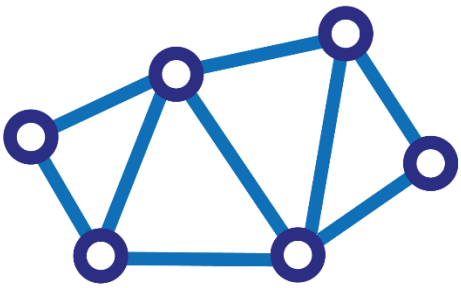

OPTIMAL LOADS

M12 State of the Art

Deliverable No.	D1.1	**Due Date**	28/02/2025
Type	Document	**Dissemination Level**	Public
Version	2.0	**Status**	
Description	The document provides an overview of current developments and technologies in data exchange of maritime logistics and related transport chain hinterland logistics provided on railway and inland waterways . It focuses on the interoperability of data and systems within the maritime industry, with the S-100 standard as a foundation for data exchange. Key topics include the GAIA-X initiative, GXFS Federation Services, and connector technologies for system integration. It also covers data models, ontologies, and the Maritime Connectivity Platform (MCP). The document discusses the implementation and management of the S-100 standard, including product specifications like S-122 (Marine Protected Areas) and S-124 (Navigational Warnings), as well as related standards, technologies, and future challenges.		
Work Package	WP1		

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1 Abbreviations

AIS	Automatic Identification System
CMDS	Common Maritime Data Structure of IMO
ECDIS	Electronic Chart Display and Information System
EEZ	Exclusive Economic Zone
ENC	Electronic Navigational Chart Data
FC	Feature Catalogue
GIS	Geographic Information System
GMWG	Geospatial Maritime Working Group
HO	Hydrographic Office
HSSC	Hydrographic Services and Standards Committee of IHO
IALA	International Organization for Marine Aids to Navigation
IC	Interoperability Catalogue
IHO	International Hydrographic Organization
IMO	International Maritime Organization
MCP	Maritime connectivity Platform
MED	Marine Equipment Directive 2014/90/EU of the European Union
MED IR	EU Maritime Equipment Directive Implementing Regulation
MSW	Maritime Single Window
NB	Notified Body
OEM	Original Equipment Manufacturer
PC	Portrayal Catalogue
PKI	Public Key Infrastructure
PT	Project Team
SOLAS	Safety of Live at Sea
TA	Type Approval
WG	Working Group

2 Table of figures

1 Introduction

The recent crises (COVID 19, Ukraine war, summer 2022 dryness with low water levels of rivers inhibiting ship transport, Suez channel obstruction, North Sea ship traffic jam/backlog have demonstrated the importance of ensuring the resilience of the supply chain and its logistics processes and reinforced the need of logistics industry to permanently optimize these processes for remaining competitive at global level. Their digitization represents a promising means for this, together with the use of suitable data driven analysis algorithms to boost corresponding data economy business models.
Inland ports and seaports are important players in global logistics and supply chains. The above-mentioned events and examples have shown, that the resilience of the supply chain and its logistics processes are essential for global competitiveness.
The project therefore aims (i) to improve the operational efficiency of multimodal transport operations, (ii) to reduce the environmental impact of these operations and (iii) to enable the necessary digitalization within the logistics supply chain by means of an appropriate data space.
Optimal-LOADS therefore consequently addresses three challenges of transportation operations in the maritime logistics environment and related transport chain hinterland logistics provided on railway and inland waterways. resulting from the shift of services to the cloud:

1. processing data with different data formats
2. dealing with/overcoming unstable internet connections during transportation
3. guaranteeing the data sovereignty of the parties involved.

For the latter, Optimal-LOADS builds on the findings of the Gaia-X initiative and on the reference architecture developed there. Gaia-X provides a secure and trustworthy data infrastructure. Requirements that arise when using a maritime data space for processing mixed proprietary, personal and open public data are to be considered. Regarding challenge no. 2 it must be ensured that the processing algorithms are with the data.
The power of such analysis algorithms could not be unleashed to its full extent as of today: E.g., for instrumenting these algorithms, an appropriate volume of data is required, but the data owners are currently still quite reluctant to provide their data for such purposes, because they

- fear the loss of control over their data,
- experience lack of fairness in data sharing, or
- are confronted with un-balanced business models inhibiting to benefit from their data.

Additional challenges are how to create trust among data providers and users, to ensure data sovereignty and to make smooth data interoperability possible in multi-stakeholder environments. This was the motivation for the foundation of the Gaia-X/IDS initiatives, pioneering and creating data spaces in various industrial sectors addressing the described challenges.
A central objective of the Optimal-LOADS project is to populate the Gaia-X/IDS Reference Architecture (RA) with real SW components in the multi-modal logistics supply chain data space, to pioneer the emerging Gaia-X/IDS data economy infrastructure services (a. o., the GXFS) for this data space, and to align it with the emerging Mobility Data Space (MDS). In bringing suitable AI-based data economy provisions to optimize and further digitize the processes of the logistics sector, international SW standards for the sovereign exchange of data between the stakeholders of such industry applications are intended to be pushed and be deployed in a cross-country demonstrator (see Figure 1: Operational Working Scheme for the Optimal-LOADS Project for the project's operational working mode).
While providing the Maritime Logistics Data Space, Gaia-X-based connector components and tool support for developing core Gaia-X infrastructure components such as GXFS, self-descriptions, identity management, etc. tuned to the maritime logistics sector, are planned to be developed, parallel to compiling best practices in making the creation of data spaces easy, which will contribute to

- an improved efficiency of the multi-modal logistics supply and transport chains,
- the valorisation of data in the logistics sector, and

- to take advantage of emerging business models in the data economy context.

With a good mix of IT industry partners and end users as the key nodes in the multi-modal logistics supply chain, the Optimal-LOADS consortium is suited to address the described challenges.

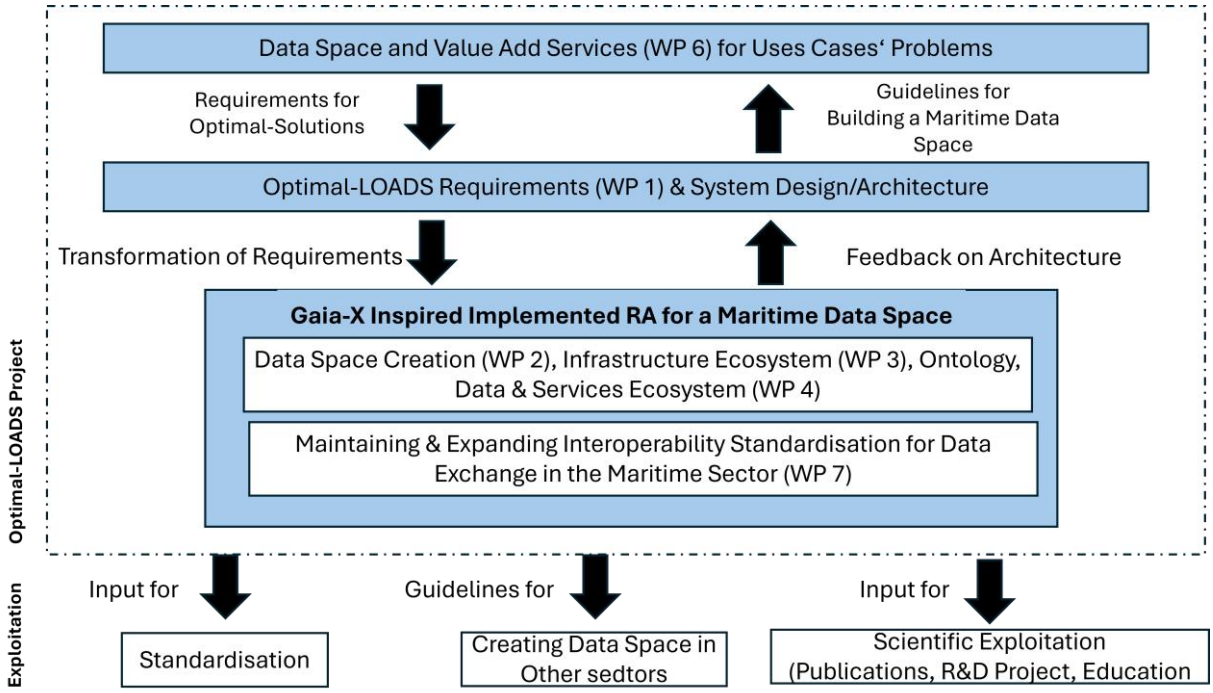


Figure 1: Operational Working Scheme for the Optimal-LOADS Project

This *State-of-the-Art* deliverable focuses on the technological landscape relevant to data exchange in high sea shipping logistics, with a particular emphasis on interoperability, data spaces, and standardized frameworks. It examines existing approaches to maritime data sharing, highlighting the role of interoperable data models and ontologies in enabling seamless communication between stakeholders.

