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Vessel Traffic Services, Use of Automatic Identification System and Radar

Final Report

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Acronyms and Abbreviations

ADAC	Arctic Domain Awareness Center
AIS	Automatic Identification System
AMHS	Alaska Marine Highway System
ARPA	Automatic Radar Plotting Aids
ASM	Application Specific Message
COLREGs	International Regulations for Preventing Collisions at Sea
CS	Carrier Sense
CSTDMA	Carrier Sense Time-Division Multiple Access
FMCW	Frequency Modulated Continuous Wave
FSA	Formal Safety Assessment
GHZ	Gigahertz
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HCPV	High Capacity Passenger Vessel
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IMO	International Maritime Organization
ITU	International Telecommunications Union
M	Meters
MMSI	Maritime Mobile Service Identity
PCA	Point of Closest Approach
PFA	Probability of False Alarm
POD	Probability of Detection
PWS	Prince William Sound
PWSRCAC	Prince William Sound Regional Citizens' Advisory Council
RCS	Radar Cross Section
SA	Situational Awareness
SAIS	Satellite AIS
SO	Self-Organized
SOLAS	International Convention for the Safety of Life at Sea
SOTDMA	Self-Organized Time-Division Multiple Access
TPCA	Time to Point of Closest Approach
TSS	Traffic Separation Scheme
USCG	U.S. Coast Guard
VHF	Very High Frequency
VMRS	Vessel Movement Reporting System
VMT	Valdez Marine Terminal
VTS	Vessel Traffic Service
VTSA	VTS Area
VTSO	VTS Operator

Executive Summary

This report, for the Prince William Sound Regional Citizens' Advisory Council (PWSRCAC), discusses the capabilities, limitations, and synergies of radar and Automatic Identification System (AIS) information in Vessel Traffic Service (VTS) operations based on published literature and on relevant documentation from the International Maritime Organization (IMO) and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA). Specific context of the Prince William Sound (PWS) VTS issues that affect local marine users is presented through summaries of PWS stakeholder consultations.

According to the guidelines provided through the IMO and the IALA documentation, as well as publications on VTS operations, radar is the primary sensor for ensuring situational awareness (SA) within the critical sectors of a VTS area (VTSA), since it obtains position, track, and size information without any cooperation from the targets (IALA 2016). Radar can also provide information on ice conditions. Even though radar may have some weaknesses, it is under the control of the VTS and therefore can help increase understanding of potential issues due to configurations and technical limitations (Brödje, Lützhöft, and Dahlman 2010). More recent solid-state radars and advanced processing can provide high spatial resolution at all ranges and discriminate small targets in adverse clutter and interference (Zhang, Dong, and Liu 2013; Amato et al. 2010).

AIS provides supplemental information such as vessel identity, call sign, and voyage related data. It is especially relevant where vessels may be obscured from other sensors and in areas outside radar coverage. AIS can be a means to provide advance notice of vessels entering a VTSA, especially if satellite AIS (SAIS) is available (IALA 2015a). However, since not all vessels carry AIS or use it reliably, AIS information does not guarantee a comprehensive overview of the traffic in the service area. This is especially relevant for the PWS VTSA, since the majority of users do not use AIS (Miller 2020). Further understanding of the issues associated with using AIS alone within designated sectors of the PWS VTSA could be achieved through a risk analysis that incorporates the details of the PWS system and environment.

Radar is a necessity for VTS, since it can actively monitor smaller vessels without AIS and it provides a means to monitor other objects such as ice. In the context of PWS in particular, the VTS is necessary for the prevention of oil spills, collisions, and loss of life. In contrast, AIS obviously cannot provide information on vessels that operate without AIS, which comprise the majority of vessels operating in PWS (Miller 2020), and therefore AIS cannot be used to identify potential collisions or obstructions in these situations (Lin and Huang 2006). AIS is only as accurate as the information provided to the AIS transponders and receivers. AIS data has been found to contain errors in position, speed, and timestamps and can cause problems for mapping ship routes. The dynamic information in the AIS message relies on GNSS and other ship equipment, and nearly all other static and voyage information is manually entered and updated. This human input leads to unintentional errors in the transmitted data. The range of AIS is influenced by many factors, including height and quality of the ship's antenna, signal strength (power), and obstructions including hills and other topographic features. Smaller vessels using lower power Class B AIS and shorter antennas would have their range significantly reduced compared to a tanker using Class A AIS. The topography around coastal AIS stations can create blind spots, especially for smaller ships. This is particularly relevant in the context of PWS, with its many fjords, bays, and mountains. In practice, VTS operators prioritize very high frequency (VHF) radio and radar, with AIS regarded as being less reliable

and which is therefore used as a complement for providing additional information such as name, call sign, and speed.

When a VTS operates without radar, the responsibility of situational awareness (detecting and monitoring ships) shifts from the port authorities to the ship operators and their equipment. This significantly increases the risk of a ship collision since it moves situational awareness from a single point of failure to many points of failure. This risk increases rather considerably during peak traffic seasons (i.e., tourism and fishing season). Considering that the risk is unquantified in this instance for PWS, stakeholders may wish to consider a risk assessment to quantify impact of equipment failure on people, infrastructure, and the environment. This risk can then be weighed against the cost of ensuring that there is adequate redundancy to essential VTS equipment, including radars. Nonetheless, in the context of the 1989 Exxon Valdez oil spill, the cost benefit may be obvious.

Based on the above, it is recommended that the Valdez VTS bring back all three of its radar sites into full operations and make contingencies for backup radar units at each of the three sites. Reliance on AIS as the primary tracking sensor for VTS operations is deemed to be inadequate and is contrary to the guidelines provided by the IMO and the IALA.

1 Vessel Traffic Services, Radar, and Automatic Identification System

1.1 Introduction

This report, for the Prince William Sound Regional Citizens' Advisory Council (PWSRCAC), discusses the capabilities, limitations, and synergies of radar and Automatic Identification System (AIS) information in Vessel Traffic Service (VTS) operations, based on published literature and on relevant documentation from the International Maritime Organization (IMO) and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA).

The remaining sections of this chapter outline the general VTS requirements and operations for radar and AIS, followed by overviews of current radar and AIS technology, and of the Prince William Sound (PWS) VTS operations. The second chapter provides context for the PWS VTS issues that affect local marine users, by presenting summaries of PWS stakeholder consultations that were carried out within this project. The third chapter discusses the various information that was compiled, along with providing summaries of current limitations of available pertinent research, and recommendations for further research. An approach is outlined for risk analysis of issues associated with reliance on using AIS without radar for VTS surveillance in specific sectors of the PWS VTS area. Final conclusions are discussed at the end. Appendix A lists the primary literature that was considered for this report, along with brief summaries of each reference.

1.2 VTS Requirements and Operations — Radar and AIS

According to the International Convention for the Safety of Life at Sea (SOLAS) Chapter V (Safety of Navigation) Regulation 12, the purpose of VTS is, in part, "to contribute to safety of life at sea, safety and efficiency of navigation and protection of the marine environment, adjacent shore areas, work sites and offshore installations from possible adverse effects of maritime traffic" (IALA 2021). The IMO Guidelines for VTS (IMO 1997) highlight the basis for a VTS and the factors affecting its operation — the fundamental bases are captured in the statements noted below.

> The benefits of implementing a VTS are that it allows identification and monitoring of vessels, strategic planning of vessel movements and provision of navigational information and assistance. It can also assist in prevention of pollution and co-ordination of pollution response. (IMO 1997).
>
> The efficiency of a VTS will depend on the reliability and continuity of communications and on the ability to provide good and unambiguous information. The quality of accident prevention measures will depend on the system's capability of detecting a developing dangerous situation and on the ability to give timely warning of such dangers. (IMO 1997).
>
> A VTS should at all times be capable of generating a comprehensive overview of the traffic in its service area combined with all traffic influencing factors. The VTS should be able to compile a traffic image, which is the basis for its capability to respond to traffic situations developing in its service area. (IMO 1997).

