Chapter 8
Vessel Traffic Management in the Era of Maritime Autonomous Surface Ships and Digitalization: Experiences in European Waters

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Abstract The safety of navigation in approaches to harbours and along coasts has been a concern since the beginning of maritime trade approximately 2000 years ago. The ways and means for facilitating the safety and efficiency of maritime navigation have undergone a remarkable transformation from lighthouses, first established in 300–280 BC in Alexandria, Egypt, combined with the use of flag signals by ships to announce their arrival when approaching a harbour, through the use of radars for electronic monitoring combined with radio communications by ships, to the use of satellite-based automatic identification systems combined with automated digital information exchange between maritime autonomous surface ships and geographically distant shore control centres.

This chapter examines vessel traffic management from an interwoven, regulatory, and technological perspective. It attempts to trace the evolution of international and European Union regulatory and organizational frameworks in response to the emerging needs of navigational safety and efficiency. In this context, essential technical jargon as key to an understanding of the topic of vessel traffic management is unpacked. Relevant work of the International Maritime Organization, International Association of Marine Aids to Navigation and Lighthouse Authorities, European Commission, and European Maritime Safety Agency (EMSA) is discussed. The transformative role of the European Maritime Single Window environment stands out while traversing the contribution of technological advancements in the maritime domain leading to the development of vessel traffic management system architecture and capabilities. Digitalization and automation in maritime infrastructure are explored for their influence and significance of contribution to navigational safety. The ensuing discussion highlights the role of maritime single windows and the EMSA's SafeSeaNet as key pillars for enhanced situational awareness in European

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waters together with the cutting-edge approach of sea traffic management. The chapter concludes with a fascinating outlook on the vessel traffic management system of the future in the emerging context of the fourth industrial revolution driven by artificial intelligence, machine learning, and maritime autonomous surface ships.

Keywords Vessel traffic management · Sea traffic management · SafeSeaNet · European Maritime Single Window environment · Vessel traffic services · Next-generation vessel traffic management

8.1 Introduction

The safety of navigation, including in port waters and along coasts, has been a concern since the advent of maritime trade dating back at least 2000 years. One of the first well-documented examples of a lighthouse, the Pharos of Alexandria in Egypt, was built in 300–280 BC (Stevenson, 2013: 5). Indeed, lighthouses, shore-side beacons, and buoys continue to serve as passive safety guides for entry into a port, strait, or channel, ships approaching a port traditionally announced their arrival through the use of flag signals. However, flag signalling by itself proved to be inefficient and insufficient for dealing with increasingly dense traffic and adverse weather conditions. Therefore, with the invention of radio, the use of flag signals was promptly replaced with radio communications in the early 1900s. Subsequently, radio detection and ranging during the Second World War and its proliferation in civilian industries witnessed the establishment in 1948 of the world's first harbour-control radar at Victoria Pier, Douglas, Isle of Man (Hughes, 2019), followed by the port of Liverpool, United Kingdom, in 1949. In the 1950s, ports in Europe, and elsewhere, were equipped with shore-side radars and a radio for communicating with vessels, bringing quick gains in efficiency. The Netherlands, for example, proceeded with setting up a radar at the approaches to the port of Amsterdam in 1952 and, by 1956, had established a system of radar stations for oversight of shipping traffic in the entire Rotterdam port area.

Although the ability to keep track of shipping traffic by radar coupled with the ability to transmit navigational messages to ships by radio constituted the first formal vessel traffic systems, these early radar surveillance systems and other aids to navigation lacked the capability to interact and respond to traffic situations. The inadequacies in surveillance and management of maritime traffic were highlighted in the wake of continuing major shipping disasters in Europe attributed to mammoth tankers, from the *Torrey Canyon* and *Amoco Cadiz* to *Erika* and *Prestige* (Djønne, 2023). The development of modern-day vessel traffic management and information systems embracing advancements in radar technology from automatic radar plotting aids to integrated electronic chart displays and information systems and new equipment, such as automatic identification systems for interacting with, advising, and assisting ships, was imperative to ensure the safety and efficiency of navigation.

This chapter examines vessel traffic management from a regulatory and technological perspective. The evolution of regulatory and organizational frameworks for navigational safety and efficiency is charted. Relevant work of the International Maritime Organization (IMO), International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), European Commission (EC), and European Maritime Safety Agency (EMSA) is elaborately discussed. The transformative role of the European Maritime Single Window environment (EMSWe) is examined. The contribution of digitalization and automation to navigational safety is explored. EMSA's SafeSeaNet is highlighted as a key pillar for enhanced situational awareness in European waters together with the cutting-edge approach of sea traffic management. The chapter concludes with an outlook on the vessel traffic management system of the future in the emerging context of the fourth industrial revolution driven by artificial intelligence, machine learning, and maritime autonomous surface ships.

8.2 International Regulatory Framework for Vessel Traffic Management

In matters maritime, IMO, established under the *Convention on the International Maritime Organization* in 1948, provides, among other things, "machinery for co-operation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade, and to encourage the general adoption of the highest practicable standards in matters concerning maritime safety and efficiency of navigation" (IMO Convention, 1948). However, it was not until 1968 that IMO formally considered that port advisory services could make a valuable contribution to safety in harbour approaches and adopted an Assembly resolution recommending to governments that they consider setting up such services in ports and their approaches, particularly in ports and terminals handling oil and noxious or hazardous cargoes (IMO, 1968).

