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The Rise of Advanced VTS/VTMS Systems

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Abstract:- The Vessel Traffic Management System (VTMS) is constantly evolving, driven by regulations, environmental concerns and technological innovation. Directives from authoritative organizations such as the International Maritime Organization (IMO) and the International Association of Maritime Aids to Navigation and Lighthouse Management (IALA) emphasize the need for maritime safety. As we move into the future, VTMS will undoubtedly leverage artificial intelligence, automation, and machine learning, evolving from a reactive system to a predictive system. Exchanging the VTMS information among maritime users will significantly ensure safe operations and minimize environmental risks. As these systems evolve, the challenges of improving them become increasingly complex. A collaborative approach by combining expertise from different areas - users, consultants and manufacturers - forms a holistic strategy that leads to innovative and reliable solutions enriched by convergence of ideas, highlighting the effectiveness of a collaborative approach in navigating the complexities of technology improvements.

I. INTRODUCTION

In the rapidly changing world of technology, the need to update mission-critical systems is paramount. These updates not only ensure optimal performance today and, in the future, but also enhance security, safety, and operational measures. The SOLAS Convention [[1]] and the e-Navigation Initiative [[2], [3]] highlight the importance of electronic data assimilation to improve navigation, and the IMO Greenhouse Gas Strategy 2023 [[4]] emphasizes the urgency of reducing carbon emissions by setting ambitious decarbonisation targets. For industry leaders, investing in VTMS goes beyond simple compliance; it is a strategic venture designed to ensure industry sustainability, operational efficiency and drive innovation.

Vessel Traffic Services (VTS) and Vessel Traffic Management Systems (VTMS) are integral components of maritime navigation and safety today. The primary purpose of VTS/VTMS is to improve maritime safety by preventing collisions, groundings and other potential hazards. [[5]] By providing real-time information about vessel movements, these systems enable active traffic management and timely action. They also play a critical role in protecting the environment by monitoring marine activities that may pose a threat to marine ecosystems.

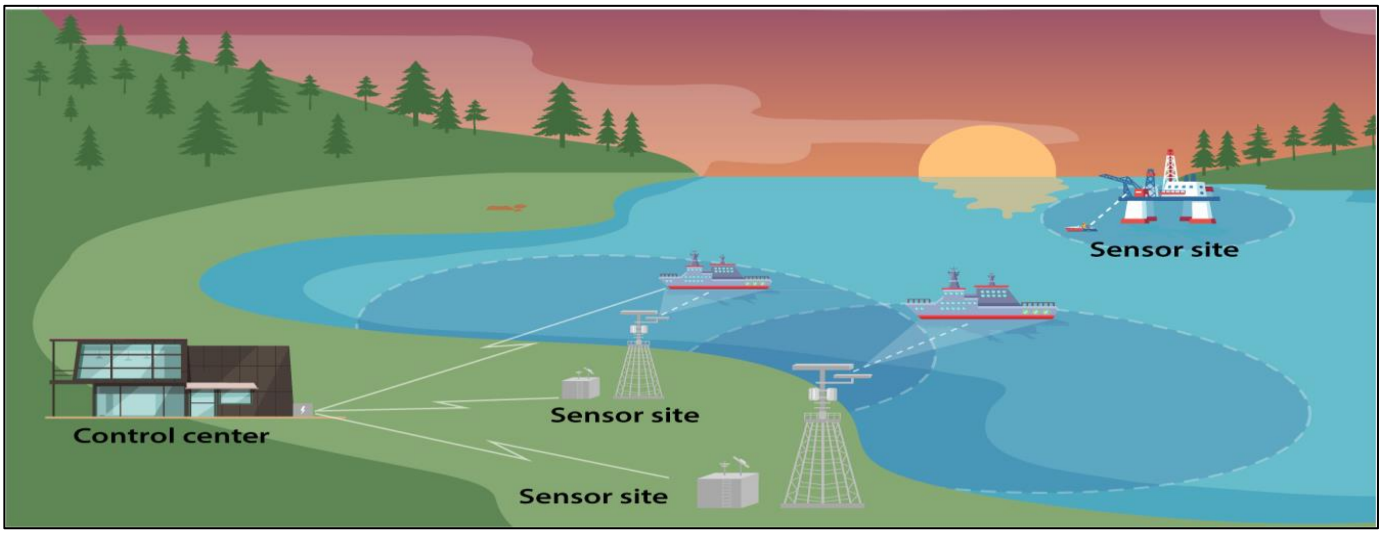

Fig 1: VTMS Overview

In addition to safety, VTS/VTMS systems are essential for the efficient functioning of ports and harbours. They facilitate smooth maritime traffic by ensuring that ships can dock and depart without delay. As shipping continues to grow and the challenges of modern shipping evolve, the role of VTS/VTMS becomes even more important. These systems must adapt to handle larger vessels, increased traffic densities, and the integration of new technologies such as autonomous ships. By staying ahead of these challenges, VTS/VTMS ensures that maritime operations remain safe, efficient and resilient into the future.

II. THE RECENT COLLABORATIVE EFFORTS OF IMO AND IALA IN REFINING VTS/VTMS REGULATIONS

Various organizations take part in the regulation of the legal, administrative and technical aspects of VTS/VTMS, led by the IMO operating under a UN mandate based on the SOLAS convention and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) [[6]].

So, when developing an update to VTMS systems, the following influences from leading international organizations should at least be taken into account. The International Maritime Organization (IMO) has revamped its regulatory framework for VTS, marked by the endorsement of IMO Resolution 1158(32) in December 2021 [[7]], which introduced new guidelines for vessel traffic services. This transformation gained further traction in December 2022, with IALA's revision of its VTS documents, notably G1111 [[8]]. This document prioritizes the establishment of functional and performance standards for VTS systems and tools. Instead of a single main guideline, it has been segmented into nine sub-guidelines, providing a more intricate and nuanced methodology for outlining functional prerequisites. Moreover, the IMO Greenhouse Gas Strategy of 2023 [[4]] emphasizing on the pressing need to curb carbon emissions, laying down aggressive decarbonisation goals.

III. VTMS SOFTWARE REQUIREMENTS, INTEGRATION OF SENSOR, ENC, COMMUNICATIONS AND INFRASTRUCTURE

Vessel Traffic Management System (VTMS) software is critical to optimizing maritime navigation and ensuring vessel safety. Its business requirements include real-time data processing, seamless integration with existing sensor, communications and ICT infrastructure, and robust cybersecurity measures [[11]]. Functionally, the software must provide accurate vessel tracking, efficient data exchange, and user-friendly interfaces that allow operators to efficiently manage and interpret huge volumes of marine data [[7]].

Fig 2: The VTS Tower at the Port of Dover
(Source Dover Strait Shipping)

Vessel Traffic Service (VTS) and Vessel Traffic Management System (VTMS) use a variety of sensors such as radar, automatic identification system (AIS), close circuit television (CCTV), radio direction finders (RDF) and met/hydro sensors to monitor and manage vessel traffic. These systems also include radio communications such as Very High Frequency (VHF), Medium and High Frequency (MF/HF), Digital Selective Call (DSC) and data communications to provide uninterrupted real-time communications. In terms of ICT, VTMS relies on servers, processors, workstations and a secure network infrastructure to efficiently process and transmit the right amount of data at the right speed [[8]].