Furthermore, the IMO Guidelines state that the Competent Authority should establish appropriate standards for equipment and ensure that the necessary facilities are provided to effectively accomplish the objectives of the VTS, relating to the capability to monitor traffic within the VTS area, interact with the vessel traffic and respond to developing situations (IALA 2015b).

IALA documentation provides detailed overviews of the regulatory background for VTS, as well as the standards associated with the implementation and operation of VTS. Of particular interest to the current report are the sections relating to the use of radar and AIS, which are discussed, for instance, in the IALA Guideline 1111 (IALA 2015a).

VTS radar systems should satisfy the identified operational and functional requirements such as coverage, targets, target separation, and environmental capabilities as well as specific security requirements that may be associated with, for example, small targets, especially in adverse clutter conditions or in the presence of large targets (IALA 2015a). Radar is of particular use in contributing to VTS situational awareness (SA) since it obtains position, track, and size information without any cooperation from the targets (IALA 2016). This is especially relevant for vessels that do not carry or do not have a functioning AIS transmitter, have an incorrect installation of an AIS, have incorrect sensor information connected to an AIS, have incorrect user information entered in the AIS, or purposely transmit incorrect AIS messages. Furthermore, VTS radar ensures that significant objects such as ice, when present, can be monitored within the VTS area (VTSA).

AIS messages, especially if satellite AIS (SAIS) reception is incorporated, can often provide advance notice of vessels entering a VTSA. More especially, the AIS data available within the VTSA provide supplemental information for VTS radar detected targets. However, since not all vessels carry AIS or use it reliably, AIS information does not guarantee a comprehensive overview of the traffic in the service area.

1.3 Radar Technology

The options for VTS radar surveillance are discussed in the IALA Guidelines (IALA 2015). VTS radar should be based on operational and validation requirements for the VTSA, and these should consider factors such as:

- Radar coverage of the VTSA, as well as locations and obstructions;
- Targets to be detected (e.g., size or radar cross section (RCS)) and speed;
- Target separation and location accuracy; and
- Environmental conditions (e.g., weather and sea state).

The requirements may also involve specific security issues such as the detection of small targets in clutter or in the presence of large targets. Detection of pollution may also be a requirement.

The IALA Guideline gives an overview of three technologies used for VTS radars, namely pulse, pulse compression, and frequency modulated continuous wave (FMCW). A pulse radar is based on high peak power and short-duration pulses, usually from a magnetron, and while it is a well-known technology, it does not provide the detection and discrimination options available with newer solid-state technologies. A pulse compression radar transmits a low peak-power, modulated chirp, which enables good range resolution at all ranges and better small target detection in adverse weather conditions. A FMCW radar transmits low peak power, continuous waveforms, which enables high range resolution at all ranges, including very short ranges.

Doppler processing within the coherent radars also provides better clutter discrimination. Furthermore, multi-frequency wideband transmission enables target and clutter decorrelation, such that targets are not missed through destructive interference during the radar illumination time and conversely that sources of clutter are not falsely detected through constructive interference (Amato et al. 2010).

Primary marine radars are in the X-band with frequencies from 8 to 12 gigahertz (GHz). This provides good resolution while using reasonably sized antennas, although X-band radiation is affected by precipitation (rain, fog, and wet snow). Radars that use S-band, with frequencies from 2 to 4 GHz, are affected less by rain and fog, but have lower resolutions and need larger antennas. The S-band RCS for targets are generally around 40% of those at X-band, with the S-band RCS for small non-metallic targets being relatively even smaller (IALA 2015). For enhanced detection of targets for ice navigation and search and rescue, supplemental radar processors can be used to increase the contrast of small targets on a radar display, such a persons in the water or small icebergs. A system of this nature was once installed with the Reef Island radar in PWS. C-CORE previously prepared a document for PWSRCAC on the benefits of various radar systems for ice detection (C-CORE 2013), which is suggested reading for anyone who is interested in a more detailed description of radar performance.

1.4 AIS Technology

1.4.1 Background

AIS was originally developed for ship-to-ship collision avoidance, as a means for coastal authorities to obtain information about a ship and its cargo and for ship-to-shore communication as a VTS tool (Tetreault 2010).

After the Exxon Valdez oil spill in 1989, Congress enacted legislation which included a provision to monitor tanker traffic to and from Valdez, Alaska. The U.S. Coast Guard (USCG) Office of Vessel Traffic Management researched various methods to improve vessel tracking and at the same time authorities from other countries were researching their own technologies. In an effort to standardize these automatic vessel identification systems, the International Telecommunications Union (ITU) and the IMO developed and adopted the AIS used today (Arroyo 2011).

The IMO mandated the use of Class A AIS for all ships over 300 gross tonnage on international voyages, ships over 500 gross tonnage not on international voyages, and all passenger ships regardless of size, by 2004 through the SOLAS convention. In 2006, specifications were published for a lower power, lower cost version of AIS, called Class B, for voluntary use by any ship not covered by the Class A regulations.

Since 2008, the ship-to-ship and ship-to-shore capability of AIS have been greatly expanded to global coverage through the reception of AIS signals from satellite. SAIS began in the early 2010s with only a few operational satellites. As of 2020, there were over 100 AIS enabled satellites in orbit from companies such as exactEarth, ORBOCMM, and Spire. In particular, exactEarth with over 60 satellites claims to offer global, persistent coverage with no gaps[1].

1.4.2 AIS Technology

AIS technology is based on the automatic transmission of vessel information at specific reporting intervals using very high frequency (VHF) radio broadcasts. There are two forms of AIS: Class A and Class B. The IMO mandate for AIS refers to Class A, while Class B is used on a voluntary basis typically by smaller or recreational vessels.

Using the self-organized time-division multiple access (SOTDMA) protocol, Class A AIS-enabled ships within range of other ships and coastal stations are able to automatically and autonomously determine available slots for message transmission (Tetreault 2005). The original Class B 'Carrier Sense' (CS) specification used a carrier sense time-division multiple access (CSTDMA) scheme that first listened for available slots before broadcast. Class B 'Self-Organized' (SO) was later added that uses the same SOTDMA protocol as Class A.

The nominal range for a Class A shore-to-ship signal is 40 nautical miles and 20 nautical miles for ship-to-ship. This range is primarily based on the height and quality of the transmitting and receiving antennas. Class B AIS operating at a lower power has nominal ranges of 5 to 15 nautical miles[2]. Within these self-organizing regions the theoretical capacity of AIS is approximately 4,000 ships (Fournier et al. 2018).

For SAIS, the satellites in low Earth orbit see a much larger area, typically around 3,000 nautical miles in diameter. The satellite field of view contains many of the SOTDMA self-organizing regions and while within each of these cells the messages are automatically scheduled, in general there is no scheduling between the regions. As a result, messages from different regions can arrive at the satellite at the same time in a process called message collisions.

There are 27 different types of AIS messages categorized in four general types of information: static data (e.g., ship name, dimensions, and ship type), dynamic data (e.g., position, speed over ground, course over ground, and heading), voyage data (e.g., destination, draught, and cargo) and safety related data (e.g., short text messages). The 27th message was added by the ITU in 2010 for improved satellite detection of AIS by reducing the message size, transmitting every three minutes, and only transmitting outside the range of an AIS base station.

The AIS message reporting interval is dependent on the type of message being sent (ITU-R 2014). For static and voyage information the interval is every six minutes. The dynamic message interval is based on a vessel's speed and course alteration and range from every 3 minutes to 2 seconds. For example, ships travelling under 14 knots transmit every 10 seconds but every 3.33 seconds if also changing course.

[1] https://www.exactearth.com/product-exactais
[2] https://www.milltechmarine.com/Class-B-AIS-Transponders_c_43.html

The information contained in the AIS messages are either from external shipboard equipment or manually entered by the ship crew. The dynamic information in AIS messages is obtained from other shipboard equipment, including the heading, speed, and course. The position and time information is from an integral or external global navigation satellite system (GNSS), for example Global Positioning System (GPS). All the static and voyage information in the messages are manually entered and updated by the ship crew and includes the Maritime Mobile Service Identity (MMSI), ship name, and dimensions, among others.