As vessel traffic services began to be implemented in a number of areas around the world, at the operational level, there was a risk of differing procedures likely resulting in confusion for masters of vessels. From a legal perspective, there was the need to ensure that such advisory services did not prejudice the right of innocent passage in territorial waters and were offered on a voluntary basis in waters outside the territorial seas. Guidelines for vessel traffic services (VTS) were, therefore, adopted at the 14th Assembly session of IMO (1986) aimed at harmonization of operational procedures for improving safety and efficiency of maritime traffic. The Guidelines suggested areas where VTS would be particularly appropriate, namely, in the approaches and access channels of a port and in areas having high traffic density, movement of noxious or dangerous cargoes, navigational difficulties, narrow channels, or environmental sensitivity. The Guidelines clarified that navigational decision-making remained the ship master's prerogative. The importance of pilotage in a VTS and reporting procedures for ships passing through an area where a VTS operates were also highlighted. The Guidelines recognized that vessel traffic services may offer different functional interaction levels, namely, as an "information service" by broadcasting or exchanging traffic conditions and safety matters; as a "navigational assistance service" normally at the request of the vessel or of own accord, in difficult navigational or meteorological circumstances; as a "traffic organization service" preventing development of dangerous situations through forward planning of vessel movements; and support of allied activities such as pilotage, search and rescue, and pollution prevention and control. Furthermore, the Guidelines expected that a VTS authority should promulgate appropriately, including through chartlets, local traffic movement rules and regulations, services offered, and area of application.

An update to the guidelines for vessel traffic services (IMO, 1997a) provided greater clarity on tasks that may be performed by a VTS in accordance with the service rendered. In the updated guidelines, the traffic management functions of vessel traffic services were delineated between the primary function and the enforcement function. The primary function was further distinguished as the strategical function of allocation of space by forward planning that can be performed by a traffic organization service and tactical function of assisting manoeuvres to avoid collision or navigational decision-making on board that related to an information service and/or navigational assistance service. The concept of a "traffic image" was introduced in the updated guidelines in the context of the capability of a vessel traffic service to interact with traffic and respond to developing traffic situations and included compiling data on the fairway situation, traffic situation, and vessels. Distinction was also made between a port or harbour VTS and coastal VTS. More importantly, violations of VTS regulatory requirements were to be addressed in accordance with established policy that is consistent with national law.[1] When rendering services, instructions issued by an authorized VTS are expected to be result-oriented, such as to not encroach on the master's responsibility for safe navigation or disturb the traditional relationship between the master and pilot. As such, in any message directed to a vessel by a VTS, it should be made clear whether the message contains information, advice, warning, or an instruction.

Further revised guidelines for vessel traffic services (IMO, 2022a) identified navigational information that can assist onboard decision-making, provide ship

[1] For example, according to the Finnish Maritime Administration *Vessel Traffic Service Act* (623/2005), Section 29—Penal provisions, "A person who deliberately or through carelessness violates orders issued by the VTS authority under section 17(1), provisions of section 21 or orders confirmed in the decision to establish a VTS referred to in section 8 or neglects the notification duty laid down in section 22 or section 23 must be sentenced to a fine for a vessel traffic service violation unless a more severe punishment is laid down elsewhere in law". (https://vayla.fi/documents/25230764/35592998/EN_2005_NR11.pdf/. Accessed 22 February 2024)

traffic information for monitoring and management, and recognize developing unsafe situations that may require a mitigation response to improve the safety and efficiency of navigation in a VTS area and the protection of the marine environment. The imperative to harmonize data exchange, information sharing, and VTS operations with ship reporting systems, ships' routeing measures, and allied services is reemphasized.

Incidentally, although guidelines for vessel traffic services were first adopted by IMO in 1968 and thereafter updated in 1986, 1997, and 2022, VTS were not specifically referred to in IMO's key pillar for maritime safety, the *International Convention for the Safety of Life at Sea, 1974* (SOLAS, 1974), until June 1997, when a new regulation to Chapter V (Safety of Navigation) was adopted by the Maritime Safety Committee (IMO, 1997b) setting out when VTS can be implemented. The new regulation, Regulation 8-2, entered into force, under "tacit acceptance" on 1 July 1999. Shortly thereafter, as part of the substantial revisions to the fifth version of SOLAS, 1974, the existing text of Chapter V was replaced, and a new, revised SOLAS Chapter V on "Safety of Navigation" was adopted in December 2000 and entered into force on 1 July 2002 (IMO, 2000). According to the new SOLAS Chapter V, "Vessel traffic services (VTS) contribute to safety of life at sea, safety and efficiency of navigation and protection of the marine environment … from possible adverse effects of maritime traffic". However, in keeping with the provisions of the law of the sea, the use of VTS may only be made mandatory in sea areas within the territorial seas of a coastal state. Chapter V, Regulation 12 identifies specific obligations of Contracting Governments:

- to arrange for the establishment of VTS where, in the Contracting Governments opinion, the volume of traffic or the degree of risk justifies such services;
- to follow the guidelines developed by the Organization in planning and implementing VTS, wherever possible; and
- to endeavour to secure the participation in, and compliance with, the provisions of vessel traffic services by ships entitled to fly their flag.