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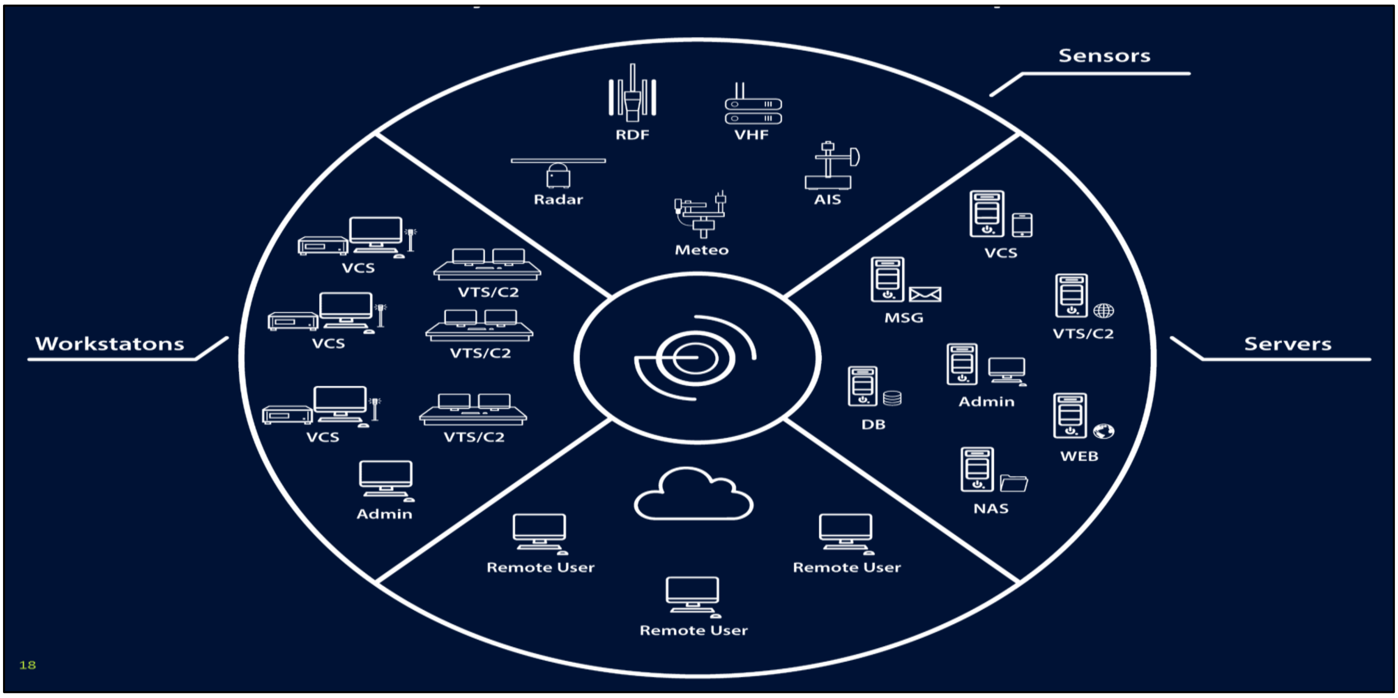

Fig 3: A General Architecture of VTMS

Navigational charts S-57 [[9]] and S-63 [[10]] are international standards established by the International Hydrographic Organization (IHO) for the exchange of digital data for navigation. The S-57 format provides a detailed specification of the data structure and attributes of Electronic Navigational Charts (ENC), ensuring consistency of chart information throughout the maritime industry. On the other hand, S-63 serves as an encryption standard, enhancing the security of ENC S-57, protecting data from unauthorized access and tampering.

Apart from its core functions, VTMS is often integrated with various other systems such as Port Management Information System (PMIS), Port Community System (PCS), Terminal Operations System (TOS), Enterprise Resource Planning (ERP), Single Window [[12]], Security Systems and GMDSS [[13]] to provide a holistic view on maritime operations and contribute to the effective management of maritime traffic in the area of responsibility. This interconnected ecosystem enables streamlined operations, enhanced safety and efficient allocation of resources in the maritime domain.

IV. PROSPECTS AND BENEFITS FROM UPDATING, DEVELOPMENT AND UNIFICATION OF VTMS

The shift from proprietary isolated systems to integrated Service-Oriented Architecture (SOA) based systems [[14]] represents a significant evolution in the maritime sector. Proprietary systems often limit interoperability and scalability, hindering the seamless exchange of data and integration of new functionalities. Upgrading and unifying VTS/VTMS is essential to harness the full potential of modern technology, ensuring efficient data flow, enhanced system performance, and adaptability to future technological advancements. This transition is not only contributing to streamlining operations but also paves the way for a more collaborative and responsive maritime environment. Examples for exchanging the VTMS and AIS information among communities are listed below:

- A project executed by the European Maritime Safety Agency (EMSA) to provide the needed AIS stations to the Beneficiaries. Those countries will be enabled to share their maritime traffic information with the European Union (EU) and non-EU Members States participating in MARE with an enhanced monitoring of the maritime traffic in the Mediterranean Sea and in an enhanced cooperation between the Mediterranean coastal States on maritime traffic monitoring. [[38]]
- European Directive to establish a joint Community for the vessel traffic monitoring and information system with a view to enhancing the safety and efficiency of maritime traffic, improving the response of authorities to incidents, accidents or potentially dangerous situations at sea, including search and rescue operations, and contributing to a better prevention and detection of pollution by ships. Attached is a copy of the Official Journal of the European Communities. [[35]]
- Integrated Coastal Surveillance System (ICSS) in India aimed to integrate and exchange the VTMS and AIS information among: (1) The Indian Coast Guard (ICG) for coastal security. (2) Indian Navy for surface target surveillance. (3) Director General of Light Houses and Light Ships (DGLL). (4) Ministry of Shipping for National Coastal Vessel Traffic Services (NCVTS). (5) Vessel Traffic Services (VTS) of public/private ports/facilities. [[37]]

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In the following section, we highlight what we believe to be the most promising avenues for advancing the VTS/VTMS concept. This system, dedicated to sea surface monitoring, movement tracking, participant communication, and environmental preservation, holds potential to enhance solution quality universally.