1.4.3 AIS Considerations for VTS

It is clear that AIS has an important role to play in a modern VTS, particularly in vessel identification. The IMO Resolution for the onboard operational use of AIS notes that AIS is a useful source of supplementary information to that derived from navigational systems (including radar) and therefore an important tool in enhancing situation awareness of traffic confronting users (IMO 2015). However, with the widespread use and availability of AIS it is important to highlight some of the limitations.

A primary issue for AIS as a VTS tool is that not all vessels carry AIS. As noted earlier, AIS is mandated for certain types of ships, but use by smaller vessels is voluntary. IMO regulations also allow for AIS to be switched off when the ship master believes the safety or security of the ship could be compromised. There are also no security mechanisms in the AIS equipment to prevent it from being intentionally or unintentionally disabled.

AIS is only as accurate as the information provided to the AIS transponders and receivers. As noted by Emmens et al. (2021), AIS data has been found to contain errors in position, speed, and timestamps and can cause problems for mapping ship routes. The dynamic information in the AIS message relies on GNSS and other ship equipment, and nearly all other static and voyage information is manually entered and updated. This human input leads to unintentional errors in the transmitted data, and of particular importance is the MMSI number, which is used to uniquely identify a ship.

The range of AIS is influenced by the same factors as VHF, including height and quality of the antenna, signal strength (power), and obstructions including hills and other topographic features. Smaller vessels using lower power Class B AIS and shorter antennas would have their range significantly reduced compared to a tanker using Class A AIS. The topography around coastal AIS stations can create blind spots especially for smaller ships. SAIS can extend the AIS reception to global coverage, but in general SAIS provides a lower rate of reporting of dynamic ship information to allow for ship route monitoring applications (Cervera and Ginesi 2008). Unlike terrestrial AIS systems that attempt to detect most AIS transmitted messages for VTS applications, typical SAIS applications do not require that all messages are detected. This is because SAIS is meant for vessel monitoring rather than collision avoidance. As a consequence to its design and wide area field of view from space, SAIS suffers from gaps in satellite coverage, latency from satellite reception of a message to when it is available for a user, and message collisions from a large density of ships in the satellite's field of view. These issues were once very significant, however, advances in SAIS technology including large satellite constellations (greater than 50 satellites), wide networks of ground stations, and additional de-collision processing techniques, have reduced the impact of these issues.

In summary, relying on AIS to provide situational awareness in a port situation is shifting the responsibility of detecting and monitoring ships from the port authorities to the ship operators and their equipment. This is a significant risk since it shifts situational awareness from a single point of failure (the VTS) to a very large number of points of failure (all of the vessels operating in the VTS zone).

1.5 PWS VTS

The PWS VTSA is shown in Figure 1, with boundaries defined as:

> The navigable waters of the U.S., north of a line drawn from Cape Hinchinbrook Light to Schooner Rock Light, comprising that portion of PWS between 146°30′ W and 147°20′ W and includes Valdez Arm, Valdez Narrows, and Port Valdez. (USCG 2017).

There are two special areas, namely Valdez Narrows and Valdez Arm, where special operating requirements apply. There are safety zones, where access is limited, at Valdez Marine Terminal (VMT), Tank Vessels Arriving/Departing VMT, Ammunition Island, Vessels Transiting to/from Ammunition Island, and Alaska Marine Highway System (AMHS) Port Valdez Ferry Terminal. There are also security zones that exist to safeguard assets from incidents due to either accidents or subversive acts. These are VMT, Tank Vessel Moving Security Zone, Valdez Narrows, and Escorted High Capacity Passenger Vessel (HCPV) or AMHS Vessels (USCG 2017).

There are two user groups that are required to use PWS VTS, namely Vessel Movement Reporting System (VMRS) and VTS users. VMRS vessels include (USCG 2017):

- Every power-driven vessel of 40 meters (m) or more in length, while navigating;
- Every towing vessel of 8 m or more in length, while navigating; and
- Every vessel certificated to carry 50 or more passengers for hire, when engaged in trade.

VTS users include the following vessels, if they are not already classified as a VMRS user, (USCG 2017):

- Every power-driven vessel of 20 m or over in length while navigating;
- Every vessel of 100 gross tons and upward and carrying one or more passengers for hire while navigating;
- Every towing vessel of 8 m or over in length while navigating; and
- Every dredge and floating plant engaged in or near a channel or fairway in operations likely to restrict or affect navigation of other vessels except for an unmanned or intermittently manned floating plant under the control of a dredge.

VTS users are required to maintain a listening watch on VHF channel 13 and comply with any measures issued by the VTS. VMRS users are required to meet all the requirements for VTS users and are also required to file a Sailing Plan, Position Reports, and a Final Report (USCG 2017).

Other vessels outside these criteria, such as small recreational or fishing vessels, should simply abide by the standard International Regulations for Preventing Collisions at Sea (COLREGs), although any vessel underway within the VTSA may be required to participate as the VTS deems necessary (USCG 2017). This would imply that an awareness of all vessels operating within the VTSA — especially in or near the Traffic Separation Scheme (TSS), special areas, safety zones, or security zones — would be particularly relevant for the VTS operation.

The VMRS users within PWS include oil tankers, tugs and barges, cruise ships, AMHS ferries, large tour boats, and some fishing boats, with other fishing boats and occasional large yachts being VTS users. However, most vessels within the VTSA are outside these two classifications and are typically smaller vessels such as seiners, gillnetters, some fishing boats, landing craft, most pleasure boats, fishing charter boats, and other non-towing vessels under 20 m, as well as military and USCG vessels (Miller 2020).

The traffic within the PWS VTSA is monitored through communications via the VTS VHF-FM network, as well as VTS radar, AIS, and closed-circuit video surveillance systems (USCG 2017). The VHF antenna sites as of 2005 are shown in Figure 2, and include installations at Valdez, Potato Point, Naked Island, Cape Hinchinbrook, Cordova, and Point Pigot (SHALL Engineering 2005). There are five radars located at three sites, Valdez (2), Reef Island, and Potato Point (2) (Miller 2020). These radars may not be currently operational and require maintenance and upgrades (Johnson 2021a; 2021b)

