com/files/AAPA_FacEngPPTJun2022.pdf, accessed 23 Nov 2023

Mercator International. 2021. Appendix IR2020-3-B Updated Roberts Bank Terminal 2 container vessel call forecast study, IAAC, 2020. https://iaac-aeic.gc.ca/050/documents/p80054/141575E.pdf, accessed 20 Nov 2023

Miros (website). Why Measure Air-Gap? https://www.miros-group.com/air-gap-why-measure-it-at-all/, accessed 11 Jan 2024.

Norwegian Coastal Administration (Kystverket) (website). https://www.kystverket.no/en/pilotage-service-and-pilotage-exemption-certificate/pilotage/compulsory-pilotage/, accessed 12 Jan 2024.

Negenborn, Rudy R., et al. 2023. Autonomous ships are on the horizon: here's what we need to know. https://northsearegion.eu/media/23978/20230630-rudy-negenborn.pdf, accessed 26 Mar 2024.

Nippon Foundation (website). MEGURI2040 Fully Autonomous Ship Program. https://www.nippon-foundation.or.jp/en/what/projects/meguri2040, accessed 12 Jan 2024.

Nishant, Shankar. 2023. How Autonomous ships are revolutionizing the maritime industry. https://maritime-professionals.com/how-autonomous-ships-are-revolutionizing-the-maritime-industry/, accessed 11 Jan 2024.

NOAA (website). Custom Chart. https://nauticalcharts.noaa.gov/updates/noaa-custom-chart-version-2-0-now-available-to-the-public/, accessed 11 Jan 2024.

NOAA (website). PORTS (Physical Oceanographic Real-Time System). https://tidesandcurrents.noaa.gov/ports.html, accessed 11 Jan 2024.

NOAA (website). Real-Time Observations. https://marinenavigation.noaa.gov/observations.html, accessed 11 Jan 2024.

National Research Council of Canada (website). Canadian Arctic Shipping Risk Assessment System (CASRAS). https://nrc.canada.ca/en/research-development/products-services/technical-advisory-services/canadian-arctic-shipping-risk-assessment-system-casras, accessed 11 Jan 2024.

Ocean Networks Canada (website). Prince Rupert Regional Ocean Observatories. https://data.oceannetworks.ca/PrinceRupertPort?rotatemin=0&refreshsec=0&qpddr=L10, accessed 12 Jan 2024.

Olcer, A.I., et al. 2023. Transport 2040: Impact of Technology on Seafarers - The Future of Work. https://commons.wmu.se/lib_reports/78/, accessed 11 Jan 2024.

OLEX. Bathydata in Olex. https://www.olex.no/depthcharts_en.html, accessed 11 Jan 2024.

OLEX. Software. https://www.olex.no/products/olex_software_en.html, accessed 11 Jan 2024.

Orange Force Marine (website). Crowdsourced Bathymetry. https://www.orangeforcemarine.com/crowdsourced-bathymetry, accessed 11 Jan 2024.

Port Revel (website). Manned Model Training. https://www.portrevel.com, accessed 11 Jan 2024.

Portlink Global. Port Management Information System (PMIS). https://www.portlinkglobal.com/solutions, accessed 11 Jan 2024

Port Skills and Safety. 2012. Marine Accident Data Study 2012 [UK Ports]. https://www.portskillsandsafety.co.uk/files/2017-05/2012%20Marine%20Accident%20Study%20-%20UK%20Ports%20-%20Final_0.pdf, accessed 11 Jan 2024.

Rinkinen, Antti. 2022. Remote Pilotage. https://www.marine-pilots.com/articles/386923-book-remote-pilotage-by-antti-rinkinen, accessed 11 Jan 2024.

Riviera (website). 2023. NYK to roll out Orca AI platform across fleet. https://www.rivieramm.com/news-content-hub/news-content-hub/nyk-to-roll-out-orca-ai-platform-across-fleet-75846, accessed 11 Jan 2024.

Rolls Royce. 2023. Autonomous Ships: The Next Step. https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/%20customers/marine/ship-intel/rr-ship-intel-aawa-8pg.pdf, accessed 11 Jan 2024.

Royal Navy (website). 2021. Royal Marines trial use of jet suit for boarding operations. https://www.royalnavy.mod.uk/news-and-latest-activity/news/2021/may/05/050521-boarding-trials#:~:text=Royal%20Marines%20have%20tested%20the,military%20operations%20in%20the%20future, accessed 11 Jan 2024.

Rylander, Robert and Man, Yemao. 2016. Autonomous safety on vessels, an international overview and trends within the transport sector. https://seatracker.ru/viewtopic.php?t=29776, accessed 11 Jan 2024.

Sea AI (website). Machine Vision for Safety at SEA. https://sea.ai, accessed 11 Jan 2024.

Shipnet. 2023. The Outlook for the Dry Bulk Market 2023 – 2030. https://www.shipnet.no/articles/the-outlook-for-the-dry-bulk-market-2023-2030#:~:text=From%202023%20to%202030%2C%20the%20global%20shipping%20industry%20is%20set,in%20the%20dry%20bulk%20market, accessed 10 Jan 2024.

Shipping Australia (website). 2023. Under the microscope: AMSA announces coastal pilotage review. https://www.shippingaustralia.com.au/under-the-microscope-amsa-announces-coastal-pilotage-review/, accessed 12 Jan 2024.