A key aspect of this analysis is the S-100 standard, developed by the International Hydrographic Organization (IHO), which serves as a foundation for geospatial and navigational data exchange. The chapter explores how S-100 integrates with other emerging technologies and regulatory frameworks, ensuring compatibility and efficiency in maritime logistics. Additionally, it discusses challenges such as technical barriers, regulatory constraints, and cybersecurity risks, providing a comprehensive understanding of the current state of maritime data exchange.

By outlining these aspects, this chapter establishes the groundwork for assessing the potential of S-100 and other interoperability solutions in future maritime data spaces, supporting the development of a more connected and data-driven high sea shipping ecosystem.

2 Data Spaces in Logistics and Maritime Industry

Data spaces have become crucial in optimizing operations within various industries, including logistics and maritime. These data ecosystems enable secure and efficient data exchange between multiple stakeholders, driving collaboration and enhancing decision-making processes. This chapter delves into the concept of data spaces, particularly focusing on the **Gaia-X** initiative, which aims to create a secure, federated data environment to promote digital sovereignty and interoperability across different platforms. Gaia-X serves as a foundational structure for developing data spaces in the logistics and maritime sectors, offering a framework for secure data sharing and service integration. The chapter also explores the role of the **GXFS Federation Services** and **Connector Technologies**, which facilitate the smooth exchange of data, ensuring compliance and trust among participating entities. Through this examination, the chapter highlights the transformative potential of data spaces in advancing efficiency, security, and innovation within the logistics and maritime industries.

2.1 GAIA-X

Gaia-X was launched as a European initiative in 2019 by the former German and the French Ministers of Economic Affairs, Peter Altmaier and Bruno Le Maire. The aim of the initiative is to create a secure federated data ecosystem that enables the digital sovereignty of data owners and the interoperability of various platforms and is largely based on Open-Source components. Gaia-X is intended to create a basis that enables the creation of data spaces in which data and services can be made available and shared and used in confidence.

To develop the overarching strategic direction of Gaia-X, an international non-profit association under Belgian law was founded in 2020: the Gaia-X AISBL (French: association internationale sans but lucratif, abbreviated AISBL). The AISBL has more than 300 members from various sectors and different countries. Its primary concern is the development of the Gaia-X framework and the specifications for data exchange.

At national level, Gaia-X Hubs have been set up which are independent think tanks that support the development and implementation of data spaces at national level before they are extended to Europe and beyond. The hubs serve as the first point of contact for interested parties in their respective country.

Furthermore, the Open-Source community plays an important role in the development of various Gaia-X service components and the creation of data spaces in different domains.

The initiative was officially launched in June 2020 and various working groups were set up, which focus on different aspects of the project, such as architecture, compliance, security, data exchange, and more, contributing to the overall development and progress of Gaia-X.

In June 2021 the first version of the Gaia-X Architecture Document was released, which defines the basic architectural principles, functionalities and various components of Gaia-X, including key elements such as the Clearing House (Gaia-X Digital Clearing House, GXDCH), Identity and Trust Management, Policy Rules and other architectural building blocks. It describes the theoretical and conceptual foundations on which the Gaia-X ecosystem is built.

In addition to the architecture document, the Technical Committee publishes two further documents that specify the concepts and structures of Gaia-X: “Identity, Credentials and Access Management” and a document on “Data Exchange”. Another committee, the Policy Rules Committee, publishes further documents on Compliance, the Trust Framework and the Policy Rules.[1] The documents are updated regularly. The current version is the Tagus release, which will soon be replaced by the Loire release. The Loire version was due to be launched in Q3 2024 but has been delayed and will be released later this year.[2]

[1] Gaia-X European Association for Data and Cloud AISBL (2022)
[2] Gaia-X European Association for Data and Cloud AISBL (2024)

In addition to the conceptual rules for data ecosystems, the Gaia-X Association also provides the software for the Digital Clearing Houses (GXDCH). The Digital Clearing House is a node of execution of the services of those compliance components that were developed by the Gaia-X Association. Gaia-X is responsible for updating the software components and institutionalizing the digital clearing houses, which act as trust anchors in the ecosystem. There are currently seven Digital Clearing Houses, with more to be added in the future. This ensures the distributed, decentralized nodes that are not operated by the Association and to which anyone can turn to obtain compliance. In this way, the association wants to enable a Gaia-X market without central supervisory authority.

Just like the initial Gaia-X architecture documents, the Gaia-X Federation Services (GXFS) were also specified in 2021. The Gaia-X Federation Services are a separate project that deals with the implementation of conceptual specifications described in the Gaia-X reference architecture.

The specifications for the GXFS are set out in separate specification documents that are being developed as part of projects funded and supported by the German Federal Government. The reference implementation of the federation services was carried out in two tender rounds. The service components of the first tender phase[3] were completed in 2023. As part of the second tender phase[4], some federation services are currently being revised and additional services are being implemented, the need for which has become apparent during the implementation of various data spaces. The services from the second tender phase were planned to be completed in spring 2024. Due to delays, the reference implementations have now been set up (autumn 2024) and only minor changes and additions are still being made. The source code of the GXFS Federated Services is publicly available on the Eclipse platform (abbreviated here as XFSC: Cross Federation Services)[5].

The implemented components of the GXFS provide reference implementations to operate the federated Gaia-X ecosystems. The federation services for building own data spaces are divided into different work packages, which include Identity & Trust, Federated Catalog, Sovereign Data Exchange, Compliance and Integration & Portal.

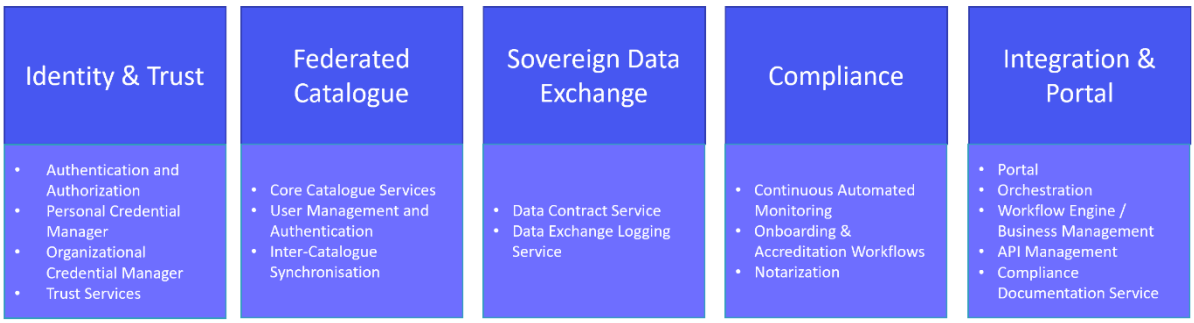


Figure 2: GXFS Toolbox and Components[6]

[3] Gaia-X Federation Services (2024)
[4] Gaia-X Federation Services (2024a)
[5] Eclipse Foundation (2024)
[6] Eclipse Foundation (2024a)

2.2 GXFS Federation Services

In detail, the Federation Services are:

“Identity & Trust” sector:

- **Authentication and Authorization Service (AAS)**

  The purpose of this service is to enable Gaia-X participants to authenticate users and systems in a trustworthy and decentralized self-sovereign manner without the need for a central source of authority. Additionally, the service aims to assure authorization of data access and data usage based on such identity data and decentral managed credentials.