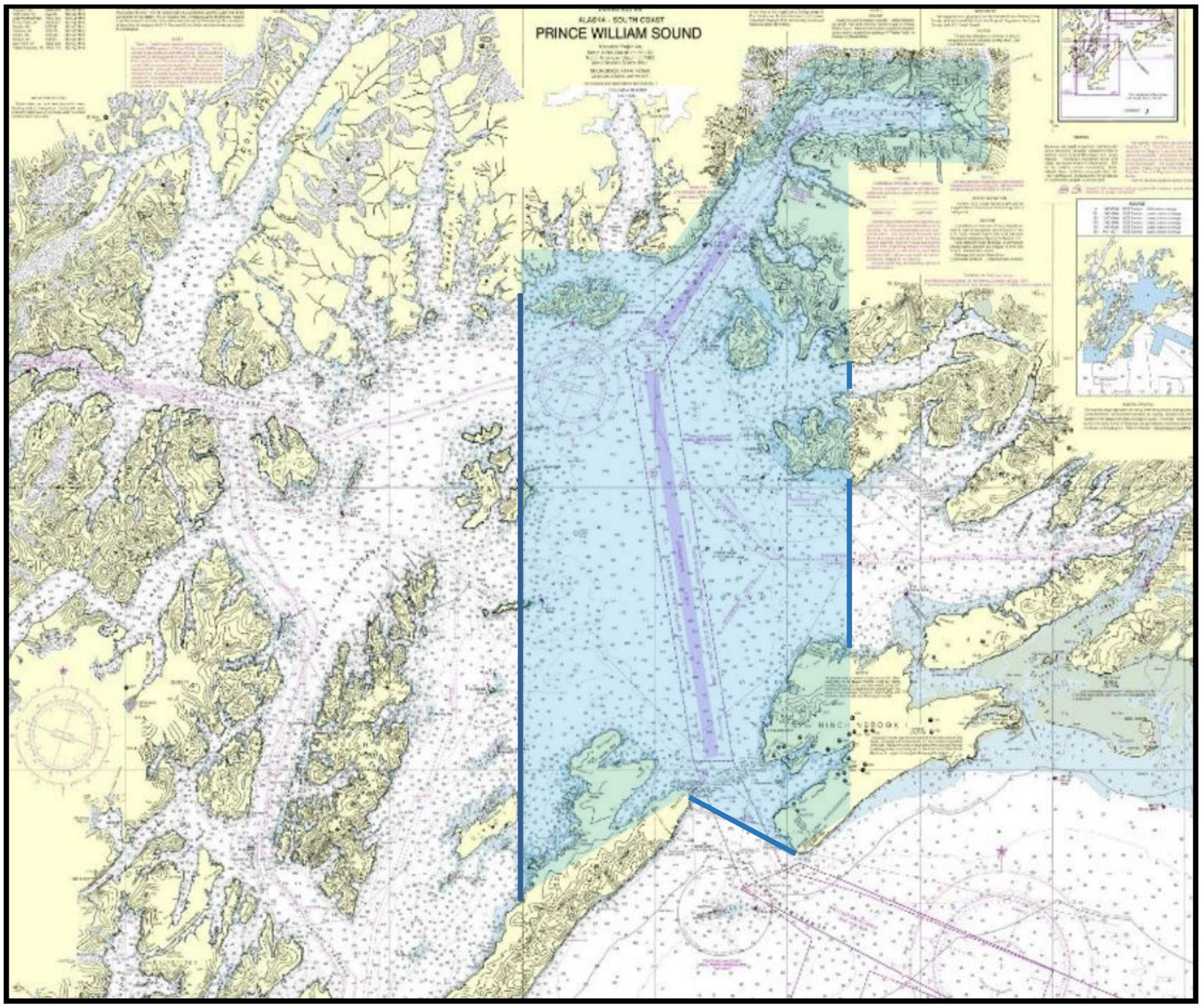

Figure 1. The PWS VTS area (blue shaded) and the TSS region (magenta) (USCG 2017).

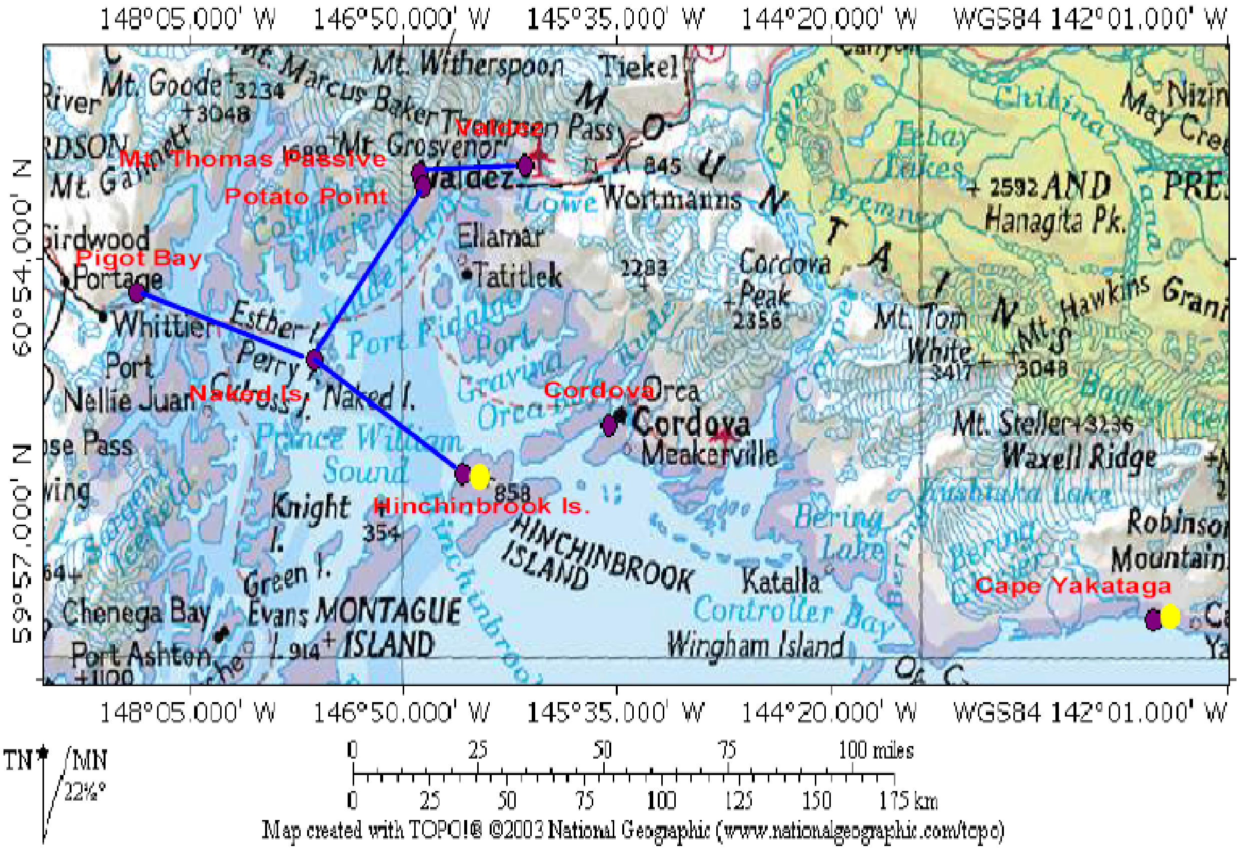

Figure 2. The PWS USCG VHF radio facilities as of 2005 — VHF sites (purple dots), microwave radio connections (blue lines) (SHALL Engineering 2005).

2 Stakeholder Consultations

To properly set the context for this report, stakeholder consultations were conducted with a small group, consisting primarily of PWSRCAC Board members and one PWSRCAC staff member. The consultation provided guidance on the issues to be addressed in this study to ensure that the proper literature was consulted. In total, seven individual interviews were conducted, each taking about 30 minutes to complete. The interviews were conducted one-on-one by telephone/video conference.

The following is the list of questions that were asked during the interview. Responses to each of these questions have been provided below. Note that interviewees have not been identified in this report and, instead, a consensus of each question has been summarized.

1. Do you use PWS in any transportation capacity?
2. With respect to the topic of AIS and radar use in PWS, what are your primary concerns (e.g., safety, environmental, etc.)?
3. Concerning the three radar sites that exist in PWS (Valdez Harbor, Potato Point, and Reef Island), how important is it that all radar sites are brought back to full operations? Are any of the radar sites unimportant from the stand point of vessel safety or environmental stewardship?
4. If you had to choose, where do you think PWS should have radar and AIS coverage? Why do you think these regions should have AIS and/or radar coverage?
5. Are you aware of VHF communications limitations within the VTS zone of PWS? If so, can you relate your experiences?
6. If you travel by vessel, what is your primary form of communication?
7. Can you describe the vessel situation in PWS (vessel numbers, vessel sizes, and regions of congestion)? (Note that we can get AIS coverage through sites like MarineTraffic.com, but because AIS isn't carried on all vessels, we do not get a complete picture).
8. Considering the vessel traffic in PWS, what portion of non-SOLAS class vessels would likely carry a working AIS transponder?

2.1 Interviewee Use of the Sound

The question on using PWS in a transportation capacity was meant to judge whether or not the interviewee's answers come from direct experience in maritime operations. In this case, all of the interviewees have general maritime experience, although not all have gained that experience within PWS.

2.2 Primary Concerns

When asked about concerns surrounding AIS and radar systems within PWS, the answers were focused on three general issues, including safety, security, and environmental protection (prevention of spills).

Six of the seven interviewees cite safety as a concern, in particular the trend towards relying more on AIS as a primary source of surveillance over radar. One person said this would be a dangerous trend, as you can't see without a radar, particularly when there is fog. Small vessels, particularly recreational vessels, typically don't have an AIS transponder and therefore the only way to see them in foggy conditions is via radar.

Three of the seven interviewees mentioned prevention and environmental stewardship as being a concern. The issue here is a concern about collisions if the VTS doesn't have radar to help with navigation. Although AIS is a collision avoidance technology, not all vessels carry it and therefore the concern would be for tankers and small recreational vessels having mishaps.