The regulatory framework under SOLAS is complemented by the role and contribution of the IALA in pursuit of its mission to ensure the provision of effective and harmonized marine aids to navigation systems and services worldwide. IALA is essentially an international, technical association, and since its establishment nearly 100 years ago, it has developed several important concepts and systems contributing to the safety of navigation, such as the IALA maritime buoyage system, differential Global Positioning System, automatic identification system (AIS), Very High Frequency (VHF) data exchange system, and vessel traffic services. Guidance on providing marine aids to navigation services and vessel traffic services accounts for more than 250 standards, recommendations, and guidelines published by IALA. The work of IALA relating to VTS is mainly organized through its VTS Committee into five IALA standards, as enumerated in Table 8.1.

It must be highlighted that whereas IALA began in 1957 as a consultative, technical, not-for-profit international organization, its work assumes added significance

Table 8.1 IALA standards for VTS and scope (IALA, n. d.)

Standard	Title	Scope
S1040	Vessel traffic services	VTS implementation VTS operations VTS communications VTS auditing and assessing VTS data and information management VTS technologies VTS additional services
S1050	Training and certification	Training and assessment Accreditation, competency, certification, and revalidation
S1060	Digital communication technologies	Harmonized maritime connectivity
S1070	Information services	Data models and data encoding
S1010	Marine aids to navigation planning and service requirements	Obligations and regulatory compliance Risk management Quality management

since the process has been set in motion for its transition to an intergovernmental organization with the adoption, in February 2020, of the *Convention on the International Organization for Marine Aids to Navigation* (IALA, 2021).

IALA apparently takes a system perspective[2] of vessel traffic services. According to the IALA Guideline on functional and performance requirements for VTS systems (IALA, 2022),[3] a VTS system comprises VTS software, hardware, communications, and sensors but excludes personnel and procedures. A defined set of operational requirements[4] is imperative for the establishment of a VTS system. The functional and performance requirements for a VTS system are derived from the operational requirements. Regarding the potential equipment and sensors for a VTS system, generic guidance is found in the IALA G1111 Guideline Series. The system approach adopted by IALA is key to understanding the contemporary developments in vessel traffic management (IALA, 2022).

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[2] The systems approach recognizes that the components that make up a system such as vessel traffic services are inter-related and inter-dependent and require consideration as a unitary whole for system effectiveness.

[3] Guideline G1111 is associated with IALA Recommendation R0128 VTS Systems and Equipment, a normative provision of IALA Standard S1040 Vessel Traffic Services (VTS).

[4] According to IALA (2022, 7), operational requirements imperative for the establishment of a VTS system would include but are not limited to the following:

- Delineating the VTS area and, if appropriate, VTS sub-areas or sectors
- Types and sizes of ships required or expected to participate in the VTS navigational hazards and traffic patterns
- Human/machine interface and human factors, including health and safety issues
- Tasks to be performed by VTS operators and/or supervisors
- Operational procedures, including communication, staffing level, and operating hours of the VTS
- Information sharing and co-operation with external stakeholders
- Legal framework

8.3 Vessel Traffic Management System in the European Union

The earliest regulatory initiative relating to VTS in European waters appears to have been taken in 1993 when Council Directive 93/75/EC (EC, 1993b),[5] Article 5, paragraph 5, obliged vessels entering or leaving a port located in a Member State to make use of local vessel traffic services *where they exist*. A reporting system requiring a specified set of information was introduced for all vessels bound for or leaving a community port and carrying dangerous or polluting goods in bulk or packaged form. The Directive was a follow-up of a common policy objective on safe seas adopted earlier in 1993 (EC, 1993a) for the introduction of a mandatory information system to give EU Member States rapid access to all important information relating to the movements of ships carrying dangerous or polluting materials and to the precise nature of their cargo.

However, a series of major maritime oil spills in rapid succession, resulting in significant deleterious effects on the marine environment, essentially triggered the accelerated implementation of vessel traffic information and management systems in Europe (EC, 1993b). Of particular relevance was the *Erika* oil spill in 1999, a 25-year-old single-hull tanker which severely polluted 400 kilometres of the French coastline and resulted in an exceptionally high damage to fisheries and tourism, making the Erika a major environmental disaster which aroused much public concern about the safety of maritime transport (EC, 2001). Even before Europe could recover from the impacts of the *Erika* oil spill, the *Prestige* carrying some 77,000 tonnes of fuel oil broke up off Spain in 2002, causing major ecological and socio-economic disaster in the coastal areas of Spain, France, and Portugal and the European Parliament adopting a resolution (EC, 2002a) calling for stronger measures that can enter into force more rapidly, besides stating that the Prestige disaster once again underlined the need for effective action at international and European Union level in order to significantly improve maritime safety.

An almost immediate regulatory response to the *Prestige* incident was the significant reinforcement, extension, and amendment of the provisions of Directive 93/75/EC (EC, 1993b) to enhance the safety and efficiency of maritime traffic and better prevent and detect pollution by ships through the establishment of the Community Vessel Traffic Monitoring and Information system (VTMIS system) together with the European Union Maritime Information and Exchange system (SafeSeaNet). The repealing Directive 2002/59/EC (EC, 2002b)[6] followed up on the

[5] Repealed by Directive 2002/59/EC of the European Parliament and of the Council of 27 June 2002 establishing a community vessel traffic monitoring and information system and repealing Council Directive 93/75/EEC

[6] Annex III to Directive 2002/59/EC is replaced by text in Annex to Commission Directive 2014/100/EU of 28 October 2014 amending Directive 2002/59/EC of the European Parliament and of the Council establishing a community vessel traffic monitoring and information system. OJ L 308 (29 October 2014), p. 2

initiative requiring set up a ship reporting and monitoring system by obliging a mandatory notification 24 hours prior to entry into the ports of Member States and a concurrent obligation on Member States for monitoring ships entering waters in their area of responsibility, including any mandatory ships' routeing systems. The information and reporting system was to be supported by the mandatory use of AIS and long-range identification and tracking (LRIT) systems by ships, with AIS fixed-base stations in EU Member States and a LRIT European Cooperative Data Centre in charge of processing long-range identification and tracking information. The 2002 Directive further required necessary equipment and infrastructure for ship reporting systems, ships' routeing systems, and vessel traffic services to be established by the end of 2007. Furthermore, in a step change, exchanges of data between Member States regarding dangerous and polluting goods carried on board ships would henceforth take place electronically.