A. E-Navigation

One of the most promising developments in the realm of VTS/VTMS is the facilitation of digital data exchange between VTS/VTMS and vessels, emphasizing e-Navigation to enhance communication with ships and other external port stakeholders. This digital transformation introduces a suite of services designed to optimize maritime operations and safety. Notably, among others, there are the following e-Navigation Maritime Services (MS) that will be implemented globally in connection with the IMO/IALA/IHO plans: MS 1 "VTS Information Service (INS)", MS 2 "Navigational Assistance Service (NAS)", MS 5 "Maritime Safety Information Service (MSI)", MS 6 "Pilotage Service", MS 10 "Maritime Assistance Service (MAS)", etc. [[15]]

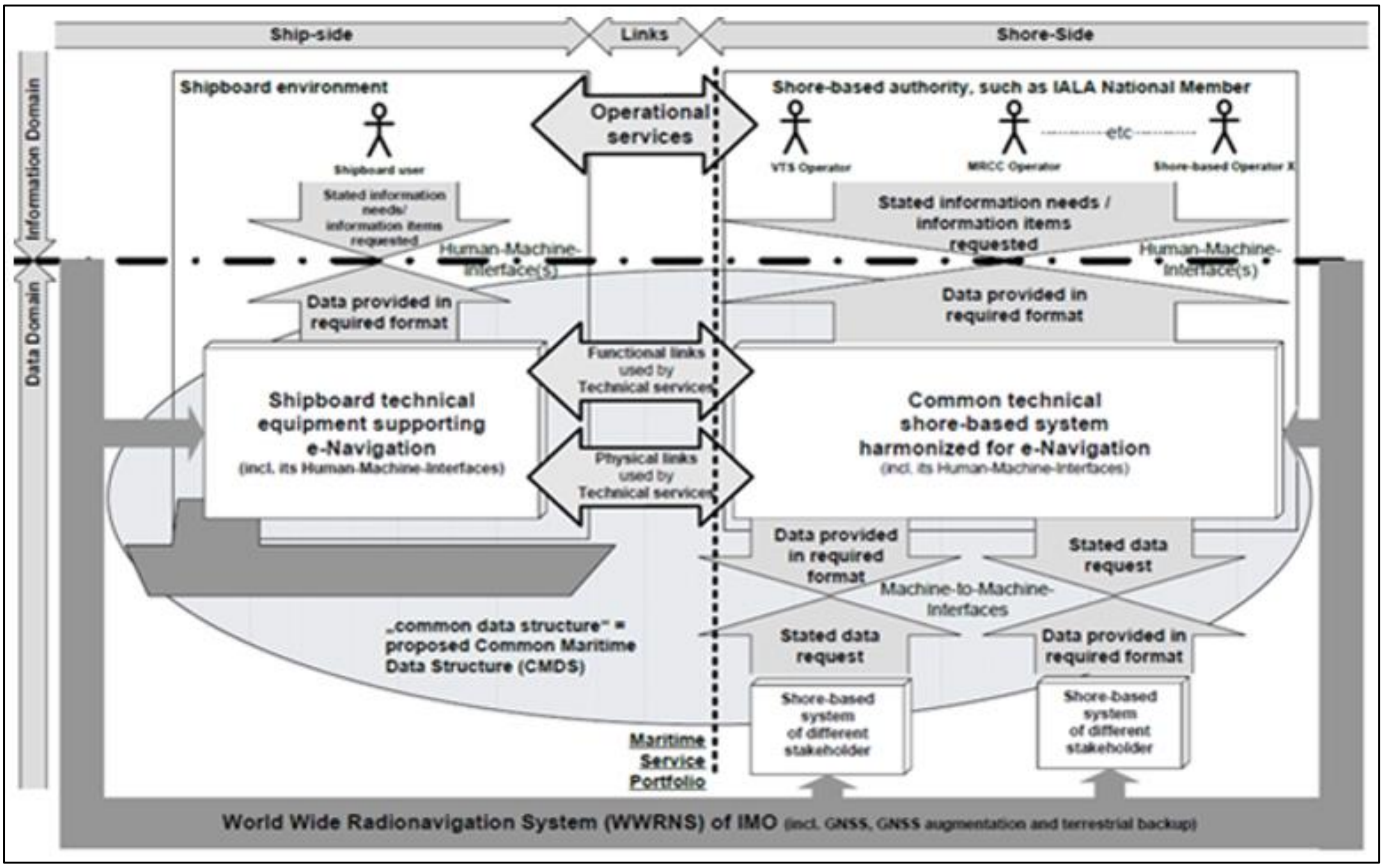

Fig 4: The Overarching Architecture of the E-Navigation Concept
(Source IMO)

B. Data Services

The integration of third-party data services into VTS/VTMS systems is seen as an important advance in improving the quality of decision-making in maritime operations. By integrating real-time weather data, including forecasts and warnings, VTS/VTMS and ships can make informed decisions, enabling safer navigation and optimized routes.

In addition, the inclusion of Earth remote sensing data, both from optical sources and synthetic aperture radar (SAR), provides a comprehensive view of the marine environment. [[16]]

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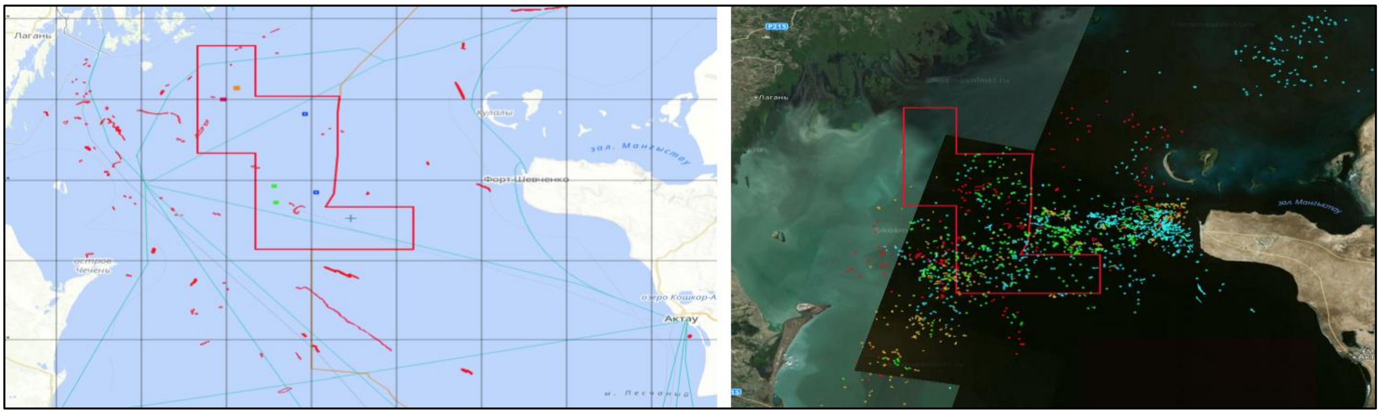

Fig 5: An Oil Spill and Vessels Detection Example
(Source Scanex)

This combination of data provides unprecedented information about marine conditions, vessels not tracked by VTS/VTMS sensors, potential hazards, and even helps in monitoring marine ecosystems. As a result, the integration of these external data sources not only improves operational efficiency but also improves maritime safety standards.

C. Unified Data Model of Port Call Process

The evolution of maritime operations has seen a significant shift towards adopting a comprehensive unified data model and ship call process. Central to this transformation is the IMO Data Model/Compendium [[22]], which provides a standardized framework for maritime data exchange, ensuring consistency and interoperability across various systems. Complementing this is the Electronic Port Call ISO 28005 [[20]], which streamlines the exchange of information during port calls, enhancing efficiency and reducing operational delays [[17]].