Two of the interviewees specifically cited port security as being an issue. In particular, the secure zone surrounding the tankers' offload region is vulnerable without radar in operation. This is a legitimate concern because any incursions of this zone would most certainly be by a small watercraft that either doesn't carry AIS or would disable the transponder before performing the incursion.

An examination of these responses suggest that all interviewees are well versed in the marine tracking technology and its limitations. The fact that vessel safety was the number one concern suggests that there are significant negative optics surrounding the combined failure of all three radar systems that operate in PWS.

2.3 Radar Site Prioritization

The question on radar site prioritization was meant to gauge the importance of each of the three radar sites. The Valdez Spit and Potato Point sites have a longer heritage than the Reef Island site, the latter of which was installed specifically for ice surveillance outside the narrows. The question was mainly to determine which sites should be a priority should limited funds be available to perform repairs or upgrades.

For this question, all seven respondents were unanimous in their suggestion that all three radar sites be brought back into operation. Each radar is very unique in its purpose and function. The Spit site is important considering the Security Zone, the Potato Point site is important for viewing traffic in the narrows considering the vessel congestion, and the Reef Island site is important for tracking ice movement across the Sound. In the case of Reef Island, the ice threat from the Columbia Glacier is somewhat diminished since the radar was installed in the early 2000s, but there are still occasions when ice is an issue and, from a safety point of view, it should be brought back into operations.

2.4 Desired Radar Coverage of the Sound

The question on desired coverage of the Sound was asked primarily to determine if there are perceived coverage gaps of AIS and radar in PWS. If there were perceived coverage gaps, then a plan should be made to address the gaps, or at least perform a risk assessment on the perceived gaps to determine the actual risk to vessel traffic.

The general consensus of the group suggests that present radar coverage is acceptable, assuming that all three sites are brought back to operation. Only one respondent indicated that expanded radar coverage is warranted. Several of the respondents suggested that AIS coverage should be throughout the entire Sound, suggesting that AIS coverage be expanded beyond its current reach. To that end, one of the respondents indicated that AIS data collected by the U.S. Coast Guard be made available to the public at no charge. This was once the case, however, privacy and security concerns have prompted Coast Guards in several countries to limit public access to these data. Considering that AIS data are now available publicly (but at a cost) from many AIS data aggregators, it does seem reasonable from a privacy and security perspective to make Coast Guard data available as a public service.

Considering the present issue that all three radar sites are non-operational, one respondent suggested that expanded radar/AIS coverage isn't the main issue; instead, increased redundancy should be considered. This seems to be a reasonable assertion, considering the present outage.

2.5 VHF Communication Issues

Since VHF radio coverage is an essential component of effective VTS operations, the question was raised to determine if gaps in VHF coverage presently exist in the Sound that would prevent effective VTS operations. Most interviewees were aware of a major VHF communication outage in late 2019 that extended to 2020 due to several failed repeater sites. Coverage has since been restored and appears to be fairly reliable now. Most of the respondents pointed to the usual issues with VHF communication in fjords and bays that are within radio shadows from the mountains.

2.6 Primary Form of Communication

Interviewees were asked about their primary form of communication in the Sound to determine if there has been a migration away from VHF communication to cell and satcom technology. VHF communication is an essential aspect to VTS operation and such a migration could be seen as being detrimental to how the centers operate. Overwhelmingly, respondents indicated that VHF is still the main form of communication in the Sound with cell phones being used on occasion to access 'data'. There was not significant (any) usage of sat phone technology among the respondents. Respondents also reported that cell coverage is pretty spotty in the Sound although coverage seems to be expanding each year.

One respondent noted that the Arctic Domain Awareness Center (ADAC) coordinated a series of regionally-focused virtual meetings throughout March and April 2021. The meetings were designed to develop a better understanding of the communications and connectivity needs of mariners operating in Alaska. The meetings were intended to provide ADAC with information to promote effective communications for Alaska's mariners and to support the mission needs of the USCG and maritime response community. Considering the objectives of the present study, this ADAC initiative may warrant further investigation by PWSRCAC.

2.7 Vessel Situation and non-AIS Vessels

The questions on vessel makeup within the Sound (questions 7-8) were meant to determine the perception of the number of non-SOLAS class (non-AIS) vessels that are operating in the Sound. Obviously, this question was not meant to quantitatively determine these vessel numbers, but rather to determine the interviewees' perception of the numbers. This would give some insight on the perception of the problem of radar outages and the reliance on AIS alone for VTS operations. Nonetheless, considering that most of the interviewees have direct experience operating in the Sound, the perception of the numbers would likely be an accurate reflection on reality.

The answers regarding vessel numbers were fairly consistent, with predominant traffic numbers coming from ferries and water taxies, fishing vessels, and pleasure craft operators. Fishing and pleasure craft would be seasonal. The SOLAS class vessels that require AIS transponders include tankers, barges, tugs, pilot boats, larger ferries, and cruise ships.

The overall perception among interviewees is that most of the vessels operating in the Sound would not carry AIS transponders. Most of the fishing vessels (purse seiners, tenders, and gill netters) operating in the Sound would be too small to require a transponder. Most of the pleasure craft operators also would not carry transponders. The perception is that only regulation of a carriage requirement would lead to a wider use of AIS transponders. Ultimately, this is the reason for the concerns over the reliance on AIS for VTS operations. Most of the Sound's traffic is not going to be visible on AIS and therefore, it is perceived that a VTS center should be aware of all traffic and not just VMRS and VTS users. Considering the considerable seasonal congestion in the Sound, this perception is well founded.

3 Use of Radar and AIS in VTS

3.1 Discussion

The general guidelines to aid in developing the requirements and operations of a VTS are clearly delineated in the IMO and IALA documentation. Some of the fundamental ideas for the operation of a VTS are stated in the IMO "Guidelines For Vessel Traffic Services" (IMO 1997), and emphasize the advantages of identifying and monitoring vessels, and generating a comprehensive SA within the VTSA, so that any potentially dangerous situations that may be developing can be detected in time to give appropriate warnings.

Based on the guidelines provided by IMO and IALA, the Competent Authority should establish appropriate standards for equipment and ensure that the necessary facilities are provided to effectively accomplish the objectives of the VTS, thereby ensuring the capability to monitor and interact with the traffic within the VTSA. (IALA 2015b)

First and foremost, it should be noted that VHF radio communication provides the primary means of developing SA for cooperating vessels. It provides the capability for real-time assessment of the situation in the VTSA, as well as a means to deliver timely information to vessels. The VTS radio infrastructure should enable adequate coverage of the VTSA and should enable VTS ship communications before the ship enters the VTSA (IALA 2015a; 2016). In practice, VHF communication is considered a vital component since it is used to obtain an indication of potential situations, in part through the way in which messages are communicated, thereby providing a means to assess the officer on watch and the situation on the bridge (Brödje, Lützhöft, and Dahlman 2010)

Sensors contribute to the information forming the SA relevant to the VTS, with a combination of sensors often yielding an increase in the quality and reliability of the information. Most importantly, radar can contribute traffic SA without any cooperation from targets. AIS can provide vessel position reports, as well as vessel and voyage information (IALA 2016). The value of AIS is in assisting VTS in identification of radar targets and in tracking of vessels in areas outside radar coverage (Tetreault 2010).

The VTS radar requirements are specified in terms of coverage, targets, target separation, and environmental capabilities as well as specific security requirements that may be associated with, for example, small targets, especially in adverse clutter conditions or in the presence of large targets (IALA 2015a). Current solid-state radar technology can combine wideband multi-frequency transmission, pulse compression, coherent processing, Doppler filtering, and clutter and interference suppression to provide high spatial resolution at both short and long ranges, and detection and separation of difficult targets such as small fast boats. Solid-state radar is also more reliable and requires less maintenance than magnetron technology. (Zhang, Dong, and Liu 2013; Amato et al. 2010)

In contrast, AIS provides automatic position reports and movement information, which provides a useful source of supplementary information to that derived from other navigational systems and sensors, such as radar. AIS has the potential to improve the detection of vessels that are obscured from the line of sight of other sensors. The limitations of AIS are the same as VHF communication and furthermore the reported position will be subject to the constraints of the GNSS data. Both the existence and validity of the AIS information is also dependent on the cooperation and competency of the vessel crew and therefore it is necessary to be cautious of potential inaccuracies in the data. Valid AIS data are dependent on the proper installation of AIS, correctly interfaced and functioning sensors, and correct manual input of static and voyage-related data (IALA 2007; 2015a). Furthermore, crew can spoof AIS messages, which is obviously a concern for VTS, regardless whether sabotage is the primary motivation.