SafeSeaNet (EMSA, n.d.) has transformed the efficiency and effectiveness of vessel traffic management in the European Union. It enables the receipt, storage, retrieval, and exchange of information for the purpose of maritime safety, port and maritime security, and marine environmental protection in addition to ensuring the efficiency of maritime traffic and maritime transport. It facilitates the exchange of information in an electronic format across a network of national SafeSeaNet systems in Member States, with the Central SafeSeaNet system established in the European Maritime Safety Agency[7] serving as a nodal point, all of which are linked together by the Union Maritime Information and Exchange network. The system is configured for the automatic transmission of data received at Member States. The central SafeSeaNet facilitates the distribution of electronic messages and exchange or sharing of data covering nearly 480 different elements (see Table 8.1 and 8.2 for a broad overview) in accordance with the VTMIS Directive (EC, 2009b), with other relevant Union legislation serving as performance enablers, inter alia, Directive 2000/59/EC on port reception facilities (EC, 2000); Directive 2005/35/EC on ship-source pollution (EC, 2005); Directive 2009/16/EC on port state control (EC, 2009a); and Directive 2010/65/EU on reporting formalities for ships arriving in and/or departing from ports and LRIT information concerning third country vessels (EC, 2010). Overall, the SafeSeaNet system supports the realization of a barrier-free, European maritime transport space (EC, n.d.).

Among the enablers of the VTMIS, Directive 2010/65/EU on reporting formalities for ships elaborated on the data subject to electronic transmission and introduced the concept of a "single window environment" effective no later than 1 June 2015, linking SafeSeaNet, e-Customs, and other electronic systems, such that all information is reported once and made available to various competent authorities and the Member States. A comprehensive Ship Pre-Arrival Security Information Form was implemented for all ships prior to entry into an EU port. Further, where reporting formalities are required and to the extent necessary for the good functioning of the single window, the electronic systems must be interoperable, accessible, and compatible with the SafeSeaNet system and, where applicable, with the

[7] The Agency (EMSA) is established by a Regulation of the European Commission (EC, 2002c).

Table 8.2 List of reporting obligations for ships in European Union ports and waters as per Regulation (EU) 2019/1239 (EC, 2019)

A. Reporting formalities resulting from legal acts of the European Union	B. Convention on Facilitation of International Maritime Traffic (FAL, 1965) forms and formalities resulting from international legal instruments
Notification for ships arriving in and departing from ports	FAL form 1: General declaration
Border checks on persons	FAL form 2: Cargo declaration
Notification of dangerous or polluting goods carried on board	FAL form 3: Ship's stores declaration
Notification of waste and residues	FAL form 4: Crew's effects declaration
Notification of security information	FAL form 5: Crew list
Information on persons on board	FAL form 6: Passenger list
Customs formalities	FAL form 7: Dangerous goods
Safe loading and unloading of bulk carriers	Maritime declaration of health
Port state control	
Maritime transport statistics	

computer systems stipulated for a paperless environment for customs and trade in the European Union (EC, 2010).

Further, to enhance the identification and monitoring of ships through reporting formalities, EU Member States are obliged by the VTMIS Directive (EC, 2002a), Article 23, to work together with the Commission to put in place, where necessary, mandatory reporting systems (MRS), mandatory maritime traffic services, and appropriate ship's routeing systems, with a view to submitting them to IMO for approval. They are also required to collaborate, within the regional or international bodies concerned, on developing LRIT systems.

Subsequently, as experience was gained and technical advancements progressed, SafeSeaNet evolved into a more integrated information system and a platform facilitating the convergence and interoperability of maritime systems and applications, including space-based technologies combining information from other EU monitoring and tracking systems (CleanSeaNet, the EU LRIT Data Centre, and THETIS) and also from external systems (e.g. satellite AIS). These developments, effective November 2015, played a central role in the development of the voluntary Common Information and Sharing Environment (CISE)[8] for the European maritime domain, through a collaborative process in the Union (EC, 2014).

[8]The CISE network spans across seven relevant sectors and user communities relating to border control and "maritime surveillance" including transport, environmental protection, control of fisheries and borders, general law enforcement, customs, and defence. CISE was explained with four key words: interoperability; improving situational awareness; efficiency; and subsidiarity. Interoperability means that the EU has to find a way to enable the information exchange between sectoral systems. Improving situational awareness implies that the information obtained in CISE should improve the situational awareness within the EU. Efficiency means that CISE should contribute to avoiding duplication in the collection of information and reducing the financial costs for all actors involved; specifically, more than 50% of gathered information was collected solely by defence communities and the maritime safety and security community. Subsidiarity means the enhancement of coordinating the collection and verification of information from all their agencies.