  The service is designed to integrate existing Identity and Access Management (IAM) systems using standard protocols. In the reference implementation, however, only the integration of OAuth2 with OpenID Connect (OIDC) was realized. In order to achieve the full range of functions, further components of the Identity & Trust Work Package such as ‘Trust Service API’ and ‘OCM’ and ‘PCM’ must be integrated.[7]

- **Personal Credential Manager (PCM)**

  The Personal Credential Manager is a wallet app for the individual user. PCM can securely store Verifiable Credentials for the user and selectively disclose the attributes contained therein for authentication and use of services.

  As part of the PCM project, a mediator service is provided in addition to the mobile app. The mediator serves as an intermediary that assists in routing messages between different Credential Managers – both the PCM and the OCM. It enables Credential Managers to establish and maintain connections by providing services such as message queueing and delivery.[8]

- **Organizational Credential Manager (OCM)**

  The purpose of the Organizational Credential Manager is to establish trust between different organizations within the Gaia-X ecosystem. The OCM helps participants securely manage their digital identities and facilitates the request, receipt, and validation of verifiable credentials, such as membership credentials from verified notaries. By doing so, it ensures that interactions within the Gaia-X ecosystem are trustworthy and secure.

  The OCM also enables the attestation of attributes to principals, such as employees or technical assets, in the form of verifiable credentials. Additionally, it helps maintain a verifiable public profile for participants, leveraging Self-Sovereign Identity (SSI) principles to establish secure and trustable connections between different parties within the ecosystem.

  The OCM was completely revised in the 2nd tendering phase. There are two different OCM projects: the OCM, which uses blockchains to securely store publicly required digital identity data, and the OCM W-Stack, which uses the did:web standard. The did:web standard makes it possible to create DIDs based on existing web domains. This means that a DID is linked to a web domain and can be resolved via HTTP(S).[9]

[7]Gaia-X Federation Services (2024b); Eclipse Foundation (2024b)
[8]Gaia-X Federation Services (2024c); Eclipse Foundation (2024c)
[9]Gaia-X Federation Services (2024d); Eclipse Foundation (2024d); Eclipse Foundation (2024e)

- **Trust Services API (TSA)**

  The aim of Trust Services is to ensure a consistent level of trust between the participants and components of the Gaia-X ecosystem.

  The Trust Services enable the creation and validation of digital signatures, which plays a central role in ensuring the integrity and authenticity of data. They also provide the functionality to sign and verify data, enable policy-driven trust, ensure chains of trust between participants and validate eIDAS-compliant signatures.

  The Trust Services can be used by other Federated Services for signing Verifiable Credentials, verifying Verifiable Presentations and for policy enforcement. For this purpose they provide a comprehensive API.[10]

"Federated Catalogue" sector:

- **Federated Catalogue (FC)**

  The Federated Catalogue serves as a directory in which various services, data and providers within the Gaia-X network are registered and described. Resources, assets and participants in GAIA-X are described by Verifiable Credentials. Verifiable Presentations, which are intended for public use, can be loaded into the respective catalogue. The aim of the catalogue is to enable consumers and end users to find the most suitable offers and to monitor relevant changes to the offers. A catalogue includes offers from one or more Dataspace domains. The standardized descriptions of participants and services enable publication in different Dataspace domains.[11]

- **User Management and Authentication**

  There was no separate tender for the 'User Management and Authentication' aspect of the catalogue. The Core Catalogue manages some administrative user roles - who is allowed to access which endpoints. Restrictions for reading access to published participant and service descriptions are not possible in the Core Catalogue.[12]

- **Inter Catalogue Synchronisation**

  There was no separate tender for the 'Inter Catalogue Synchronisation' aspect of the catalogue. Intercatalogue synchronisation can be solved via the Credential Event Service (CES), where published participant and service descriptions are listed. Interested catalogues can then download the corresponding credentials and publish them.[13]

"Sovereign Data Exchange" sector:

- **Data Contract Service (DCS)**

[10]Gaia-X Federation Services (2024e); Eclipse Foundation (2024f)
[11]Gaia-X Federation Services (2024f); Eclipse Foundation (2024g)
[12]Gaia-X Federation Services (2024g); Gaia-X Federation Services (2024f)
[13]Gaia-X Federation Services (2024g); Gaia-X (2024)

The 'Data Contract Service' provides interfaces for the negotiation of data contracts in which the agreed conditions (policies) for the planned data exchange are recorded. Essentially, the service enables the sending of offers and counter offers that lead to approval or rejection. The contract is packaged in a human and machine-readable format based on ODRL. The service is not intended to handle the transaction of data.[14]

- **Data Exchange Logging Service (DELS)**

  The Data Exchange Logging Service in Gaia-X is used to log data transactions in a transparent and traceable manner. The logs ensure that data has been transmitted and received, and that rules and obligations (data usage policies) have been complied with. Operational issues or fraudulent transactions can be clarified. The logging service enables companies to automate audit processes and strengthen trust in the data ecosystem. Additionally, logs can be used as a basis for clearing and billing, but this is not the scope of this service.[15]

"Compliance" sector:

- **Continuous Automated Monitoring (CAM)**

  The Continuous Automated Monitoring Service provides transparency to Gaia-X participants about the compliance of individual services, offered in the Gaia-X Federated Catalogue. This is achieved by automatically interacting with the service-under-test using standardized protocols and interfaces to retrieve technical evidence.[16]

- **Onboarding & Accreditation Workflows (OAW)**

  As part of the workflow engine, the OAW engine implements workflows onboard and accredit providers and their assets, particularly software assets and nodes. Additionally, the workflows of the OAW engine also include the administration and offboarding of providers and their assets. The OAW engine is used to perform accreditation of software assets and nodes to prove their compliance by the Onboarding Authority, namely the AISBL, or Conformity Assessment Bodies (CABs) authorized by the AISBL. The Onboarding & Accreditation Workflows no longer have their own repository. The source code has been integrated into the orchestration engine (ORCE).[17]

- **Notarization API**

  The main functionality scope of the Notarization API is to provide a way to enroll new issuers into a dataspace federation. The Notarization API is meant to be installed within the issuer's organization domain. It enables the operating organization to define certificate schemas and to issue, manage and withdraw digital certificates. The API is used to convert existing traditional certificates (e.g., ISO 27001, ISO 9001) into W3C-compliant Verifiable Credentials (VCs) and to issue new digital certificates for companies that previously had no traditional certification. It provides external APIs to process notarization requests, enabling organizations to obtain digital attestations for their credentials. Furthermore, the Notarization API integrates electronic identification mechanisms, such as eID and video identification, to verify business owners and organizations.[18]

[14]Gaia-X Federation Services (2024h); Eclipse Foundation (2024h)
[15]Gaia-X Federation Services (2024i); Eclipse Foundation (2024i)
[16]Gaia-X Federation Services (2024j); Eclipse Foundation (2024j)
[17]Gaia-X Federation Services (2024k); Eclipse Foundation (2024k)
[18]Gaia-X Federation Services (2024l); Eclipse Foundation (2024l)

“Integration & Portal” sector:

- **Portal**

  A Minimal Viable Gaia-X (MVG) was to be implemented as part of GXFS. The main functionalities of this MVG are represented by the portal with a web-based user interface. An organization can onboard itself in the portal as a new participant and manage its data. Participants can publish their own services or find and use those of others.[19]

  Key Features of the portal are:

  1. Role-Based Access: The portal distinguishes between different roles to provide tailored functionalities: Visitor, Participant distinguished in two sub-roles provider and consumer and Federator.
  2. Content Discovery: The portal enables users to search, explore, and view content from the Gaia-X Federated Catalogue.
  3. Onboarding & Registration: New participants can register and board themselves through the portal. Federators are responsible for reviewing and approving registration requests, and for issuing verified credentials to new Gaia-X participants.
  4. Service Orchestration: Services can be orchestrated and instantiated via the portal. To enable this, a service provider can publish templates for service instantiation as part of the Service Offering Verifiable Credentials in the catalogue.