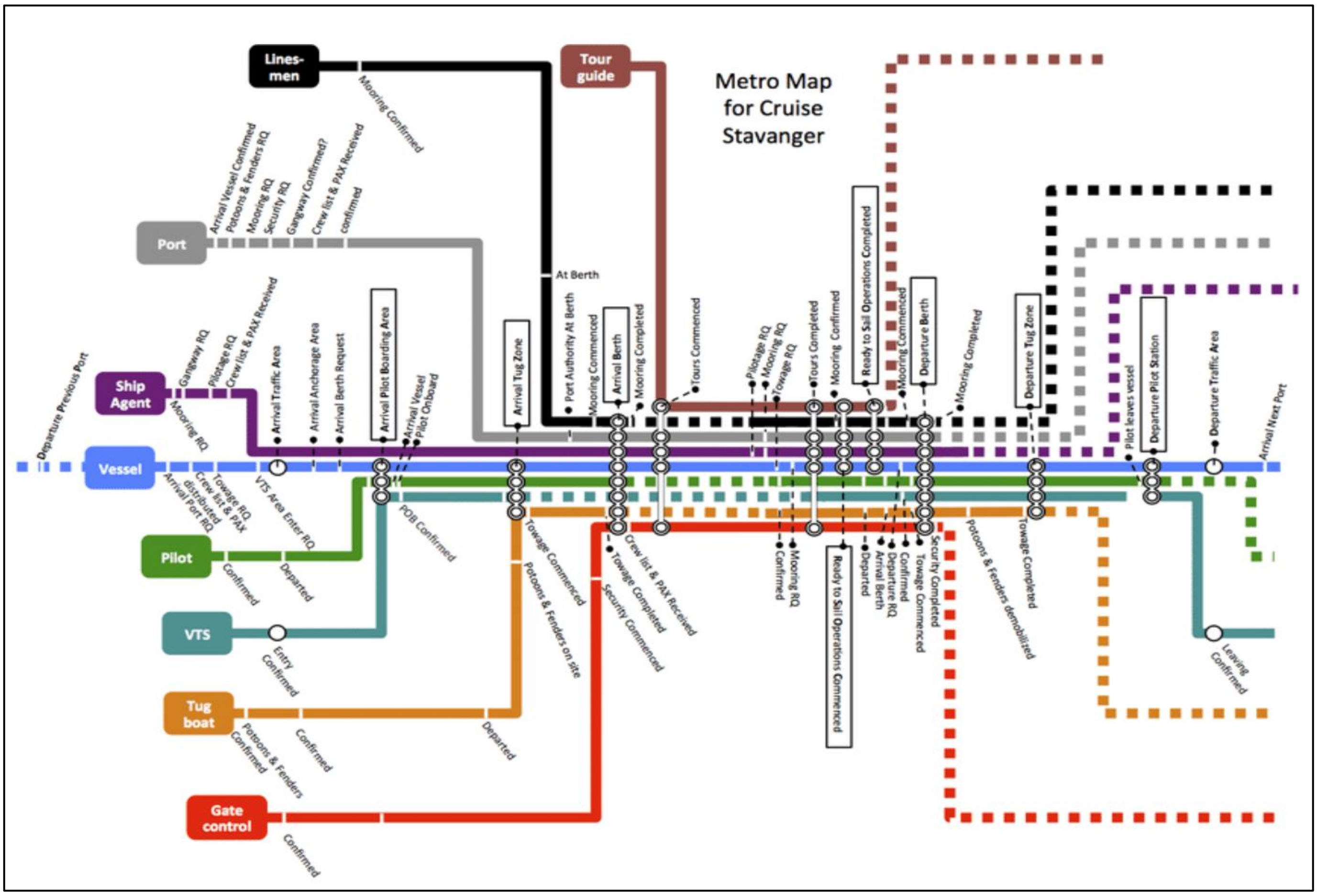

Fig 6: Port Call Process Illustration
(Source IMO)

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Furthermore, the transition to navigational charts based on the S-100 standard [[18], [23]] offers a more detailed and dynamic representation of maritime environments. Together, these components form a robust data model that promises to revolutionize the maritime industry's approach to information management and navigation.

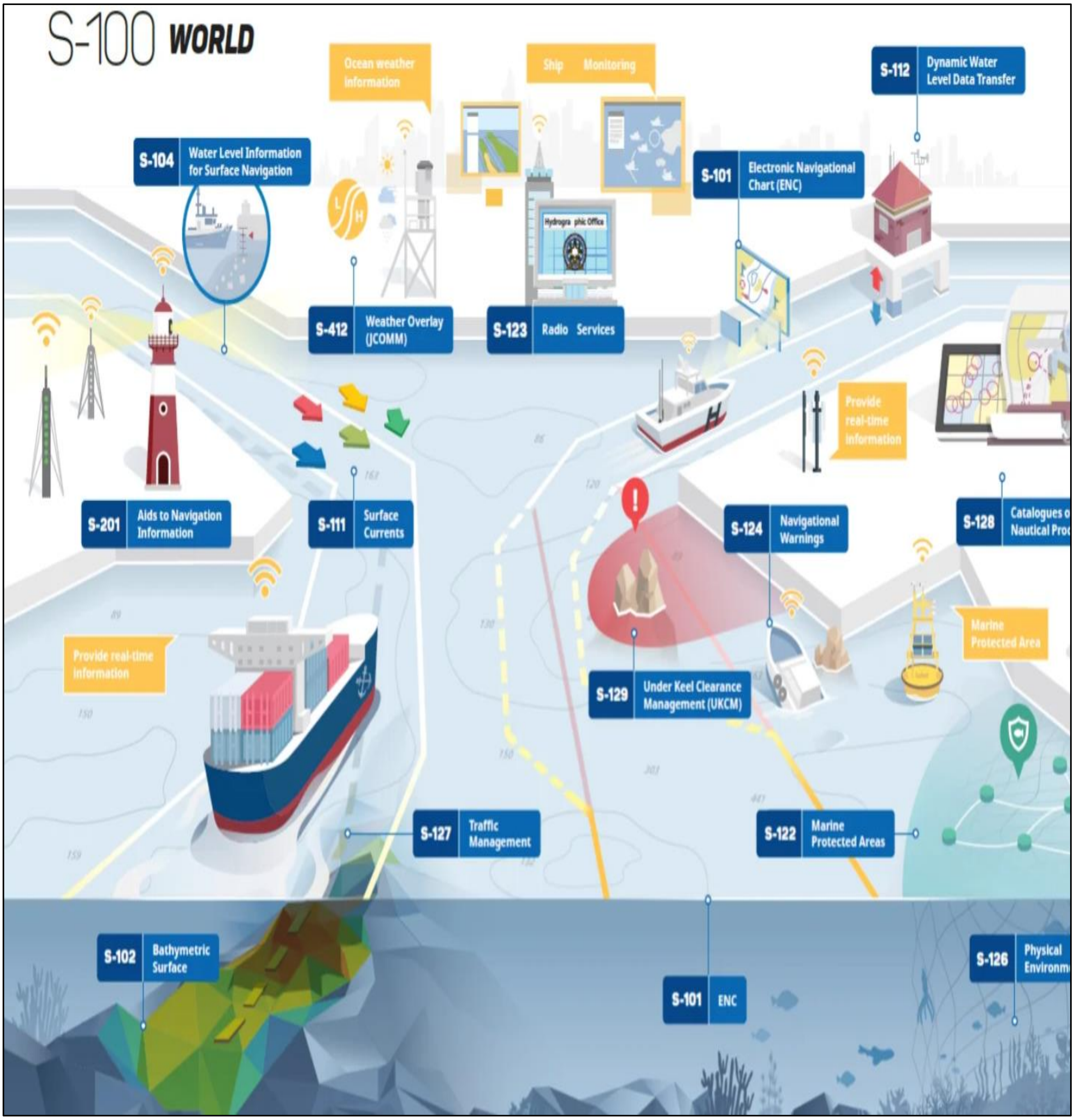

Fig 7: The S-100 Universal Hydrographic Data Model
(Source IHO)