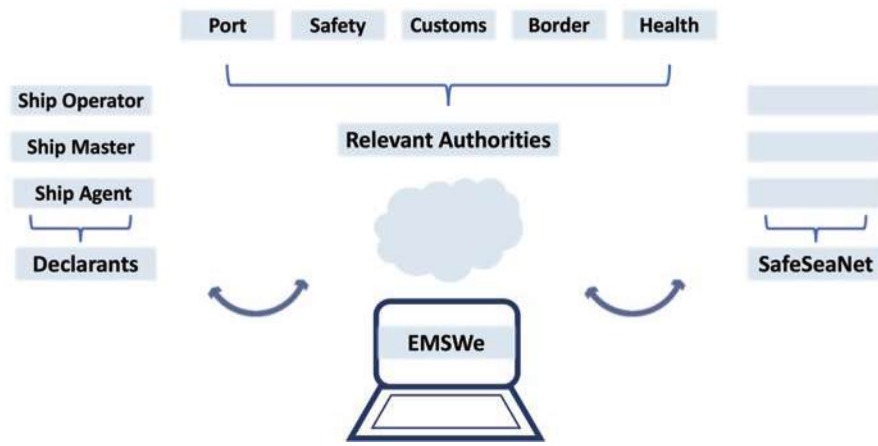

Fig. 8.1 European Maritime Single Window environment (EMSA, n.d.)

The single window concept implemented in 2015 was rechristened as the European Maritime Single Window environment (EMSWe) (Fig. 8.1) in 2019 via Regulation (EU) 2019/1239 (EC, 2019), repealing Directive 2010/65/EU. The corresponding maritime National Single Window (mNSW) implemented in each Member State constitutes the comprehensive reporting entry point (listed in Table 8.2) for maritime transport operators, performing the functionalities of data collection from the declarants and data distribution to all relevant competent authorities and providers of port services. The front-end interfaces of the mNSWs on the side of the declarants are harmonized at the EU level by the use of common interface software for system-to-system exchanges of information developed at the EU level. The European Commission developed the interface module and provides updates when needed, while the Member States are charged with the responsibility of integrating and managing the interface module and updating the software as and when new versions are provided by the Commission. An easy-to-use graphic user interface (see examples in Figs. 8.2 and 8.3) with common functionalities forms part of the mNSWs for manual reporting by declarants (see, e.g. EMSA, 2014; Swedish Maritime Administration, n.d.).

The mNSWs are supported by several common databases that enable the reuse of the information provided and facilitate the submission of information by declarants. The EMSWe Central Ship Database (Table 8.3) includes a reference list of ship particulars and their reporting exemptions, as reported to the respective mNSW, and currently holds information on more than 300,000 ships, including more than 120,000 active ships. The Central Geographical Database manages, stores, and shows the Member States and EMSA maritime applications reference geographical features that include geographical areas of common interest, such as the exclusive economic zone, fisheries areas, traffic separation schemes, and territorial waters. The submission of information by declarants is facilitated by the Common Location Database that holds a reference list of location codes, including the United Nations

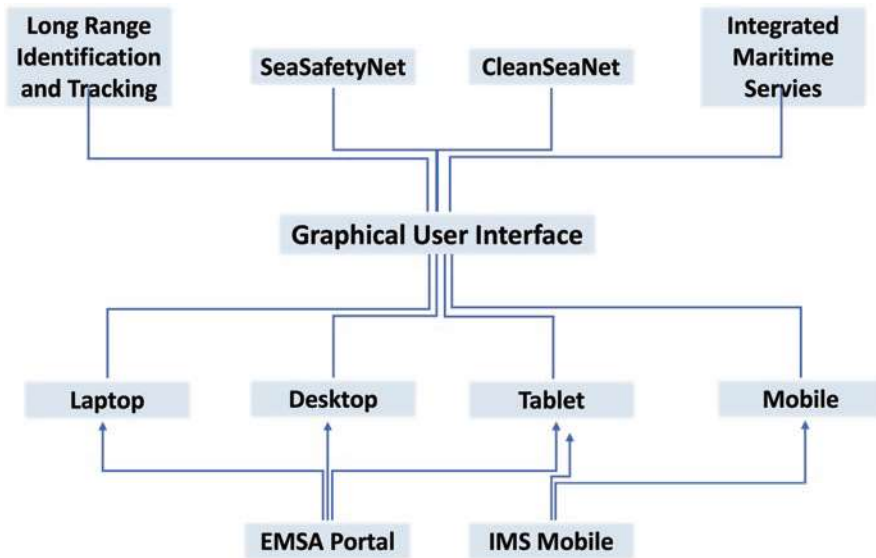

Fig. 8.2 SafeSeaNet Ecosystem Graphical User Interface (EMSA, n.d.)

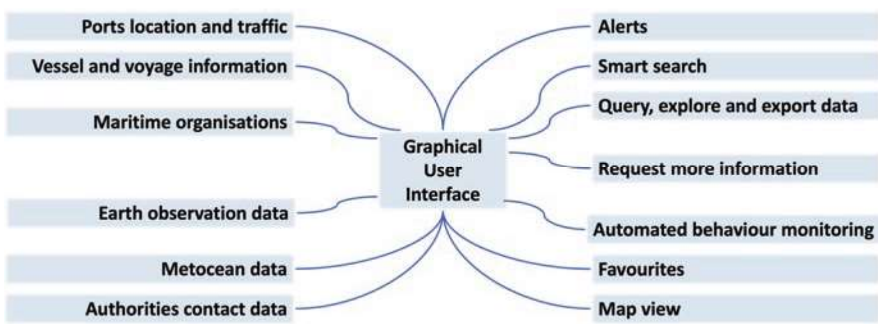

Fig. 8.3 SafeSeaNet Ecosystem Graphic User Interface data layers and functions and services (EMSA, n.d.)