- **Orchestration**

  The orchestration service enables consumers to instantiate and manage infrastructure services such as virtual machines via services published in the catalogue.

  The Orchestration service provides a Life Cycle Management Engine (LCM Engine) to orchestrate and communicate with different LCM services and interface with the Gaia-X Portal. It provides an API that enables the implementation of Life Cycle Management Services for the services offered within the Gaia-X ecosystem. This includes automating the deployment, monitoring, scaling, and termination of services, ensuring that services are managed throughout their lifecycle in a consistent and compliant manner.[20]

- **Workflow Engine/Business Management**

  The Workflow Engine primarily supports the process to approve and trace service provisioning. Additionally, it assists the federator to keep track of participation requests, approving participants, managing participant interaction, approving participant credentials, and tracking the quality-of-service descriptions.

  There were no calls for tenders for the Workflow Engine; all work on this was carried out in Onboarding & Accreditation Workflows (OAW).[21]

- **API Management**

  For the GXFS services, an API management service was planned with an API gateway that would serve as a single point of contact for information about available API services and version management. In addition, the API management was to provide statistics on the use of the APIs and serve to increase security.

[19] Gaia-X Federation Services (2024m); Eclipse Foundation (2024m)
[20] Gaia-X Federation Services (2024n); Eclipse Foundation (2024n)
[21] Gaia-X Federation Services (2024g)

There were no calls for the API management.[22]

- **Compliance Documentation Service**

  To prove that a federation service fulfils all defined requirements, it is necessary to provide suitable evidence (e.g. in the form of specifications, concepts or certificates). The Compliance Documentation Service defines how compliance with 'Security and Privacy by Design' must be documented by each federation service.

  There were no calls for the API management.[23]

When using Federated Services, it should be noted that they were implemented in two tender rounds and by different companies. In some cases, adjustments are necessary so that the services can work together.

2.3 Connector Technologies

One dataspace component that is not covered by the Gaia-X Federation Services is the data connector. Data space connectors are software components that realize communication in a data space between the network nodes using the peer-to-peer principle (P2P). They connect the actual data providers and data consumers to the dataspace. A data connector offers two important functions:

1. **data exchange services**: they serve as the Application Programming Interface (API) to other participants in a data space to achieve interoperability.
2. **trusted data processing**: implementation of mechanisms to enforce policies and a common basis for cyber security.

There are several data connector types that differ in their feature set, in the accessibility of their source code, in their compatibility with each other and in their development maturity. The IDSA (International Data Spaces Association) Data Connector Report provides an initial overview of many existing connector solutions.[24]

The most used connectors are currently based on the 'Eclipse Dataspace Components Framework' (EDC).[25] The EDC connector implements the following architectural principles[26]:

1. a modular and highly extensible framework,
2. separate control and data planes,
3. an asynchronous and highly available system,
4. policy negotiation and orchestration of data transmission,
5. fully auditable transmission processes,
6. elimination of individual sources of error,
7. cloud-aware policy enforcement and projection,
8. available standard implementations and blueprints.

[22] Gaia-X Federation Services (2024g)
[23] Gaia-X Federation Services (2024g)
[24] International Data Spaces Association (2024)
[25] Eclipse Foundation (2024o)
[26] Catena-X (2024)

But the EDC also has some disadvantages, in particular:

- Lack of integration with Gaia-X Federated Services
- One-way communication: If the consumer needs to send data back to the provider as part of the data exchange, a separate channel with its own contract and policies must be used for this.
- No contract negotiation to date - Only several contracts offer with different policies are possible for the same data offer.

Various Dataspace projects use the Eclipse Dataspace Connector or have their own fork of the Connector. The frequently referenced 'Catena-X' project, which aims to create a dataspace for the automotive industry, also uses a customized version of the EDC, which is published as the Tractus-X EDC[27]. Tractus-X EDC differs in particular in that it offers Catena-X-specific extensions, e.g. for connecting the consortium's own catalogues for finding participants and services.

The EDC uses the Dataspace Protocol (DSP) as its communication protocol, version 1.0 of which has been available since this year and the aim is to establish this as the standard for communication in dataspaces. The DSP is intended as the foundation for ensuring interoperability and bridging different systems.[28]

The Data Connector Report only lists three connectors that currently use the Gaia-X Digital Clearing House and only two of them are open source:

- Ocean Provider
- FIWARE Data Space Connector

Unlike other connectors, the Ocean Provider[29] - as the name implies - is only required on the part of the data provider. It offers a REST API for the provider. The consumer can access the data via https. Data exchange contracts are recorded as smart contracts on a blockchain. It takes care of checking access to the data, accessing the data, encrypting it and transferring it. The Ocean protocol is blockchain-bound, whereby all EVM-compatible blockchains are supported. Data offers can be monetized directly using the associated 'Ocean' ERC-20 token.

The Ocean Provider is easy for end users to use, as it is offered as an off-the-shelf solution with extensive documentation and as a service. The disadvantage is that it is tied to a blockchain and the Ocean Enterprise Collective, which maintains the provider and the Ocean Protocol. The Ocean Provider is not intended to be extended with customized extensions.[30]

The Fiware Connector is still a relatively new component, which appears promising due to its integration with the services provided by Gaia-X. Identity management via DIDs and verifiable credentials is already implemented in the Fiware Connector and there are documented processes for onboarding that integrate GXDCH.

As with the Ocean Provider, the Fiware Data Space Connector has no further requirements for the consumer. They do not need to operate any service components to participate in the data space as consumers. They only need a DID and any verifiable credentials requested by the provider to be able to obtain data from the respective provider. The data is transferred via a https-based protocol. The REST-based data plane is currently the only data plane in the Fiware Connector. However, additional data planes can be created for other protocols.[31]

[27] Eclipse Foundation (2024p)
[28] International Data Spaces Association (2024a)
[29] Ocean Protocol (2024)
[30] Ocean Protocol (2024a)
[31] FIWARE Foundation (2024)

3 Interoperability in Logistic Data Exchange

Chapter 3 focuses on Interoperability in data Exchange, essential for improving efficiency, safety, and sustainability in logistic operations.

It highlights **ISO-4891**, developed through the I2PANEMA initiative, which addresses challenges in integrating maritime data due to regulatory, security, and technological limitations. Originally focusing on smart logbooks, it now covers broader smart applications, supporting secure data sharing and digitalization.

This chapter evaluates further applicable international standards and present international standardisation activities for data exchange in the logistic domain. The chapter also explores the role of **data models and ontologies in maritime logistics**, enabling secure and automated data exchange, enhancing safety, and improving decision-making. It mentions key initiatives like the IMO, MarineTraffic, and European projects advancing maritime ontologies.

Finally, the **Maritime Connectivity Platform (MCP)** ensures seamless communication among vessels, ports, and stakeholders, enhancing data interoperability.

3.1. International Standardisation

3.1.1 ISO 4891

The newly developed ISO-4891 standard, which was co-developed within the I2PANEMA initiative, was introduced after it was determined that ships and their data, as well as equipment, could not be easily integrated with other infrastructures due to regulatory and security concerns. In particular, the outdated technical state of ships and the electronic layer on which they operate require additional cybersecurity measures before connections to other technical services can be enabled. This limitation has hindered innovation and slowed digitalization within the maritime sector. Due to the interest of maritime stakeholders—including ship managers, ports, and authorities—ISO-4891 was designed to address and protect these shared interests. As a smart logbook, it facilitates the digital collection of data and enables simplified reporting. During the seven-year standardization phase, the need for an easy integration of ship data into the maritime market was addressed within ISO. As ISO-4891 specifically addressed this need, the scope was expanded from a smart logbook to smart applications. Since then, the standard has been titled "Ships and Marine Technology — Interoperability of Smart Applications for Ships."