D. VHF Data Exchange System

The maritime industry is on the cusp of a major transformation with the advent of AIS 2.0, commonly known as VDES (VHF Data Exchange System). Building on the core capabilities of the original AIS, VDES offers advanced communications functionality by integrating additional frequencies and messages for specific applications [[19], [21]]. This not only facilitates more reliable terrestrial communications, but also paves the way for satellite communications, bridging the gap between ships and shore stations.

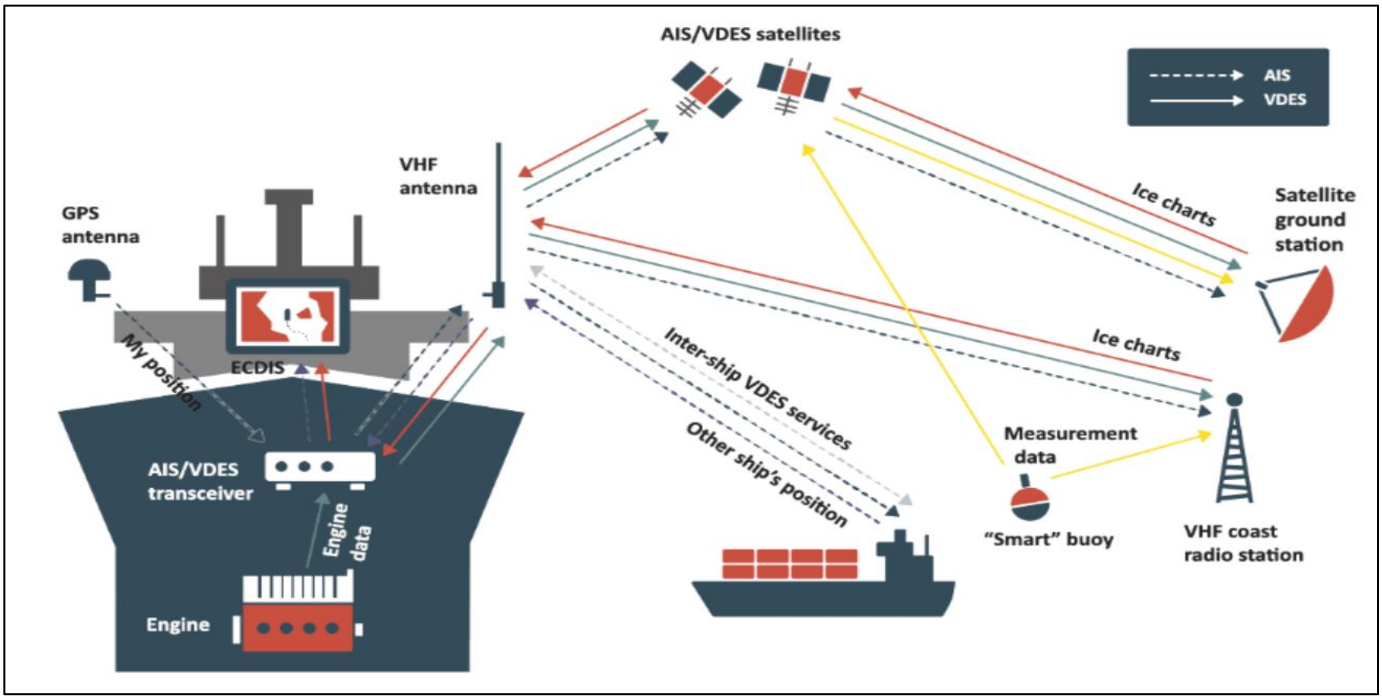

Fig 8: AIS and VDES
(Source Sternula)

As VDES standards near finalization, the industry expects a smooth transition with minimal hardware modifications and only minor software updates. This evolution means a transition to more efficient, reliable and comprehensive maritime communications systems.

E. Radar Processing for Oil Spill Detection and Sea Sensing

Radar technology has long been a cornerstone of maritime navigation, but its applications have expanded beyond simple vessel detection [[24]]. Advanced radar processing is now effectively used to detect oil spills, providing timely warnings that can mitigate environmental damage. By analysing radar backscatter from the sea surface, anomalies such as oil spils can be effectively detected under certain conditions. This real-time detection capability is critical for rapid response, ensuring that containment and clean-up operations begin without delay as oil spills pose a serious threat to marine ecosystems and coastal communities.

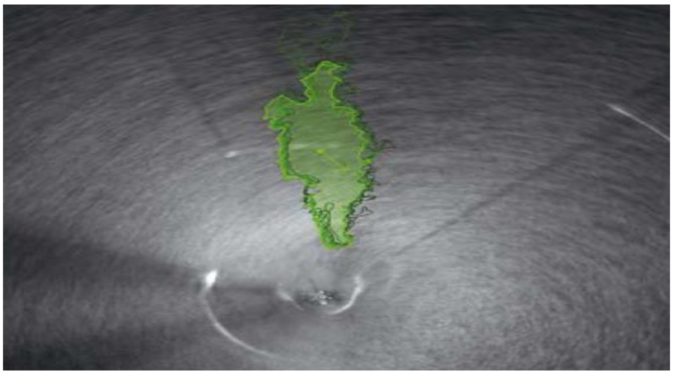

Fig 9: Oil Spill Detection using Radar
(Source Rutter)

In addition to detecting oil spills, radar technology is also used to detect ocean currents, waves and bathymetry in real time. In addition, understanding wave and current patterns can help optimize shipping routes, ensure fuel efficiency and on-time arrivals and provide a more complete map of these parameters and save costs compared to hydrographic buoys, which provide only point data.

F. Remote Pilotage and Autonomous Ships

The maritime industry is on the cusp of a technological revolution with the advent of remote piloting and autonomous ships. Remote pilotage allows experienced pilots to control vessels from a distance using modern communication and navigation systems, eliminating the need to be physically present on board. This not only improves safety, but also provides flexibility in operation. On the other hand, autonomous ships equipped with sophisticated sensors and artificial intelligence-based algorithms can navigate the waters without human intervention [[25]]. Such advanced maritime services are also deployed on the basis of modern VTS/VTMS.