Code for Trade and Transport Locations (UN/LOCODE), the SafeSeaNet-specific codes, and the port facility codes as registered in the Global Integrated Shipping Information System of IMO. Furthermore, the Common Hazmat Database incorporates a list of dangerous and polluting goods that are to be reported to the mNSW, and the Common Ship Sanitation Database enables receipt and storage of data related to the Maritime Declarations of Health. EMSA provides the elaboration of the EMSWe specifications, namely, the EMSWe dataset, which includes all the information that might be requested by national authorities or port operators for administrative or operational purposes when a ship makes a call in any port of the

Table 8.3 EMSWe central ship database: data sources and set of ship information (EMSA, 2022)

Central ship database: data sources	Central ship database: set of ship information
SafeSeaNet (ship data from port call notifications, incident reports, ship mandatory reporting systems and exemptions) EU LRIT Cooperative Data Centre (ship data from the EU LRIT ship database) THETIS (ship data from port state control inspections) Fishing vessels record (information on EU fishing vessels) Commercial data provider IHS Markit (information on commercial ships of 100 GT and above)	Ship identification (e.g. IMO number, name, MMSI number, fisheries IR number) Inmarsat call number Ship type (different code lists: IHS, UN, PSC) Construction details (dates of ship construction) Status (from IHS and THETIS) Dimensions (e.g. gross tonnage, length overall, length between perpendiculars) Dimensions for fishing vessels (classes) Company information (ISM company, owner) Technical details (e.g. hull, engines) Technical details for fishing vessels (e.g. fishing gears, segment) Port state control information (bans) Fisheries control information (equipment and license indicators) Reference list for fishing vessels (RFMO and SANCO lists)

IHS IHS Maritime (formerly Lloyd's Register-Fairplay), *IR number* information request number for fishing vessel, *ISM company* company as defined in the IMO International Safety Management (ISM) Code, *MMSI* Maritime Mobile Service Identity, *PSC* port state control, *RFMO* Regional Fisheries Management Organization, *SANCO* Directorate General Health and Consumers, European Commission, *THETIS* EMSA port state control inspection database, *UN* United Nations Fleet segmentation, of the fishing fleet, as adopted by the Food and Agriculture Organization of the United Nations, is based on the dominant gear used in terms of percentage of time: more than 50% of the time at sea using the same fishing gear during the year. The segments include polyvalent vessels using more than one gear, with a combination of passive and active gears, seiners, dredgers, trawlers, and longliners

European Union and includes technical specifications, standards, and procedures for the EMSWe.

A pilot study on interoperability (EMSA, 2022) mapped together all pieces of information that were common to several reporting formalities in EU waters to apply the reporting-once principle. The study resulted in the definition of an overall dataset of 478 individual data elements in EMSWe that were structured in 46 datasets (Table 8.4).

As of January 2024, the common web interface, the SafeSeaNet Ecosystem Graphical User Interface (SEG), provides access to all EMSA's maritime applications and datasets including SafeSeaNet, Integrated Maritime Services, LRIT, and CleanSeaNet (Fig. 8.2). The SEG implements system-to-system interfaces. Its functionalities enable users to benefit from integrated data flows, options for data visualization, and services such as automated vessel behaviour monitoring (Fig. 8.3).

Table 8.4 Overview of the EMSWe data model (EMSA, 2022)

First tier	Second tier	Third tier	Fourth tier	Fifth tier
Message header	Issuer party			
	Authenticator	Authenticator location		
Voyage	Itinerary	Additional security measures taken		
		Previous port facility, period of stay		
	Person on board	Identity or travel document		
		Visa		
		Crew effects		
		Health details		
	Ship	Inmarsat number		
		Ship registry details		
		ISSC		
		Company security officer	CSO information	
		IMO company		
	Ship-to-ship activity	Security measures applied *In lieu of the approved plan*		
		Activity geographical coordinates		
	Agent at port	Agent at port communication Agent at port address		
	Transport equipment			
	Cargo	Cargo item details	Dangerous goods	DG subsidiary risk
				DG package
				DG additional information
			Transport equipment	
			Cargo item package	
		Transport contract		
		Ship to shore activity		
	Ships stores			
	Waste	Waste item		
	Additional information			
	Primary purpose of call			
	Health	Sanitary measures		
	Maritime transport statistics			
	Customs			

8.4 Contemporary Developments in European Vessel Traffic Management

Continuous enhancement of the maritime picture is an ongoing endeavour for the European Union, while VTS and other maritime service providers seek detailed, reliable real-time information about occurrences at sea to be able to perform their duties effectively. Two advanced functionalities accessed through EMSA's SEG—automated behaviour monitoring and STAR Tracking—are noteworthy. Automated behaviour monitoring algorithms for "near real-time" detect specific or anomalous behaviours (such as spoofing positions, not reporting position, sudden change of heading, sudden change of speed, etc.), alerting users within approximately 15 minutes, and "historical" automated behaviour monitoring algorithms use archived position reports or position reports from a database of specific, detected situations and events, for example, detecting port calls globally. Automated behaviour monitoring algorithms can be helpful in vessel tracking and monitoring for verification of reporting obligations or for early warning of potentially dangerous situations affecting the safety of navigation. STAR Tracking is the main ship tracking application at EMSA. It processes and stores up to 1700 ship position reports per second on a 24/7 basis from different ship reporting systems including MRS, terrestrial-AIS, satellite-AIS, LRIT, and vessel monitoring systems. Among other functionalities, STAR Tracking can merge ship positions to form ship tracks and correlate datasets with available positions to identify vessels whenever possible.