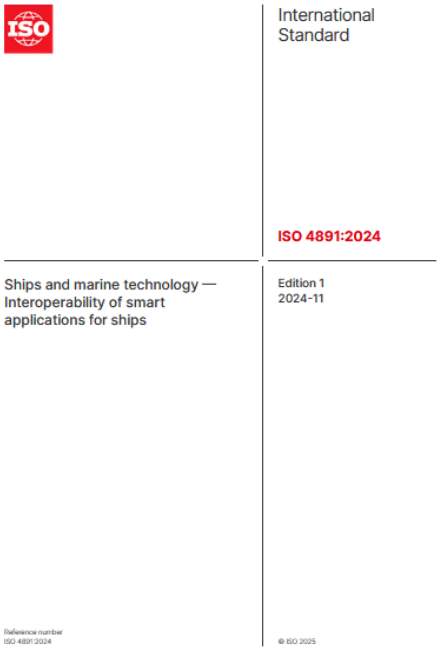


Figure 3: ISO 4891:2024

This initiative has focused on preparing and supporting the standard's successful publication in November 2024. Various objectives have been pursued, and technical developments have been carried out to facilitate the integration or representation of applications as smart applications for other use cases and service providers. The

primary focus has been on describing and clarifying how the standard interacts with other standards and use cases within the initiative, as well as on implementing the international demonstrator.

The efforts have not been limited to technical implementations. Since no smart applications have yet been certified under ISO-4891, preparations and developments were necessary within this initiative. These included reference developments, test suites, and the clarification and coordination of a legal approval process with classification societies and flag states.

Reference Developments and Test Suites

Technical tests were developed, which allow developers of other use cases to use them as test suites to verify the compatibility of their implementations. This ensures that smart applications can communicate with each other and authenticate securely. Through this initiative, other partners can implement the relevant components from their use cases or services, enabling them to participate in the ISO-4891 ecosystem and generate added value through interactions with other smart applications—for example, the smart logbook provided by NautilusLog in this context. Currently, reference developments and work on two demonstrators within the international use case are being finalized.

Coordination of a Legal Approval Process

Following discussions with the German Minister of Transport in Singapore, efforts in this initiative have focused on clarifying the approval requirements for the German flag state. These discussions are currently ongoing with BG-Verkehr. As part of this process, the legally relevant aspects have been reviewed with the flag state, along with the functional scope. Identified gaps are being addressed.

Approximately 7.5 years ago, the German flag state recognized the advantages of a smart logbook. However, no legal framework existed at the time. With the introduction of ISO-4891, such a framework is now available, leading to an in-depth review by the German flag state. This review aims to ensure the interoperability of a smart flag state with a smart logbook from both technical and legal perspectives, while also assessing potential conflicts of interest. Consequently, a joint ZIM project proposal was submitted in December. This initiative aims to analyse the requirements for data and processes necessary for a smart flag state under the strict provisions of ISO-4891.

International Demonstrators

The first demonstrator is being implemented with partners in Singapore and within the "Digital Corridor" initiative connecting ports in Singapore and Rotterdam. In this context, the smart logbook from NautilusLog was integrated with the port infrastructure of the Maritime and Port Authority (MPA) Singapore. The second demonstrator is being carried out in collaboration with JR-East in Tokyo, Japan. The smart logbook from NautilusLog was installed on public ferries to provide data for the Smart City initiative.

The implementation was originally scheduled for completion in February; however, due to delays, the testing phase only commenced in February. In addition to the provided documentation on ISO-4891 and related information, collaboration with other partners will be further intensified. The results from the demonstrators will be shared to illustrate the possibilities and added value of ISO-4891.

3.1.2 ISO 19100 Geographic Information standard series

In the 19100 Geographic Information standard series, several standards are specifically dedicated to the quality of geographic Information:

- ISO 19113 on the specific concepts,
- ISO 19114 on the principles for quality evaluation and, together with
- ISO 19138, on the description of quality assessment methodologies,
- ISO 19131 on specifications,
- ISO 19115 on the reporting of quality assessment results as metadata,
- ISO 19139 on the implementation of metadata communication.

These are domain-oriented standards, specific to Geographic Information, i.e. related to the following issue:

"In what measure is the geographic world well represented by the data?"

Organisational or managerial quality, at a more general level, is the object of the ISO 9000 family on Quality Management Systems[32]. To support this goal the organisation EuroGeographics developed Guidelines for Implementing the ISO 19100 Geographic Information Quality Standards.

These guidelines describe why it is important to implement the standards and gives practical suggestions on how to read and understand the standards and how to carry out the actual implementation process.

3.1.3 IEC 63173-1

The "IEC Standard 63173-1 for MARITIME NAVIGATION AND RADIOCOMMUNICATION EQUIPMENT AND SYSTEMS – DATA INTERFACES" defines requirements for:

Transfer of routes planned on ECDIS according to IEC 61174 standard on ships or on shore using S-421 data infrastructure route plan based on S-100.

This part of the IEC 63173 standard specifies an S-100 compliant product specification for route plan intended for exchange of information. It specifies the content, structure, and metadata needed for creating fully S-100 compliant route plan information and its portrayal within an S-100-based application. The IHO manages all numbers for S-100 compliant product specifications and has assigned S-421 for this route plan IEC standard.

The IEC Standard 63173-1 specifies a data format for the route plan exchange. The format of the route plan exchange includes some limited vessel static information. The standard is not intended to provide all ship static information for transfer, it can be obtained by other methods based on the IMO FAL Compendium data structure such as AIS.

Presently (status March 2025) within IEC work is ongoing to review IEC 63173-1 and prepare IEC 63173-1 ED2.

3.1.4 IEC 63173-2

The "IEC Standard 63173 for MARITIME NAVIGATION AND RADIOCOMMUNICATION EQUIPMENT AND SYSTEMS – DATA INTERFACE – Part 2" defines requirements for the Secure exchange and commu-

[32] EUROGEOGRAPHICS (o. J.)

nication of S-100 based products 32 (SECOM). The scope of SECOM includes service interfaces for data exchange and data protection to enable secure communication of primarily S-100 based products, and interface for service discoverability.

This standard complements S-100 to gain technical interoperability up to the level of exchanging information securely online. The SECOM service interface consists of specifications and definitions of a set of interfaces, i.e. APIs. The service interface includes the public side exposed on the internet. The “last mile” links between SECOM service instance and the end-user application is described in an informative Annex B. This allows different solutions between the service and shore/ship’s system/applications.

SECOM data protection contains a protection scheme for the information exchange in line with IHO S-100. The data protection scope is between end-users. The service discoverability interface includes methods for service discoverability and supports dynamic use of loosely coupled services. SECOM is primarily applicable for IP based session-less interactive web services for information exchange. Other possible means of exchange, for example general distribution of files is not included. SECOM is not intended to define by which physical layer the transport is performed as long as IP communication can be supported.

Presently (status March 2025) within IEC work is ongoing to review IEC 63173-2 and prepare IEC 63173-2 ED2.

3.1.5 IALA

IALA G1117

The Guideline introduces the VHF Data Exchange System (VDES) at an overview level. The Guideline is intended to assist in the understanding, development and promotion of VDES.

IALA G1128

This Guideline provides information on how to make specifications of maritime Technical Services. A Maritime Service (MS) can be implemented by one or more maritime services. Taken from the concepts of service-oriented architecture, a Technical Service refers to a set of related software functionalities that can be reused for different purposes together with policies that govern and control its usage.

This Guideline aims at improving the visibility and accessibility of available maritime technical services and information provided by them. This enables service providers, consumers, and regulatory authorities to share a common understanding of a Technical Service and how to implement and use it. The Guideline is intended for service architects, system engineers and developers in charge of designing and developing a Technical Service or designing and developing a device to use it.