Long-range sensors provide the option for supplementary information to help identify overdue or unannounced vessels, or for identification of search and rescue resources. SAIS provides one option for long-range detection, however it can be limited by missed detections due to data collisions when the field-of-view contains high traffic areas and by data latency from downlinking and dissemination (IALA 2015a). However, significant improvements are being made on these issues.

Thus, radar is a necessity for VTS, since it can actively monitor smaller vessels without AIS and it provides a means to monitor other objects such as ice. Radar deficiencies can be minimized and indeed newer solid-state radar and advanced processing can provide clutter and interference rejection and high spatial resolution at all ranges. In contrast, AIS obviously cannot provide information on vessels that operate without AIS, which comprise the majority of vessels operating in PWS (Miller 2020), and therefore AIS cannot be used to identify potential collisions or obstructions in these situations (Lin and Huang 2006). In practice, VTS operators (VTSO) prioritize VHF and radar, with AIS regarded as being less reliable and which is therefore used as a complement for providing additional information such as name, call sign, and speed. While the radar information is known to have weaknesses, it is under the control of the VTS and therefore can help increase understanding of potential issues due to configurations and technical limitations (Brödje, Lützhöft, and Dahlman 2010).

3.2 Summary

3.2.1 Current Limitations

During the initial period of integration of AIS by VTS almost 20 years ago, there were a few studies that evaluated the contribution of AIS in comparison to radar. However, both technologies as well as GNSS and data fusion and display have advanced since then, such that their use today is generally considered to be synergistic, with the capabilities and limitations of each inherently understood. There is also an implicit assumption that radar will be used in the sectors of the VTS area where detection of vessels is required, regardless of the use of AIS. More recent research has focused on the fusion and display of information from the various sensors, with the aim of developing an expert system.

While the exact interaction between AIS and radar will likely vary among VTS centers, and indeed among nations, the synergistic use of the two data sources is accepted. Thus, there appears to be no specific evaluation of the current technologies to operate independently within the critical sectors of a VTS system. If AIS were proposed as an alternate source of surveillance to radar, the exact areas and vessels with valid information as well as its importance within the VTS system would have to be evaluated. Reliability analyses of the AIS information transmitted would also be pertinent.

With more recent emphasis on security of vessels and harbor infrastructure, there is a significant onus on the ability of authorities to identify traffic that would have previously been able to operate separate from the VTS. The ability of VTS sensors to identify smaller vessels that do not carry AIS should be understood in terms of the vessel size and speed, and in relation to varying environmental conditions.

3.2.2 Recommendations

The majority of the publications relating to radar and AIS for VTS deal with advancing the technical capabilities of radar and AIS separately, or refining the fusion of data from these two systems. Since it is generally assumed that both systems will operate in tandem in critical sectors of a VTS area, there is limited research on the difference of using both radar and AIS compared to using AIS alone. The synergies between radar and AIS are well known and are highlighted by the publications on their individual capabilities and shortcomings, including ongoing technological improvements.

One option for evaluating the risk of operating PWS VTS without radar would be to perform a risk analysis of the scenarios. This would incorporate the specific details of the PWS system and environment, and provide a proactive indication of the major issues that are relevant to the local vessel traffic. An outline of the approach for a risk analysis is discussed in the next section.

Perhaps some of the unique characteristics of the PWS VTS area are the use of the traffic area by numerous smaller vessels such as fishing, tour, and pleasure boats, with much larger tanker, cargo, and cruise ships transiting through the Sound (with the added possibility of ice that calves from the Columbia Glacier). Due to the different regulations and practices involved in the participation of these various vessels within the VTS, there may be a higher potential for collisions between these two distinct user groups. Thus, a more detailed evaluation may be prudent, especially of the issues around the varied traffic use and the surveillance capabilities of both the VTS and the larger vessels. Of particular interest is the detection and monitoring of small vessels by large vessels and the VTS within the PWS context.

3.2.3 Procedure for Risk Analysis of Using AIS without Radar

A proactive assessment of the vessel traffic and VTS operations within PWS, including the scenario of using AIS without radar, would help ensure that potential vessel collision risks are understood. A risk analysis of the VTS operations within PWS could be evaluated based in part on the principles given in the IMO Formal Safety Assessment (FSA) as well as guidelines associated with safety case evaluations. The philosophy behind the FSA approach is captured in "The Maritime Engineering Reference Book" (Molland 2008), as given below.

> The adoption of FSA for shipping represents a fundamental cultural change, from a largely reactive approach, to one that is integrated, proactive and soundly based upon the evaluation of risk.
>
> There are two principal scenarios to be considered, namely:
>
> 1. Accidental collisions or groundings due to either technical (propulsion, sensor, communication) or human faults, which may be exacerbated by environmental factors such as weather, tides, ice; and
> 2. Intentional attempts to interfere with vessel traffic.

A risk analysis would involve modelling the various components of the vessel traffic, the VTS, and the environment, in order to determine the desired performance parameters. The requirements for the model would include:

- Statistical characterization of vessel traffic within PWS, according to type, size, and occurrence;
- AIS usage (Class A and B);
- AIS reception within the VTSA;
- Radar installations and capabilities within the VTSA;
- Statistical characterization of meteorological and oceanographic conditions;
- Statistical characterization of routes and corresponding frequency of use; and
- Frequency of adverse incidents with vessels (mechanical, electronic, environmental, human).

Based on these inputs, and an appropriately defined model, one could determine, for instance:

- Radar probability of detection (POD) and probability of false alarms (PFA) for vessels of interest (size class and speed) and season (meteorological, fishing and, tourism) for VTS and shipborne radars;
- Distributions of Point of Closest Approach (PCA) and Time to Point of Closest Approach (TPCA) for detected, identified, and unknown vessels; and
- Probability of a PCA less than a threshold separation for either a powered or a drifting vessel.

Since there are limited data available for some of the contributing factors, such as route tracks for smaller fishing and pleasure boats, it is likely that a simulation approach would be appropriate, where existing data are combined with realistic models as required.

3.2.4 Conclusion

According to the guidelines provided through the IMO and the IALA documentation, as well as publications on VTS operations, there is an understanding that radar is the primary sensor for ensuring SA within the critical sectors of a VTSA, since it obtains position, track, and size information without any cooperation from the targets (IALA 2016). Radar can also provide information on ice conditions. Even though radar may have some weaknesses, it is under the control of the VTS and therefore can help increase understanding of potential issues due to configurations and technical limitations (Brödje, Lützhöft, and Dahlman 2010). More recent solid-state radars and advanced processing can provide high spatial resolution at all ranges and discriminate small targets in adverse clutter and interference (Zhang, Dong, and Liu 2013; Amato et al. 2010).

AIS provides supplemental information such as vessel identity, call sign, and voyage related data. It is especially relevant where vessels may be obscured from other sensors and in areas outside radar coverage. AIS can be a means to provide advance notice of vessels entering a VTSA, especially if SAIS is available (IALA 2015a). However, since not all vessels carry AIS or use it reliably, AIS information does not guarantee a comprehensive overview of the traffic in the service area. This is especially relevant for the PWS VTSA, since the majority of users do not use AIS (Miller 2020).

Since there is a general assumption that radar would normally be used in critical areas of a VTSA, there is limited specific information on the risk of using AIS alone for SA within VTS. This would essentially be equivalent to using only VHF radio communications within the VTSA, albeit with a higher update rate than would be possible with voice communications. To help understand the issues associated with using AIS alone within designated sectors of the PWS VTSA, one could complete a risk analysis that incorporates the details of the PWS system and environment.