Interoperability is a current area of focus in EU vessel traffic management. Despite advancements in the provision of vessel traffic services, a lack of interoperability among a dense multitude of VTS and MRS in European waters means that ships crossing several mandatory ship reporting systems and VTS areas along their route are often required to report similar information in each area. Currently, in European waters, there are more than 16 IMO-adopted MRS in addition to more than 100 VTS, which causes avoidable reporting burdens for ships, impacts the efficiency of coastal station operators' services, and hinders awareness of their areas of control. Figure 8.4 illustrates the case of multiple mandatory ship reporting requirements for a vessel on voyage from Alexandria, Egypt, to Gdansk, Poland. Harmonized implementation of VTS and MRS, particularly in European waters is, therefore, an urgent imperative.

With regard to interoperability, a pilot project in the European Union (EMSA, 2022) demonstrated the ability for ships to electronically submit MRS and VTS reports and reuse the information available in SafeSeaNet. The pilot project, which was joined by 14 coastal states in the European Union, also explored new technologies, such as VHF Satellite Data Exchange (VDE-SAT), to communicate MRS and VTS reports between ships and the shore (Fig. 8.5).

An outcome of the EU pilot project on the facilitation of ship-to-shore reporting was a proposal to the IMO Expert Group on Data Harmonization (EGDH 2/5) in September 2020 to carry out modelling of the dataset related to the ship reporting

Fig. 8.4 Example of MRS reporting along a route from Alexandria (Egypt) to Gdansk (Poland) (EMSA, 2022; ESRI, 2016, 2018)

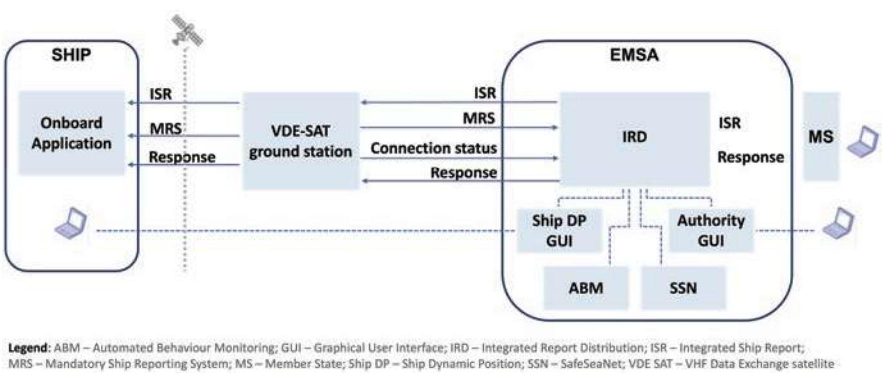

Fig. 8.5 Concept of the VHF Satellite Data Exchange capability (EMSA, 2022)

system (IMO, 2020). Consequently, a new IMO dataset on ship reporting systems (Resolution A.851(20)) was submitted to the 46th session of the IMO Facilitation Committee (9–13 May 2022) (IMO, 2022b, c) for inclusion in the IMO Compendium on Facilitation and E-Business, which is a tool for software developers that design the systems needed to support electronic data exchange of information. By harmonizing the data elements required during a port call and by standardizing electronic messages, the IMO Compendium facilitates the exchange of information between ships and the shore and the interoperability of single windows, reducing the administrative burden for ships linked to formalities in ports.

Sea traffic management (STM) is yet another concept that emerged from an EU co-financed project in 2019 to improve the exchange of information between ships and between ships and the shore for increased situational awareness and to act as a catalyst for improving the safety of navigation in the Baltic Sea area in addition to optimizing capacity utilization and just-in-time operations. The set of systems and procedures at the core of the STM concept attempting to guide and monitor sea traffic is a route exchange protocol and an organized traffic management entity called the Sea Traffic Management Centre that is similar

Table 8.5 Sea traffic management: brief description of potential services (Swedish Maritime Administration, n.d.)

Service	Description
Route cross-check	Can be done prior departure or on arrival at designated area Can include, under keel clearance, air draught, no violation of no-go areas, maritime safety information and compliance with mandatory reporting
Route optimization	Get ships' route optimized from different service providers Would include best route in terms of weather forecast, surface currents, fuel consumption, no-go areas regarding draft, areas with sensitive nature, conflicts with other ships' routes, etc.
Enhanced monitoring	Shore centres will be able to detect if planned schedule is not kept or if ship deviates from planned route Shore centres can foresee possible dangerous situations and suggest route modifications (geographic and/or speed) due to traffic or other impending conditions
Ship-to-ship route exchange	Will provide the intentions of other ships Will provide a new tool which helps the officer on watch to plan ahead, foresee possible dangerous situations, and reduce route detours due to traffic conditions
Port call synchronization	Makes sure that the ship does not arrive before the port is ready Ship and port exchange estimates to find the first available time when all resources to handle the port call are available Early estimate to let ship adjust speed and save fuel Ultimate goal: all ships arrive just in time and no need for anchoring
Port call optimization	Key actors make port call plans transparent Efficiency in the whole process chain Improved resource utilization for all port actors

to air traffic management. STM seeks to integrate the entire shipping and port logistics chain by using standards and creating interoperability, thereby opening the possibility for offering a number of value-added services including route cross-checks, route optimization, ship-to-ship route exchange, port call synchronization, port call optimization, winter navigation, and importing pilot routes as briefly described in Table 8.5 (Swedish Maritime Administration, n.d.; Lind et al., 2014).