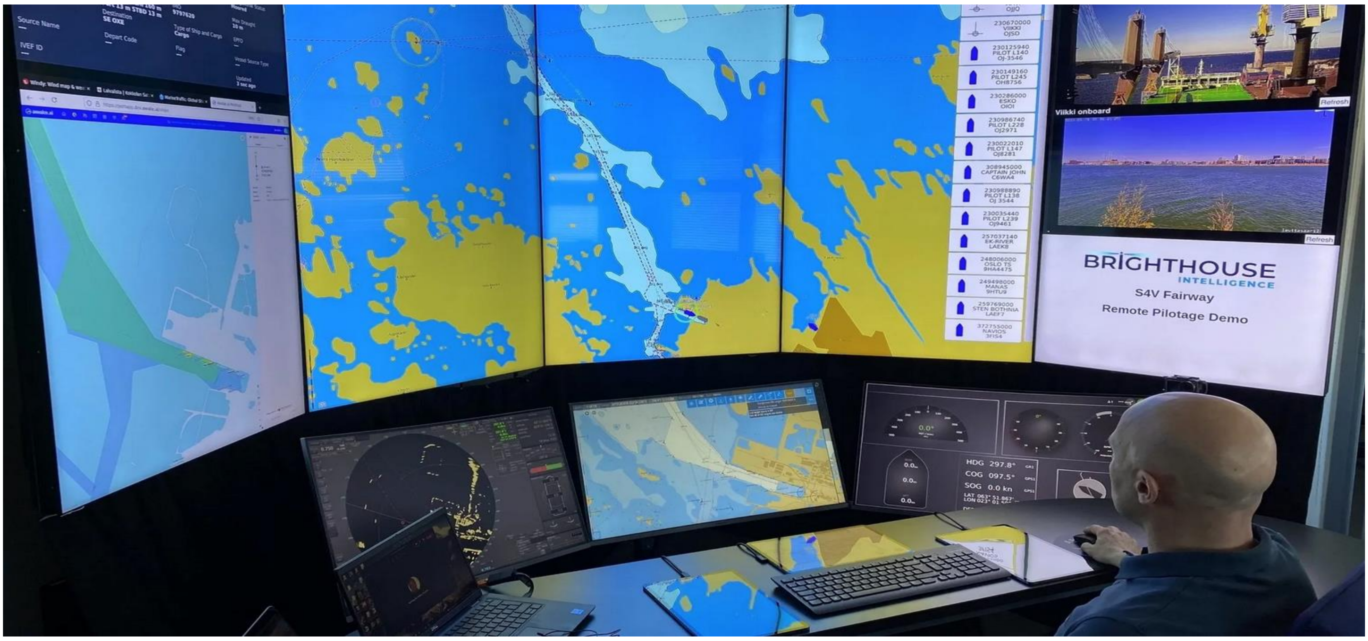

Fig 10: Remote Pilotage Example
(Source Port of Kokkola, Finland)

G. Satellite AIS and LRIT

Traditional radar and AIS/VHF systems have limitations in providing tracking of ships due to limitations in the propagation of their radio waves beyond the horizon. Satellite AIS service [[26]] offers global vessel tracking by capturing AIS signals from space, ensuring that vessels are monitored even in the most remote areas. Similarly, the Long-Range Identification and Tracking (LRIT) [[27]] system provides global position data of a nation's flag vessels. These systems bridge the coverage gaps of traditional methods by providing vessel monitoring beyond the coverage of traditional VTS/VTMS radars and AIS. As maritime operations expand and security concerns increase, the integration of satellite AIS and LRIT is becoming indispensable for global maritime surveillance.

H. Expanding Coverage by Combining Data with other Sources and Systems

Providing comprehensive coverage often requires more than just traditional Vessel Traffic Management System (VTMS) sensors [[28]]. By integrating external maritime surveillance systems, authorities can gain a broader and more detailed understanding of maritime activities. Joint ships, equipped with modern sensors and communications, can act as floating monitoring stations, expanding the surveillance area.

Mobile ground vehicles equipped with specialized equipment can be deployed in coastal areas to enhance monitoring capabilities, especially in regions where fixed installations may be difficult. The interoperability between these systems ensures a seamless and reliable surveillance network, enhancing the safety, security and efficiency of maritime operations.

Drones are changing the way we think about maritime surveillance. Aerial drones, with their high-altitude vantage points, can quickly cover large areas, providing real-time imagery and data. Water or surface drones can navigate complex waters, collect data and transmit it back to control centres. Underwater drones, or autonomous underwater vehicles (AUVs), dive into the depths of the ocean, collecting information that was previously unavailable. As technology advances, integrating these drones into the maritime surveillance ecosystem will be critical, providing unprecedented coverage and insight into the maritime domain. [[29]]

I. Simulation in Maritime Operations

Simulation has emerged as a vital tool in the maritime sector, allowing stakeholders to recreate complex scenarios and understand potential outcomes. By mimicking real-world conditions, simulation provides a risk-free environment to test strategies, train personnel, and optimize operations. It offers insights into how different variables interact, enabling better decision-making and proactive measures. As technology advances, the accuracy and realism of these simulations continue to improve, making them indispensable for maritime planning and training.

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Fig 11: VTS Operation Simulation
(Source ADPC)

Predictive analysis leverages historical data to forecast future events, and its application in the maritime domain is transformative. By analysing patterns and trends, predictive analysis can anticipate potential challenges, from adverse weather conditions to traffic congestions in busy shipping lanes. This foresight allows maritime operators to take proactive actions, ensuring smoother operations and minimizing risks. As data collection methods become more sophisticated, the accuracy of these predictions will only enhance, solidifying predictive analysis as a cornerstone of modern maritime operations.

J. *Advanced Analytics*

Business intelligence (BA) and business intelligence (BI) are revolutionizing the maritime sector by providing stakeholders with actionable insights derived from massive amounts of data. With carefully designed key performance indicators and dashboards, these tools offer a comprehensive view of operations, highlighting areas of safety, efficiency and environmental impact. By analysing these metrics, marine operators and management can make informed decisions, ensuring not only the safety of their vessels, but also the sustainability of their practices [[30]].

Fig 12: BI/BA Example for Port Operation
(Source Sercel)

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In an industry where commitment to strategy, accuracy and timely decisions are paramount, advanced analytics meets evolving needs with a focus on customer satisfaction. Using key performance indicators, operators can measure their performance, identify areas for improvement, and implement strategies that prioritize the customer experience. As the industry becomes increasingly interconnected, the role of advanced analytics in improving safety, efficiency, environmental responsibility and customer satisfaction becomes even more important.

K. Learning Management Systems and Knowledge Base

In the rapidly evolving maritime sector, learning management systems (LMS) [[31]] have become key tools for continuous learning and professional development. These platforms offer structured courses, simulations and real-time scenarios, ensuring that maritime professionals are up to date with the latest developments. Combined with a comprehensive knowledge base, an LMS provides instant access to a wealth of information, from instruction manuals to safety protocols. Together they form a comprehensive educational structure that promotes a culture of knowledge sharing and continuous improvement in the maritime world.