The Guideline is intended to be read by enterprise architects, service architects, information architects, system engineers and developers in pursuing architecting, design and development activities of other related services. The document provides meta-information explaining how Technical Services shall be specified. The guidance included helps provide Service Specifications, Service Designs and Service Instance Descriptions for any kind of e-Navigation Technical Service in a standardized way. Any Technical Service Specification in the context of e-Navigation shall comply with this Guideline. 1.2. LINK TO S-100 AND PRODUCT SPECIFICATIONS This Guideline is intended for but is not limited to Technical Services based on S-100 Product Specifications. However, since e-Navigation is currently in a transitional phase, an S-100 Product Specification may not always exist for a particular application.
In that case, the proposed specification or data model shall make use of the concepts of S-100 whenever possible. Technical Service Specifications following this Guideline shall provide references to the appropriate S-100 Product Specifications if available or to the appropriate S-100 features and attributes in their data models. Like

the S-100, the graphics and textual descriptions may use different data types than the XSD schemas. This is because XSD technology does not provide these data types but can be used synonymously[33]

3.1.6 IMO FAL Compendium

The IMO Compendium on Facilitation and Electronic Business (IMO Compendium) is a reference model which aims to harmonize the semantics and format for all information in the maritime domain relevant to the IMO. The IMO data set and reference model ensures that IT systems from different stakeholders can exchange data with shared meaning, supports harmonization of MSWs, port call optimization and not least will facilitate the development of green and digital corridors.

Collaboration with the World Customs Organization, the United Nations Economic Commission for Europe, the International Standards Organization and now with the International Hydrographic Organization (IHO) ensures full alignment across the supply chain. Since July 2019, the IMO Expert Group on Data Harmonization (EGDH) set up by the Facilitation Committee, is responsible for the technical maintenance and extension of the IMO Compendium.

The next meeting of the EGDH will take place from 17 to 21 March 2025 (EGDH 12).[34]

3.2 Data models & Ontologies in maritime logistics

This section discusses the role of data models and ontologies in maritime logistics, with a focus on ontology engineering. As the maritime sector moves towards more interoperable solutions for improved operational efficiency and safety, ontologies become crucial for achieving semantic interoperability. They enable secure data sharing, facilitate decision-making, enhance safety, and ensure compliance with regulations. The section also reviews key players and initiatives in maritime ontology development, highlighting efforts from organizations like the IMO, MarineTraffic, and various European projects. These initiatives aim to improve data exchange, enhance situational awareness, and promote sustainability within the maritime industry.

3.2.1 Ontology Engineering

The maritime sector, traditionally reliant on manual, fragmented, and undocumented communication methods, is increasingly recognizing the need for interoperable solutions to enhance operational efficiency and safety. These new approaches not only enable secure and automated data sharing but also pave the way for advanced services that can significantly improve the sustainability of maritime activities.

Ontologies, which are structured frameworks representing a set of concepts and their interrelationships within a specific domain, are foundational for achieving semantic interoperability in the maritime industry. By fostering a shared understanding of data across various maritime systems, ontologies enable these systems to communicate and collaborate effectively. The application of ontology-based approaches offers several key benefits to the maritime sector:

[33] International Association of Marine Aids to Navigation and Lighthouse Authorities (2024)
[34] International Maritime Organization (2024)

- **Semantic Data Integration:** Ontologies provide a common vocabulary and logical structure for data representation, simplifying the integration and exchange of information between different systems. This integration is crucial for maintaining the operational efficiency of maritime vessels and ensuring seamless interactions among all systems involved.

- **Enhanced Interoperability:** By establishing a shared understanding of data, ontologies are essential for effective communication between systems and external stakeholders, such as port authorities, regulatory bodies, and shipping companies. This enhanced interoperability promotes better collaboration, reduces congestion in ports, and streamlines the entire maritime logistics chain.

- **Improved Situational Awareness and Safety:** Ontologies enable maritime systems to achieve interoperability with external systems, granting access to real-time data on weather conditions, navigational hazards, and vessel traffic. This improved situational awareness enhances safety by supporting more informed decision-making processes, ultimately leading to safer maritime operations.

- **Effective Decision-Making:** The integration of ontologies within maritime information infrastructures supports advanced decision-making processes, such as route optimization, fuel efficiency, and emergency response. By enabling maritime systems to process and analyze large volumes of data, ontologies facilitate more accurate and timely decisions, thereby enhancing overall operational efficiency.

- **Regulatory and Environmental Compliance:** Ontologies can be designed to incorporate international maritime regulations and environmental standards, ensuring that maritime operations adhere to legal requirements and contribute to sustainability efforts. For instance, ontology-driven systems can optimize fuel consumption and minimize emissions, thereby reducing the environmental impact of maritime activities.

This section offers a comprehensive review of the state-of-the-art in ontology engineering as it applies to the maritime industry, highlighting its current applications, challenges, and potential future developments.

3.2.2 Key Players and Initiatives in Maritime Ontology Development

International Maritime Organization (IMO): The IMO's e-Navigation Initiative utilizes ontologies to standardize and enhance data exchange across various maritime systems. This initiative focuses on improving navigational safety and supporting coordinated global maritime operations[35]

MarineTraffic: The **MarineTLO** (The Marine Traffic Linked Ontology) integrates data from multiple sources such as vessel tracking, weather reports, and port information. This integration improves situational awareness and supports informed decision-making in maritime operations[36]

International Data Space Association (IDSA): The International Data Space Association (IDSA) develops secure, standardized frameworks for data sharing, cross industries, including maritime operations. These frameworks enhance interoperability, ensure data privacy, and facilitate the efficient exchange of real-time data, supporting cross-border collaboration and the integration of advanced technologies like IoT.

World Wide Web Consortium (W3C): W3C's development of Semantic Web standards, including RDF and OWL, provides the foundation for creating interoperable and semantically rich data models. These standards enhance data exchange and integration across various maritime systems, supporting more efficient and accurate communication within the sector.

[35] Weintrit (2011)
[36] Athanasiou, et al. (2013)

GAIA-X Initiative: GAIA-X focuses on creating a secure and interoperable data infrastructure for maritime operations. The initiative emphasizes balancing data privacy with the need for global data exchange, ensuring secure data sharing among maritime stakeholders.

Danish Maritime Authority (DMA): The DMA provides a standardized framework for maritime data sharing, which improves decision-making and operational coordination among stakeholders. This framework enhances communication, situational awareness, and management of maritime operations.

The Smart Ship Application Platform (**SSAP**): developed through collaborative efforts, standardizes data interfaces for IoT applications in maritime operations, facilitating the integration of advanced technologies into everyday maritime activities.

European Commission Related Projects:

Project Name	Program and Time Period	Focus
RECON-SURVE	ITEA3 (2011-2015)	Focused on wide-area sea-border surveillance, studying lessons learned from previous maritime projects in the ITEA context.
EfficienSea 2	H2020 (2015-2018)	Aimed at achieving safer and more efficient water operations using Cloud Computing technologies and the Maritime Cloud framework, involving a consortium of 32 partners from ten countries.
STM Validation Project	EU Funded (2015-2019)	Focused on improving sea traffic management through collaboration with leading companies, maritime authorities, and ministries across six European countries.
KEI.POP	EUREKA (2016-2019)	Developed a standardized communication platform for ship-to-ship-to-shore data exchange in the Maritime Cloud, enhancing secure traffic handling and synchronized logistics integration, as a South Korean and German joint project.
MAREMIS	Germany and Singapore (2021-2023)	Created Big Data and machine learning models to measure and reduce emissions from maritime transport, improving local air quality.
VPORT	Industry / TUBITAK (2006-2024)	Focused on terminal operation systems for port management and communication.
VMARINE	Industry / TUBITAK (2012-2013)	Managed marina operations and communications between port authorities.
Silicon Economy Logistics Ecosystems	BMDV (2020-2023)	Developed an OSSW infrastructure for the platform economy of the future, exploring new paradigms for logistics data sharing across supply chains.
IPANEMA	ITEA 17001 (2018-2022)	Developed the first prototype IDS components to enhance port operations through IoT integration.