Based on the above, it is recommended that the Valdez VTS bring back all three of its radar sites into full operations and make contingencies for backup radar units at each of the three sites. Reliance on AIS as the primary tracking sensor for VTS operations is deemed to be inadequate and is contrary to the guidelines provided by the IMO and the IALA.

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Appendix A: **Literature on VTS Use of AIS and Radar**

The current project aims to identify the literature on the use of radar and AIS in VTS, with particular reference to the use of these systems in the PWS VTS. Of particular interest is the use of these systems, both separately and collaboratively, to provide the necessary information to ensure safe maritime operations.

The goal of the initial literature search is stated in the Scope of Work.

A. Ascertain research papers and literature related to the use of AIS and surveillance radar by vessel traffic systems, especially noting any interactions between the two systems.

Results for the literature review are given in the following three subsections, which deal with the combined use of AIS and radar, as well as with the separate capabilities of radar and AIS.

A.1 Radar and AIS in VTS

The literature relevant to the combined use of radar and AIS is listed in Table 1. The first few references relate to IALA/IMO documents that specify the requirements of VTS. The published references that follow are listed in order of relevance.

Table 1. Publications on use of radar and AIS in VTS.

Title	Reference
IALA Guideline 1111 – Preparation of Operational and Technical Performance Requirements for VTS Systems, Edition 1.0	(IALA 2015a)
R0128 (V-128) Operational and Technical Performance of VTS Systems	(IALA 2015b)
Vessel Traffic Services Manual, Edition 6	(IALA 2016)
Recommendation V-128–On Operational and Technical Performance Requirements for VTS Equipment	(IALA 2007)
New International Guidelines for Vessel Traffic Services. Revision of IMO Resolution A.857(20)	(Uyà Juncadella and Martínez de Osés 2020)
A. 857 (20). Guidelines For Vessel Traffic Services	(IMO 1997)
Comparison between ARPA Radar and AIS Characteristics for Vessel Traffic Services	(Lin and Huang 2006)
The What's, When's, Whys and How's of VTS Operator Use of Sensor Information	(Brödje, Lützhöft, and Dahlman 2010)
Comparison Between Information Provided by Radar and AIS in The Integrated Vessel Traffic Systems	(Angelova and Alexandrov 2019)
Study of Data Fusion of AIS and Radar	(L. Chang and Xiaofei 2009)
The Role of Integrity for Maritime Traffic Situation Assessment	(Banyś et al. 2011)

A.1.1 Summary of References on VTS Use of Radar and AIS

IALA Guideline 1111 – Preparation of Operational and Technical Performance Requirements for VTS Systems, Edition 1.0 (IALA 2015a)

The IALA Guideline is a comprehensive document that presents the requirements for VTS systems. The topics included cover radar, AIS, environmental monitoring, electro-optical systems, radio direction finders, long-range sensors, radio communications, data processing, VTS human/machine interface, decision support, external information exchange, and verification and validation. The highlights noted below relate only to the pertinent issues associated with radar, AIS, and VHF communications.

For radar systems, the Guideline highlights the need to identify the operational and functional requirements such as coverage, targets, target separation, and environmental capabilities as well as specific security requirements that may be associated with, for example, small targets, especially in heavy clutter conditions or in the presence of large targets.

AIS provides automatic position reports and movement information, which should be correlated with radar data. AIS has the potential to improve the detection of vessels that are obscured from the line of sight of other sensors. The limitations of AIS are the same as VHF communication, and furthermore the reported position will be subject to the constraints of the GNSS data. Both the existence and accuracy of the AIS information is also dependent on the cooperation of the vessel crew.

Long-range sensors provide the option for supplementary information to help identify overdue or unannounced vessels, or for identification of search and rescue resources. SAIS provides one option for long-range detection, however it can be limited by missed detections due to data collisions when the field-of-view contains high traffic areas and by data latency from downlinking and dissemination. However, significant improvements have been made on these problems since the 2015 report date.

Radio communications provide the capability for real-time assessment of the situation in the VTS area, as well as a means to deliver timely information to vessels. The VTS radio infrastructure should enable adequate coverage of the VTS area and should enable VTS ship communications before the ship enters the VTS area.

R0128 (V-128) Operational and Technical Performance of VTS Systems (IALA 2015b)

This contains the IALA recommendation for the Operational and Technical Performance of VTS Systems. It gives an overview of the aims and objectives and general provisions of VTS systems, with the requirements contained in the IALA Guideline G1111. The background information given highlights the need to evaluate the performance of the VTS systems, both for design and ongoing operations, to ensure that the objectives are met. It reiterates the IMO Guidelines that the Government or the Competent Authority establish appropriate standards for equipment and ensure that the necessary facilities are provided to effectively accomplish the objectives of the VTS, relating to the capability to monitor traffic within the VTS area, interact with the vessel traffic and respond to developing situations.

Vessel Traffic Services Manual, Edition 6 (IALA 2016)

The "Vessel Traffic Services Manual" is a comprehensive guide of the policies related to the provision, operation, and effectiveness of VTS. It includes discussion on legal framework, function, provision, principles, need, cost benefit, planning and organization, procurement, equipment, personnel, training, records, procedures, and quality management.

With respect to the VTS equipment, it is noted that VHF radio provides the primary means to obtain real-time SA and to deliver VTS services. Sensors contribute to the information forming the SA relevant to the VTS, with a combination of sensors often yielding an increase in the quality and reliability of the information. Radar can contribute traffic SA without any cooperation from targets. AIS can provide vessel position reports, as well as vessel and voyage information.

Recommendation V-128–On Operational and Technical Performance Requirements for VTS Equipment (IALA 2007)

This document contains the annexes for the operational and performance requirements of VTS. The first is an overview of the core operational requirements, and then the following five annexes deal separately with the performance requirements for the main sensors, including radar and AIS.

It states that "AIS is a useful source of supplementary information to that derived from other navigational systems and sensors, including radar." It is necessary to monitor the information to ensure that it is accurate. "The validity of AIS data received from ships is dependent on the proper installation of AIS, correctly interfaced and functioning ship's equipment, and correct manual input of static and voyage-related data. Until further regulations dictate stricter data accuracy requirements in the AIS mobile units, caution has to be taken when using AIS data for processing."

New International Guidelines for Vessel Traffic Services. Revision of IMO Resolution A.857(20) (Uyà Juncadella and Martínez de Osés 2020)

This paper presents an update on the key revisions that are expected to the IMO Resolution A.857(20), and it is included here to ensure that the revisions have no substantive effect on the present study. One change of note is that there will no longer be a distinction made in the type of VTS in terms of providing information, organization, or assistance.

A. 857 (20). Guidelines For Vessel Traffic Services (IMO 1997)

The "Guidelines for Vessel Traffic Services" contains two annexes, the first is Guidelines and Criteria for VTS and the second is Guidelines on Recruitment, Qualifications and Training of VTS Operators.

Of particular interest are the statements relating to the basis for a VTS and the factors affecting its operation. "The benefits of implementing a VTS are that it allows identification and monitoring of vessels, strategic planning of vessel movements and provision of navigational information and assistance. It can also assist in prevention of pollution and co-ordination of pollution response." "The efficiency of a VTS will depend on the reliability and continuity of communications and on the ability to provide good and unambiguous information. The quality of accident prevention measures will depend on the system's capability of detecting a developing dangerous situation and on the ability to give timely warning of such dangers." "A VTS should at all times be capable of generating a comprehensive overview of the traffic in its service area combined with all traffic influencing factors. The VTS should be able to compile a traffic image, which is the basis for its capability to respond to traffic situations developing in its service area." The traffic image should include all significant targets in the VTS.

Comparison between ARPA Radar and AIS Characteristics for Vessel Traffic Services (Lin and Huang 2006)

While some aspects of this publication may be dated, it attempts to directly compare characteristics of the information derived from automatic radar plotting aids (ARPA) and AIS. It highlights that ARPA is a necessity for VTS, as it can actively monitor small vessels (without AIS installed). Radar deficiencies, such as clutter due to atmosphere and sea state, can be minimized. In contrast, AIS does not provide information on smaller ships within the VTS area, and therefore cannot be used to identify potential collisions or obstructions in these situations, so that "AIS cannot replace ARPA radar in VTS operations." AIS can complement the radar and VHF communication data, and therefore enhance the quality of the information and hence navigation safety. It can also provide additional voyage related information.