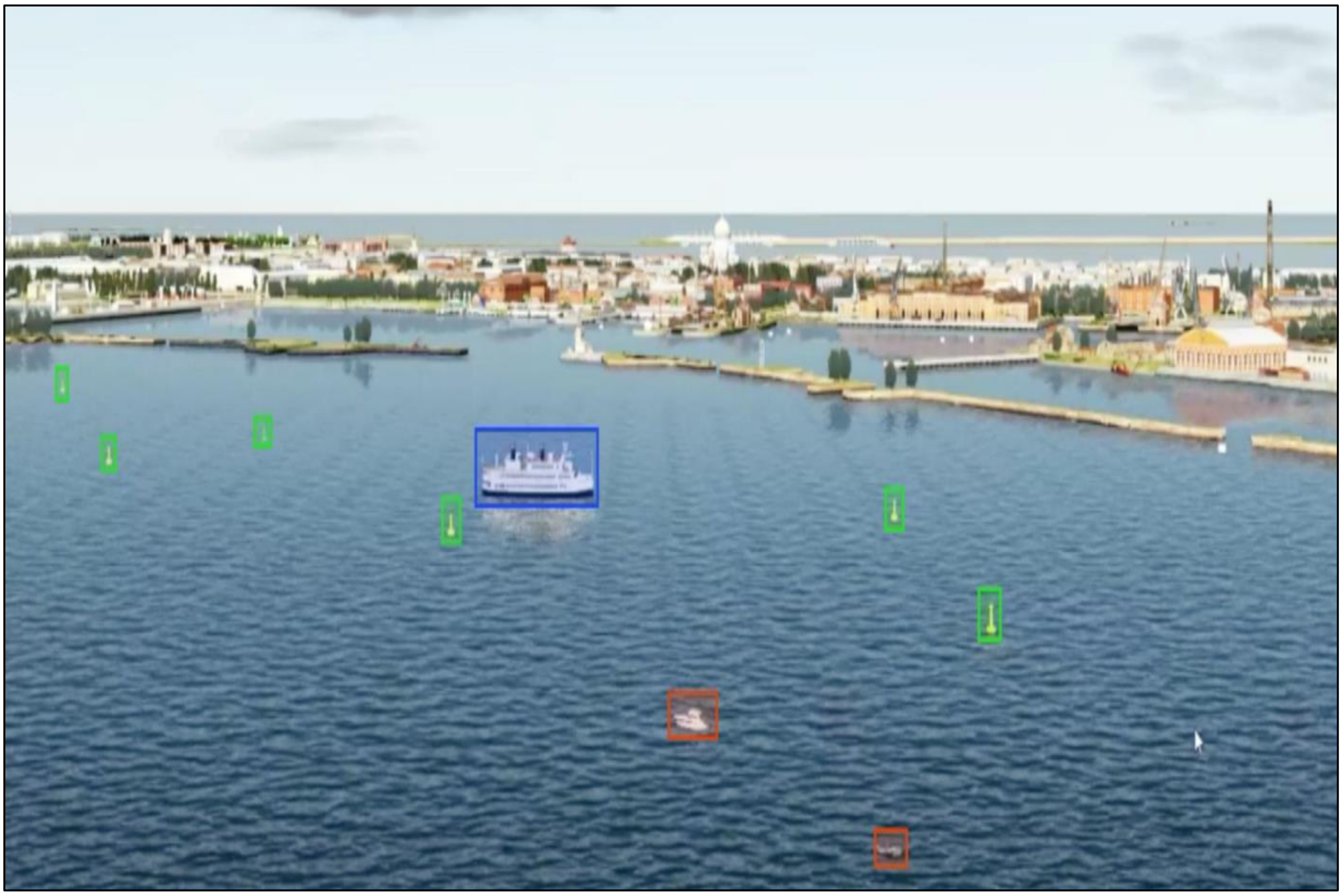
L. VTS/VTMS Data for Commercial Purposes

In today's interconnected maritime industry, data sharing has become critical to streamline business operations. Ships, yachts and agencies benefit greatly from real-time data exchange, improved route planning, fuel efficiency and on-time delivery. This seamless flow of information not only streamlines operations, but also promotes transparency and trust among stakeholders [[19]].

Moreover, when yachts and ships venture into remote waters, access to updated data becomes paramount to their safety and operational efficiency. Agencies with this data can offer customized services, from bunkering to maintenance, ensuring smooth sailing. Essentially, data sharing is transforming the maritime commercial environment, promoting collaboration and maximizing VTS/VTMS profitability.

M. Artificial Intelligence

The integration of AI-powered CCTV video analytics into VTS/VTMS operations represents a significant leap forward in maritime surveillance, they provide continuous, real-time monitoring, ensuring that every movement within the CCTV monitored area is captured and analysed. Such analytics is used, for example, to identify violations and anomalies [[32]], recognize the type of vessel, its actual draft and size, its condition, etc.



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B

Fig 13: Example of AI Video Analytics of VTMS CCTV footage

AI analyses radar and AIS data for safer navigation. It predicts ship trajectories over a significant time interval, predicts safety domains, detects potential collisions and proposes scenarios for safe passing decisions [[33]]. AI also suggests optimal routes, especially on congested waterways. AI processes huge volumes of traffic data efficiently. It identifies patterns, peak traffic times, and potential bottlenecks. The result is smoother vessel movements and reduced waiting times.

The role of AI in deciphering radio communications is also significant. It effectively identifies urgent calls or distress signals supporting operators. The problem of identifying the emotional state of negotiators is also solved, for example, to identify excessive fatigue, etc. When applied to VTMS, AI has a unique ability to evaluate multiple data sources as a whole. Namely, it analyses data from radars, CCTV systems, AIS, Met/Hydro, etc. This consolidated data set increases situational awareness and capacities of AI.

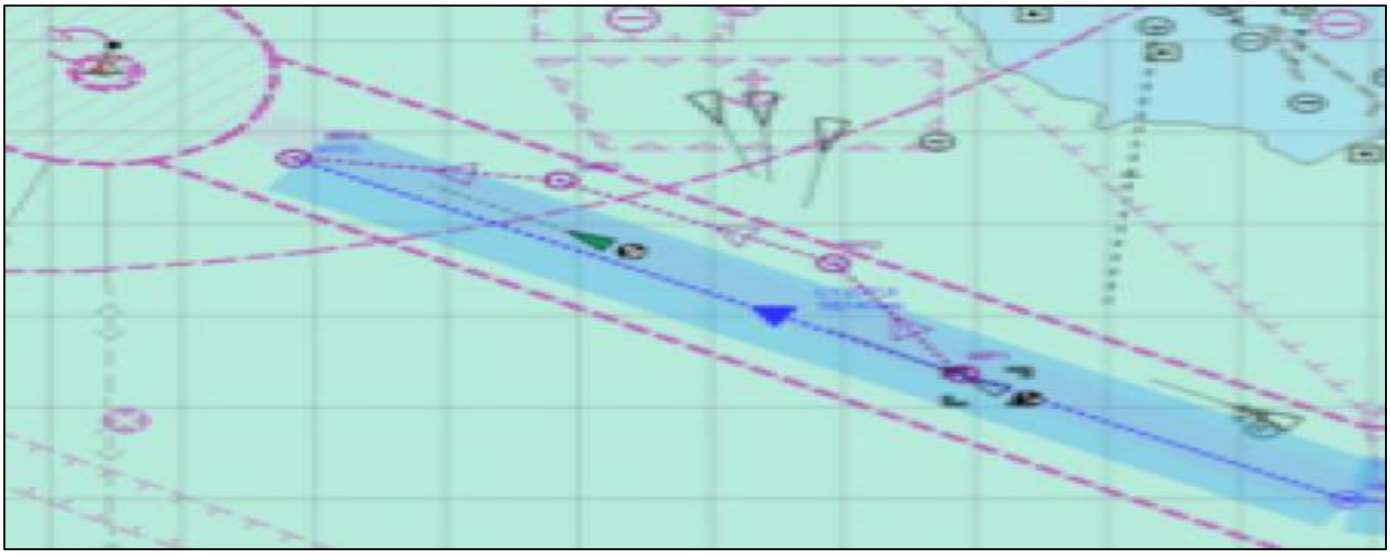

Fig 14: Example of AI-Generated Ship Trajectory, Dynamic Safety Domain and Safe Route for Ships to Diverge