DataNetPort	BMBF Effizien-zCluster (2020-2023)	Worked on data sovereignty and international cooperation in port logistics, extrapolating national findings to international conditions.
DataPorts	Horizon 2020 (2020-2022)	Created a data platform for connecting cognitive ports, focusing on data sharing and AI-based data processing in port environments.
MobiDS	mFund BMDV (2019-2022)	Linked communal, regional, and national data platforms via data spaces, exploring IDS/GaiaX data sharing paradigms for mobility data.
Mobility Data Space	BMDV (2021-2024)	Established a data marketplace for self-sovereign data exchange, focusing on best practices for creating and maintaining data spaces.
SINLOG	mFund BMDV (2019-2022)	Digitalized documents in German waterway transportation and logistics, improving the integration of German waterways into the multi-modal supply chain.
MaritimeData Spaces (MDS)	RCN funded IPN (Norway) (2018-2021)	Developed an open ecosystem for secure, robust, and trusted maritime data exchange among ship and shore stakeholders in a federated space.
Marispace X	BMWK Gaia-X Förderwettbewerb (2022-2024)	Created a digital maritime data space based on Gaia-X principles, focusing on data sovereignty, security, interoperability, and modularity, with big data processing across edge, fog, and cloud computing.
PORTO	ITEA4 (2023-2026)	Aims at developing an operations data platform for real-time, standardized updates on vessel port activities and next port calls, addressing the maritime supply chain visibility issue through digitalization and global connectivity.

Figure 4: European Commission Related Projects

3.2.3 Current Technologies and Applications

Mobility Data Spaces (MDS)

The Mobility Data Space (https://www.mobility-data-space.de/en.html) is an open and decentralized data ecosystem that facilitates the secure exchange and utilization of real-time traffic and mobility data. Developed by the International Data Spaces Association, MDS prioritizes data sovereignty, allowing data providers to control how their data is used while ensuring trust and quality assurance. This system supports the development of data-driven mobility applications and services through secure, traceable, and standardized data exchanges.

MDS operates as a decentralized network, where data is managed through networked connectors rather than a centralized platform. Data providers create "usage policies" to govern data access via "data apps" within secure connectors, ensuring compliance and limiting access to only aggregated outputs.

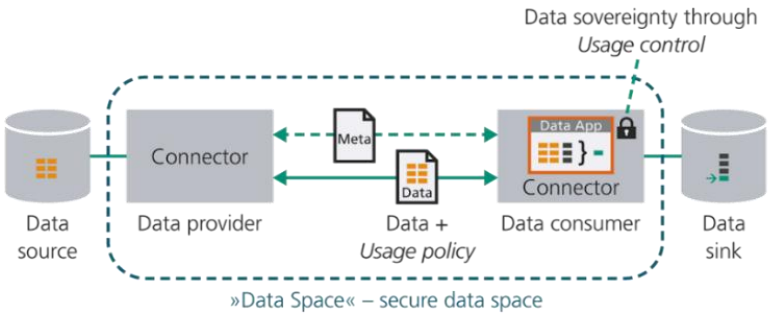


Figure 5: "Data Space" - secure data space

Key components include a **Data Marketplace** for publishing data sources, a **Vocabulary Provider** for standardized data formats, an **Identity Provider** for secure communications, and a **Clearing House** for logging transactions.

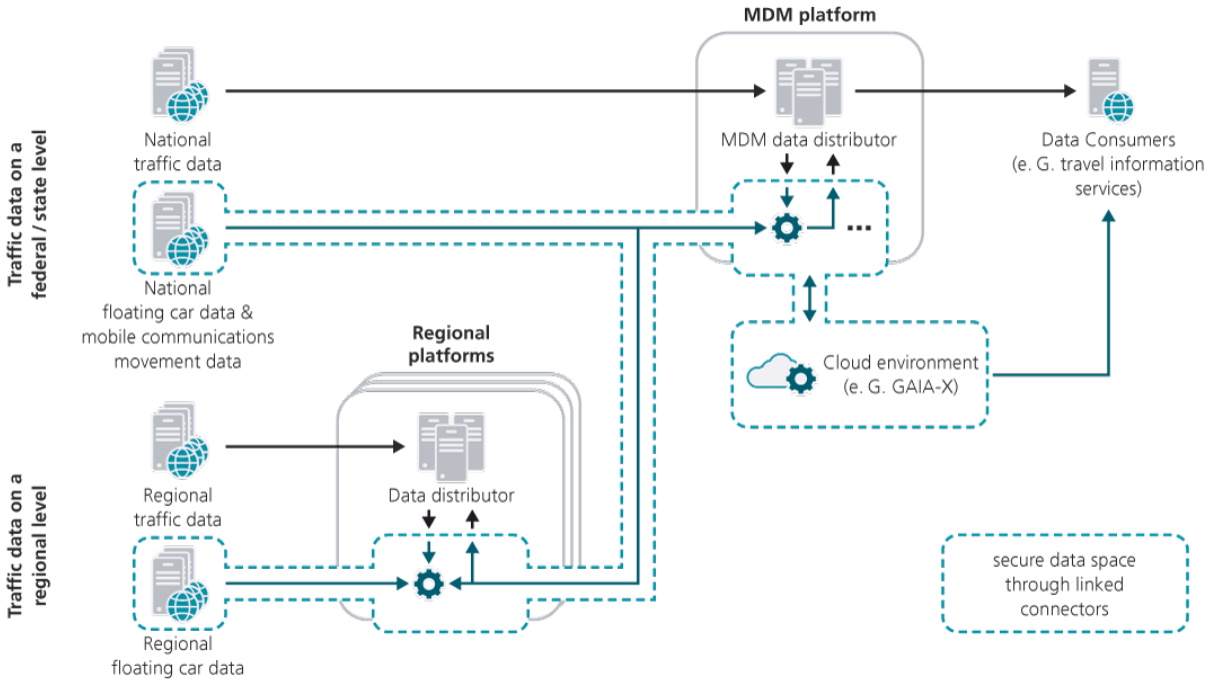


Figure 6: Traffic data on a regional and federal/state level

Cloud ecosystems play an important role in expanding the Mobility Data Space (MDS) by offering scalable resources necessary for executing resource-intensive tasks such as AI-driven data analysis and large-scale data management. The integration of IDS (International Data Spaces) connectors within cloud environments provides a security level equivalent to traditional platforms, while also offering the benefit of scalability tailored to demand.

The GAIA-X initiative complements MDS by establishing a secure and high-performance data infrastructure across Europe. This infrastructure facilitates the connection of existing European cloud services into a distributed network, thereby promoting European data sovereignty and reducing dependency on international providers. The interconnected framework supports innovation and the development of new data ecosystems while ensuring adherence to stringent European data security and privacy standards.

Furthermore, the integration of regional data platforms into the MDS significantly enhances the visibility and availability of mobility data at both regional and national levels. This integration supports broader initiatives, such as smart city developments, by making localized data accessible on a larger scale. By connecting diverse data sources—including open data initiatives and commercial services—MDS fosters a comprehensive ecosystem that enhances the effectiveness of data utilization across multiple domains.

3.3 Maritime Connectivity Platform (MCP)

The Maritime Connectivity Platform (MCP) is an open-source technology digital maritime domain. It brings common internet standards to maritime navigation and transportation systems.

MCP enables infrastructures for efficient, secure, reliable and seamless electronic information exchange among maritime stakeholders using available communication systems. MCP is an open and vendor-neutral technology.

The MCP has been evolving for a number of years. Around 2015, the development escalated significantly, when three large projects collaborated on the common use and further development of the technology. These were the EU projects 'EfficienSea2' and 'STM Validation project' and 'SMART Navigation project' funded by the Korean government. During these projects an MCP testbed was established, which now has been running for several years, and nearly 100 organisations have signed up to the platform.