Soyer, B., Tettenborn, A. and Leloudas, J. 2022. Remote Controlled and Autonomous Shipping: UK Based Case Study. https://www.swansea.ac.uk/media/Remote-Control-and-Autonomous-Shipping-Final.pdf, accessed 11 Jan 2024.

Splash247.com. 2023. Port of Montreal receives funding for expansion project in Contrecoeur. https://splash247.com/port-of-montreal-receives-funding-for-expansion-project-in-contrecoeur/, accessed 10 Jan 2024.

Scott Polar Research Institute, https://www.spri.cam.ac.uk, accessed 10 Jan 2024.

Starlink (website). https://www.starlink.com, accessed 11 Jan 2024.

Sudom, Denise et al. 2023. NRC Canadian Arctic Shipping Risk Assessment System (CASRAS): Report for Fiscal Year 2021-22. https://nrc-publications.canada.ca/eng/view/ft/?id=3a748ae9-588d-4ed2-8ca4-5577401ef729, accessed 11 Jan 2024.

Szlapczynski, R., & Szlapczynska, J. 2015. A Target Information Display for Visualising Collision Avoidance Manoeuvres in Various Visibility Conditions. The Journal of Navigation, 68(6), 1041-1055. doi:10.1017/S0373463315000296. https://www.cambridge.org/core/journals/journal-of-navigation/article/abs/target-information-display-for-visualising-collision-avoidance-manoeuvres-in-various-visibility-conditions/EFE4220DD261BE19DAE4CC6E0F94D467, accessed 11 Jan 2024.

Transport Canada (website). Enhanced Maritime Situational Awareness. https://tc.canada.ca/en/campaigns/protecting-our-coasts-oceans-protection-plan/stronger-partnerships-indigenous-coastal-communities/expanding-enhanced-maritime-situational-awareness-program, accessed 11 Jan 2024.

Transportation Economics & Management Systems Ltd. 2023. Marine Pilotage in Canada. Report prepared for CMPA. https://www.marinepilots.ca/news-docs/Canadian-Pilotage-Cost-Benefit-Analysis-2023.pdf, accessed 11 Jan 2024.

The Maritime Executive. 2022. First Autonomous Navigation and Berthing Test on a Containership. https://maritime-executive.com/article/first-autonomous-navigation-and-berthing-test-on-a-containership#:~:text=A%20Japanese%20containership%20completed%20the,Foundation%20to%20develop%20autonomous%20shipping, accessed 11 Jan 2024.

Thoresen, Carl A. 2018. Port Designer's Handbook. Ice Publishing, London.

Trelleborg (website). Automated Mooring Systems. https://www.trelleborg.com/en/marine-and-infrastructure/products-solutions-and-services/marine/docking-and-mooring/automated-mooring-systems, accessed 11 Jan 2024.

Transportation Safety Board of Canada. 1995. MOR SM9501, A Safety Study of the Operational Relationship Between Ship Masters/Watchkeeping Officers and Marine Pilots. https://www.tsb.gc.ca/eng/rapports-reports/marine/etudes-studies/SM9501/SM9501.html, accessed 11 Jan 2024.

Transportation Safety Board of Canada. 2022. Marine transportation occurrences in 2022. https://www.tsb.gc.ca/eng/stats/marine/2022/ssem-ssmo-2022.html, accessed 11 Jan 2024.

UK Admiralty (website). Admiralty Maritime Data Solutions. https://www.admiralty.co.uk, accessed 11 Jan 2024.

University of Southampton, Lloyds Register and Qinetiq. 2017. Global Marine Technology Trends 2030; Autonomous Systems. https://www.southampton.ac.uk/smmi/news/2017/09/12-gmtt2030-autonomous-systems.page, accessed 12 Jan 2024.

Utmel Electronic (website). Millimeter Wave Radar: Advantages, Types, and Applications. https://www.utmel.com/blog/categories/sensors/millimeter-wave-radar-advantages-types-and-applications, accessed 11 Jan 2024.

Vancouver Fraser Port Authority. Active Vessel Traffic Management Program. https://www.portvancouver.com/marine-operations/avtm/, accessed 10 Jan 2024.

Vancouver Fraser Port Authority. Enhancing Cetacean Habitat and Observation (ECHO) Program. https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/, accessed 10 Jan 2024.

Wavefront Systems (website). Vigilant Forward Looking Sonar (FLS) for Crewed Surface. https://www.wavefront.systems/vigilant-crewed-surface/, accessed 11 Jan 2024.

Wollebaek, Anette Bonnevie. 2014. Envisioning seafaring in 2025. https://phys.org/news/2014-03-envisioning-seafaring.html, accessed 12 Jan 2024.

Yukinori, Hashino. 2022. Japanese Consortium Ticks Off Autonomous Shipping Milestone. https://www.nippon.com/en/japan-topics/g02047/#:~:text=A%20recent%20autonomous%20test%20voyage,the%20commercialization%20of%20the%20technology, accessed 11 Jan 2024.

Zitterbart, Dan, et al. 2023. Brief to Canadian Maritime Advisory Committee "From Coast to Coast: Increasing whale detection capacity in the Canadian Atlantic…." (Private communication from Clear Seas). (Final Report 2023 https://apps.dtic.mil/sti/trecms/pdf/AD1207369.pdf, accessed 11 Jan 2024.