AI can detect anomalies in the behaviour of vessels. Early detection of anomalies prevents possible accidents and criminal and dangerous incidents. This ensures the safety of both ships and port infrastructure. AI checks the accuracy of data from multiple sensors. It double-checks and flags discrepancies for manual review. For example, video analytics can check AIS data on dimensions and draft, which are not always accurate. This ensures that decisions are based on reliable information.

AI provides predictive information by analysing data. Operators receive guidance to make informed decisions. AI-powered decision support is truly making a difference. Artificial intelligence effectively filters and corrects sensor data. This improves the accuracy and reliability of this data. In this case, we are talking about improving the quality of CCTV video and radar images.

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The "spring" of artificial intelligence (AI) in VTS/VTMS operations is revolutionizing the maritime industry. AI enables improved decision making, safety and operational efficiency. By analysing huge data sets, AI provides unprecedented insights and the role of artificial intelligence in VTS/VTMS operations is transformative. It is clear that the future of maritime operations is closely related to the integration of artificial intelligence.

N. Environment Protection

The integration of VTS/VTMS data into environmental monitoring is a testament to the maritime industry's commitment to sustainable development [[34]]. Using this data, authorities can gain insight into current and past environmental parameters, such as real-time atmospheric or hydrological data. This information is invaluable for understanding the state of the marine environment and making informed decisions to protect it.

The pursuit of net-zero emissions is a global priority, and the maritime sector is no exception. VTS/VTMS data plays a key role in this endeavour by providing accurate information on vessel movements, fuel consumption and other relevant metrics. By analysing this data, ports and maritime authorities can implement strategies to reduce carbon emissions and move closer to a net-zero future.

One of the most serious environmental threats in maritime operations is oil spills. Fortunately, modern VTS/VTMS systems can detect oil spills using radar signals. This early detection capability allows for rapid response, minimizing environmental impacts and ensuring the conservation of marine ecosystems.

Heavy maritime traffic can lead to increased pollution levels. However, with VTS/VTMS data, traffic can be optimized to ensure smooth vessel movements, reducing downtime and therefore emissions. By optimizing ship traffic, ports can significantly reduce pollution levels, promoting cleaner air and water.

VTS/VTMS data provide a unique opportunity to estimate greenhouse gas (GHG) and carbon emissions from maritime transport. By analysing ship movement, speed, fuel consumption and other relevant data, authorities can get an accurate picture of emissions. This data-driven approach enables targeted action to reduce greenhouse gas emissions in line with global sustainable development goals.

Maritime accidents not only pose a threat to human life, but also have significant environmental consequences. VTS/VTMS systems provide real-time data on vessel movements, allowing potential collision courses or other hazards to be detected early. By preventing accidents, these systems play a critical role in protecting marine ecosystems from potential threats.

Improving environmental protection through VTS/VTMS is a testament to the maritime industry's commitment to sustainability. By harnessing the power of data, ports and maritime authorities can make informed decisions that will benefit both the environment and their operations. As technology continues to advance, the role of VTS/VTMS in protecting the environment will become increasingly prominent, paving the way for a sustainable maritime future.

V. CONCLUSION

The maritime industry, with its vastness and complexity, is undergoing a transformation phase, including taking advantage of the great capabilities of VTS/VTMS. These systems, once limited in their capabilities, have now become the core of many operations, from enhancing security and communications to playing a key role in preserving the environment. The shift from isolated proprietary systems to integrated, data-driven platforms underscores the industry's commitment to innovation and sustainability. By adopting service-oriented architecture (SOA) and e-navigation integration, the maritime sector is poised to provide seamless connectivity, real-time monitoring and enhanced decision-making capabilities.

Additionally, the integration of third-party data services, advanced radar processing, and the emergence of artificial intelligence in VTS/VTMS operations exemplify the industry's forward-thinking approach. These advances should not only streamline operations, but also strengthen environmental protection measures. Oil spill detection, emissions assessment and marine traffic optimization are just a few of the many ways VTS/VTMS contributes to a cleaner, more sustainable marine environment. The inclusion of predictive analytics, advanced analytics and modelling tools further enhances the industry's ability to anticipate problems and take proactive action, ensuring smoother operations and minimizing environmental risks.

The development and advancement of VTS/VTMS systems demonstrate the maritime industry's unwavering commitment to achieving operational excellence while prioritizing environmental stewardship. As the industry continues to address the challenges of the modern era, the integration of advanced technologies and data-driven approaches will undoubtedly pave the way for a safer, more efficient and sustainable maritime future. The outlook looks promising, with VTS/VTMS leading the way and leading the maritime world towards a brighter, greener future.

ABBREVIATIONS

- AI - Artificial Intelligence
- AIS - Automatic Identification System
- AUVs - Autonomous Underwater Vehicles
- BA - Business Analytics
- BI - Business Intelligence
- CCTV - Closed Circuit Television
- DSC - Digital Selective Call
- ENC - Electronic Navigational Charts
- ERP - Enterprise Resource Planning
- GHG - Greenhouse Gas
- GMDSS - Global Maritime Distress and Safety System

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- IALA - International Association of Marine Aids to Navigation and Lighthouse Authorities
- ICT - Information and Communication Technology
- IHO - International Hydrographic Organization
- IMO - International Maritime Organization
- INS - VTS Information Service
- ISO - International Organization for Standardization
- KB - Knowledge Base
- LMS - Learning Management Systems
- LRIT - Long Range Identification and Tracking
- MAS - Maritime Assistance Service
- MF/HF - Medium and High Frequency
- MSI - Maritime Safety Information Service
- NAS - Navigational Assistance Service
- PCS - Port Community System
- PMIS - Port Management Information System
- RDF - Radio Direction Finders
- S-100 - Universal Hydrographic Data Model
- S-57 - Navigational charts standard
- S-63 - Encryption standard for S-57
- SAR - Synthetic Aperture Radar
- SOA - Service-Oriented Architecture
- SOLAS - Safety of Life at Sea, IMO Convention
- TOS - Terminal Operations System
- VDES - VHF Data Exchange System
- VHF - Very High Frequency
- VTMS - Vessel Traffic Management Systems
- VTS - Vessel Traffic Services

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