The Whats, Whens, Whys and Hows of VTS Operator Use of Sensor Information (Brödje, Lützhöft, and Dahlman 2010)

This study focuses on how VTS operators use available sensor information to build their SA, with the aim of using it as a basis for Human Factors analysis to help develop an Intelligent Decision Support System. VTSOs prioritize VHF and radar, with AIS regarded as a complement for providing additional information such as name, call sign, and speed. AIS is not regarded by the VTSOs as being reliable. While the radar information is known to have weaknesses, it is under the control of the VTS and therefore can help increase understanding of potential issues due to configurations and technical limitations.

VHF communications is considered a vital component in building the SA and is used to obtain an indication of potential situations. This is achieved in part through the way in which messages are communicated, through assessing the officer on watch and the situation on the bridge.

Comparison Between Information Provided by Radar and AIS in The Integrated Vessel Traffic Systems (Angelova and Alexandrov 2019)

This is a limited study of the accuracy of navigational data derived from radar and AIS, to minimize potential errors in data fusion. Discrepancies in the position data arise from differences in time synchronization. However, in properly functioning systems, this should be minimized.

Study of Data Fusion of AIS and Radar (L. Chang and Xiaofei 2009)

This is a study of the data fusion of AIS and radar. The differences between the two sources of information are discussed. While AIS can yield high accuracies in navigational data, it is not available for all vessels.

Therefore, it cannot replace radar. It is also noted that AIS can suffer from incorrect operation or interference in transmission.

The Role of Integrity for Maritime Traffic Situation Assessment (Banyś et al. 2011)

This is a general overview of approaches for modelling the integrity of data sources for marine navigation, with emphasis on AIS information. While some of the characteristics and limitations of AIS are mentioned, these are also covered in more detail in other references. Later work in this area may be of additional interest (to be determined).

A.2 Radar in VTS

Along with VHF communications, radar has long been the main sensor technology within VTS. Recent publications on radar in VTS include, for example, development of tracking applications and fusion with other information in the VTS. Older work on the capabilities of radar within VTS obviously do not include more recent technological advances, and are therefore not included here.

Table 2. Publications on use of radar in VTS.

Title	Reference
A Study on the Radar Operational and Technical Performance Requirements for Vessel Traffic Service	(Jeon 2020)
The Impact of Radar Distance Measurement Accuracy on the Accuracy of Position Fixing in VTS Systems	(Czaplewski, Guze, and Świerczyński 2018)
Research on Marine Solid State Radar and Its Application	(Zhang, Dong, and Liu 2013)
Fully Solid State Radar for Vessel Traffic Services	(Amato et al. 2010)

A.2.1 Summary of References on VTS Use of Radar

A Study on the Radar Operational and Technical Performance Requirements for Vessel Traffic Service (Jeon 2020)

The requirements of radar systems for VTS based on IALA guidelines were analyzed and experimentally verified for X-band radar. These include detection distance, target separation in range and azimuth, and target position accuracy. The study therefore highlights actual performance capabilities of a VTS radar.

The Impact of Radar Distance Measurement Accuracy on the Accuracy of Position Fixing in VTS Systems (Czaplewski, Guze, and Świerczyński 2018)

This paper presents a method for improving the accuracy of a ship position as estimated from radar. It is based on adjusting the radar-detected edge of the target to the actual ship position. This correction is relevant for accurately fusing multiple data sources for a target, for example from different radar sites or indeed from AIS, in order to avoid ambiguous or incorrect associations.

Research on Marine Solid State Radar and Its Application (Zhang, Dong, and Liu 2013)

This paper provides an overview of the advantages of solid-state radar, with one of the applications areas being VTS. These systems can use pulse compression, Doppler processing, coherent signal processing, clutter suppression, and interference suppression. VTS radars "must provide high spatial resolution assuring an accurate estimation of the vessel position, the discrimination of vessels on short-range and the robust detection of small fast targets." The solid-state radars can accomplish this as well as provide increased detection in sea and atmospheric clutter. These factors may contribute to a better understanding when comparing current radar and AIS capabilities.

Fully Solid State Radar for Vessel Traffic Services (Amato et al. 2010)

This paper discusses the capabilities of the LYRA 50 solid-state radar (ca. 2010) in the context of VTS. These radars provide high spatial resolution to ensure accurate estimation of target position and target separation, even in adverse clutter conditions. The background on VTS radars, both magnetron and solid state, is discussed first, followed by an explanation of the technology and resulting advantages of the solid-state radar, due to wideband multi-frequency transmission, coherent processing, and Doppler filtering.

A.3 AIS in VTS

AIS has been used over the previous couple of decades for ship collision avoidance. Its integration into VTS continues to evolve alongside other sensor systems. The references listed in Table 3 highlight the use of AIS in VTS.

Table 3. Publications on use of AIS in VTS.

Title	Reference
Development and Analysis of AIS Applications as an Efficient Tool for Vessel Traffic Service	(S.-J. Chang 2004)
Does Automatic Identification System Information Improve Efficiency and Safety of Vessel Traffic Services	(Wiersma and van't Padje 2005)
AIS Implementation-Success or Failure?	(Norris 2007)
Expanded Use of Automatic Identification System (AIS) Navigation Technology in Vessel Traffic Services (VTS)	(Tetreault 2010)
Alaska AIS Transmit Prototype Test, Evaluation, and Transition Summary Report for the Near Shore Arctic Navigational Safety Information System (ANSIS)	(Gonin and Johnson 2018)

A.3.1 Summary of References on VTS Use of AIS

Development and Analysis of AIS Applications as an Efficient Tool for Vessel Traffic Service (S.-J. Chang 2004)

This paper presents a statistical analysis of the performance of AIS within VTS. The potential advantages of AIS are listed as vessel identification and supplemental navigation and voyage information, message communication, better vessel detection, and tracking (potentially longer range, avoidance of shadows or blind spots). While the specifics of the analysis may be dated now, including accuracy of GNSS, it gives an indication of the many factors that affect the integrity and quality of AIS information. Among the deficiencies noted were quality of AIS installation, performance of sensors linked to AIS, and inadequate training of mariners.

Does Automatic Identification System Information Improve Efficiency and Safety of Vessel Traffic Services (Wiersma and van't Padje 2005)

This study investigated the consequences of AIS for VTS using a VTS simulator. It looked at opportunities and threats posed by AIS in port situations, and included evaluation of data reliability. (A copy of the full publication is still being sourced.)

AIS Implementation-Success or Failure? (Norris 2007)

This paper gives a historical perspective on the issues with the implementation of AIS, noting how the stated guidelines influenced the perception of its intended use and its functioning. It highlights, in particular, how a perceived lack of need for training resulted in problems with AIS installations and with the resulting AIS data.

Expanded Use of Automatic Identification System (AIS) Navigation Technology in Vessel Traffic Services (VTS) (Tetreault 2010)

This paper discusses the potential for expanded use of AIS within VTS, mainly to augment or replace operations accomplished through VHF voice communications. This could aid in dissemination of information — such as meteorological or hydrographic — through binary messages, in enhancing navigation safety through telecommanding AIS equipment aboard vessels, and in executing VTS functions — such as traffic advisories — through AIS.

It is acknowledged within the paper that the value of AIS has been in assisting VTS in identification of radar targets and in tracking of vessels in areas outside radar coverage.

Alaska AIS Transmit Prototype Test, Evaluation, and Transition Summary Report for the Near Shore Arctic Navigational Safety Information System (ANSIS) (Gonin and Johnson 2018)

This is a USCG report on developing AIS transmit capabilities in Alaska. AIS transmit uses ASM to disseminate maritime safety/security information, such as meteorological and hydrographic data. The report describes the technical details of the AIS transmit system, and shows the location and coverage of the transmitters, including Valdez. This is part of the ongoing development of the extended use of AIS.

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