8.5 An Outlook on Vessel Traffic Management System of the Future

In the future, there will likely be an exponential demand for vessel traffic management systems (VTMS) in increasingly complex maritime systems, particularly for real-time monitoring and analysis of vessel traffic. In a digitalized world, the huge volumes of data generated by onboard sensors, AIS, radar systems, and weather systems, among others, underscore the need for data-driven solutions. In terms of system capabilities, the burgeoning demand on VTMS comprises, among others, enhanced operational efficiency and safety; predictive capabilities for minimizing risks and optimising routes for fuel efficiency and just in time arrivals; identifying abnormal vessel behaviours; detecting potential threats for aiding timely intervention; and monitoring and ensuring compliance with regulatory norms. Future supervision of navigation in coastal areas by a VTMS will require the ability to manage a massive amount of data and receive, elaborate, and return navigation strategies to each ship. Emerging trends in VTMS to achieve multifarious demands include the infusion of advanced technologies such as artificial intelligence and machine learning and increasing the integration of VTMS with other systems such as weather monitoring and systems for enhanced safety, security, and efficiency. Market research on current trends suggests that by the end of 2030, the market share of VTMS installations, maintenance, and operations worldwide will reach approximately USD 7.13 billion (Gupta, 2023).

The next-generation VTMS (NG-VTMS) is expected to serve fully automated ports. NG-VTMS would deploy artificial intelligence to identify traffic hotspots and intervene, when needed, by warning ships to avoid hotspots and to take alternate routes up to 30 minutes in advance. High-speed computing would aid in quickly analysing data from multiple sensors, such as radar and video surveillance, and supporting time-sensitive decision-making to prevent collisions. Maritime, 5G base stations would provide secure and reliable real-time data transfers between ships as well as between ships and the port, enabling NG-VTMS to ascertain precise and real-time information on vessel movements (Hirdaramani, 2023).

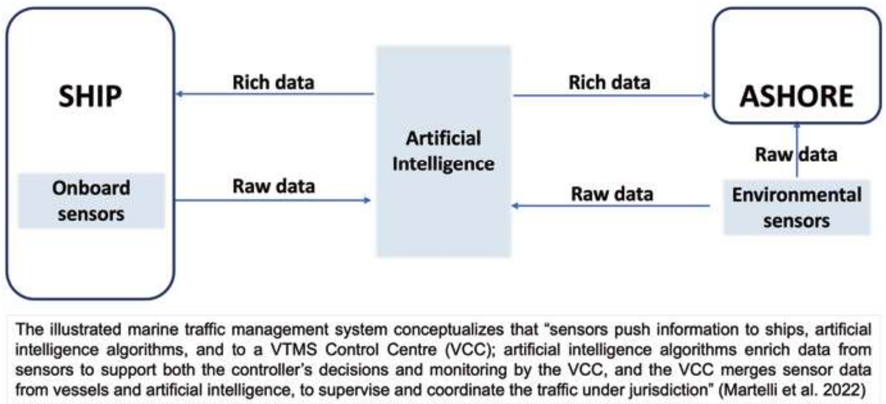

Fig. 8.6 Concept of a marine traffic management layout for autonomous ships (Martelli et al., 2022)

With the growth of Industry 4.0[9] and ships with different degrees of autonomy, with uncrewed vessels likely operating in the same environment as human-crewed vessels, new and technologically advanced VTMS will need to be established along coasts worldwide. With the advent of maritime autonomous surface ships, advances in VTMS design are imperative to facilitate autonomous ship interactions for safe navigation. Martelli et al. (2022) conceptualize a VTMS framework for autonomous ships founded on four pillars: navigation control, orchestration, communication, and data analysis as illustrated in Fig. 8.6 with an accompanying brief explanation. However, such a VTMS framework for maritime autonomous ships is easier to conceptualize than implement, with design challenges spanning the pillars of the framework.

To sum up the discussions in this chapter, through collaborative initiatives and cutting-edge digital platforms and a shared vision of safety and efficiency, Europe appears to be charting a pioneering path in redefining VTM for the future. The harmonization of practices, strong emphasis on interoperability, adoption of digital tools, and forward-thinking regulatory frameworks echo Europe's commitment to remaining at the forefront of global maritime safety and efficiency.

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[9] Industry 4.0 is a major driver of the fourth industrial revolution, also referred to as the New Industrial Revolution. It refers to the current phase of rapid technological transformation comprising cyber-physical systems which focus significantly on interconnectivity, automation, machine learning, and real-time data.

According to the World Economic Forum, the current paradigm change goes beyond Industry 4.0: "The Fourth Industrial Revolution … is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres". The technologies today include artificial intelligence, robotics, the Internet of Things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing. https://www.unido.org/sites/default/files/files/2020-06/Unido_industry-4_A4_09.pdf

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