The MCP itself initially addresses the goals of the e-navigation initiative of IMO, but the ambition is for the MCP to support digitalisation in the Maritime domain at large. It relies on the Internet concept of Web Services and with special services for identity management and service management supporting the IMO concept of Maritime Services. The MCP supports actors to use digital services to exchange public as well as private information. Potential commercial and non-commercial institutions can become provider of the MCP using their own installations of the MCP. For this, the MCC is established as a neutral and independent consortium of interested parties. It will act as the coordinator for the provision of guidelines and standards. The MCC adopts the open structure of the World Wide Web Consortium (W3C) and interested parties are encouraged to join these initiatives and bring in their visions and competencies. The Maritime Connectivity Platform (MCP) is composed of several components, each at different stages of maturity.

The **Maritime Identity Registry (MIR)** is well-defined and thoroughly specified in the IALA guideline G1183, titled *"Provision of MCP Identities."* This ensures a clear framework for managing maritime identities within the MCP.

The **Maritime Service Registry (MSR)** has been under development for some time, with substantial knowledge accumulated in the field. A prototype has existed since 2015, and parts of its interface are already defined in IEC 63173-2 (SECOM). The remaining elements of the MSR are expected to be formalized as an IALA guideline by 2025, further strengthening its standardization.

The **Maritime Messaging Service (MMS)** is in the final stages of development and is set to be published as an RTCM standard in early 2025. This will provide a standardized approach for secure and efficient maritime communication.

Lastly, the **decentralized trust system** currently exists only as a conceptual framework. However, the *Optimal-LOADS* project is expected to play a crucial role in its further development. This includes refining its specifications and progressing towards the creation of a functional prototype.

Each of these components contributes to the overall advancement of the MCP, ensuring a more structured, secure, and interoperable maritime digital infrastructure.

The MCP consortium (MCC) is governing the body of the MCP. It defined the criteria of being MCP service providers and endorses organisations to be such. The MCC has been structured in a way inspired by the World Wide Web consortium (W3C). And as with W3C, the MCC has a few number of host members, which are all non-profit organisations. An addition to these, there are regular members, which can also be for-profit-organisations. The host members form the board which decides on new members and endorses MCP service providers. Documents defining the criteria for being MCP services providers must be adopted by the General Assembly, in which all members are represented, with veto possibility for the host members. Furthermore, the MCC has an advisory board and a few governmental observers that are represented at the board, but without voting rights.

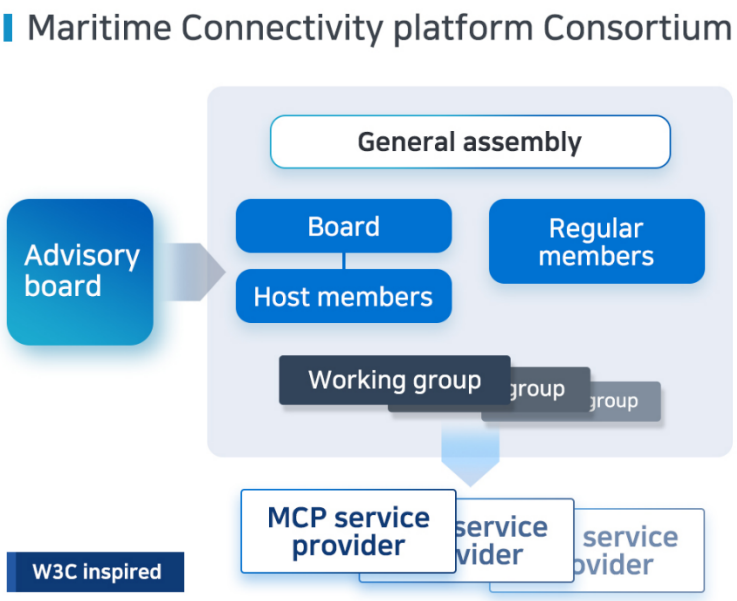


Figure 7: MCP

In October 2024, during the session of the IALA DTEC 3 Committee Meeting, a specific MMS demonstration underscored the system's advancements in security and efficiency in maritime connectivity.

Julius Moeller from AMSA, Christopher Saarnak from DMA and Thomas Christensen from AIVeNautics led the session, showcasing harmonised solutions for distributing navigational warnings within the e-navigation framework. The demonstration emphasized real-time data exchange and the implementation of a public key infrastructure (PKI) to ensure secure communications among maritime entities.

Key features included the integration of the IHO's S-124 product specification for standardized navigational warning datasets and a prototype user interface, NavUI, which allows users to visualize warnings on digital charts, enhancing situational awareness. The MMS is designed to be carrier agnostic, allowing flexibility to use various communication methods, including standard internet and non-IP options like VDES.

Live Navigational warning data from Australia, Korea, Denmark and Canada was demonstrated. The event highlighted the collaborative efforts among various organizations under the umbrella of the Open Digital Incubator, to modernize maritime services, paving the way for safer and more efficient navigation at sea.

4 The S-100 Standard as a Foundation for Data Exchange

In the evolving landscape of maritime logistics, seamless data exchange is a critical enabler for efficiency, safety, and sustainability. High sea shipping, as a global industry, demands standardized and interoperable data models to facilitate collaboration across stakeholders, from port authorities and shipping companies to regulatory bodies and logistics providers. As already mentioned, the concept of data spaces has emerged as a key paradigm for enabling trusted, sovereign, and scalable data sharing. By leveraging interoperable data models and ontologies, maritime data spaces can ensure that heterogeneous systems and organizations can communicate effectively. This approach not only enhances operational efficiency but also enables advanced analytics, automation, and decision-making based on harmonized data. A crucial enabler for this interoperability is the S-100 standard, developed by the International Hydrographic Organization (IHO). As a comprehensive framework for maritime data exchange, S-100 provides a common structure for different types of geospatial and navigational

data, ensuring compatibility across various systems and stakeholders. By adopting S-100 within a logistic data space, a unified data ecosystem can be addressed, that supports real-time situational awareness, optimized routing, and enhanced safety measures, all while maintaining compliance with international regulations.

This chapter explores the state of technology in maritime data exchange, with a particular focus on the role of S-100 and interoperable data models in shaping the future of high sea shipping logistics.

4.1 S-100 Introduction

S-100 came into force on 1 January 2010. S-100 is the document that explains how the IHO will use and extend the ISO 19000 series of geospatial standards for hydrographic, maritime and related issues. S-100 extends the scope of the existing S-57 Hydrographic Transfer standard. Unlike S-57, S-100 is inherently more flexible and makes provision for such things as the use of imagery and gridded data types, enhanced metadata and multiple encoding formats. It also provides a more flexible and dynamic maintenance regime via a dedicated on-line registry.

S-100 provides the data framework for the development of the next generation of ENC products, as well as other related digital products required and provided by the hydrographic, maritime and GIS communities. Details are described in chapter: 4.5 S-100 based product specifications

The S-100 IHO Data model with its product specification S-101, is the new “follow-up” Data model S-57, developed at the end of the 1980’s to produce ENCs for use in ECDIS[37].

The improved capabilities of computer hardware, the collected experiences with operation of ECDIS on ships using ENC data in the S-57 data format as well as increasing requests from users regarding new functions and its integration into ECDIS brought the S-57 concept to its limits. Especially the concept for the presentation of aids to Navigation, Navigational Information and other definitions for presentation on ECDIS defined via a “presentation library” (latest Version (PresLib) 4.0) published by IHO as responsible international organization make it challenging for the stakeholders to update existing systems on the ships as well as to implement the handling of further developments. Consequently, the demands to revise the database concept for ENC raised and the development of the S-100 concept under coordination of IHO started after a consulting period officially in 2005.

[37] *The **Electronic Chart Display and Information System (ECDIS)** is a computer-based navigation system that replaces paper charts, complying with **IMO regulations**. It integrates **Electronic Navigational Charts (ENC)**, GPS, radar, and sensors to enhance situational awareness and improve maritime safety (IMO)*

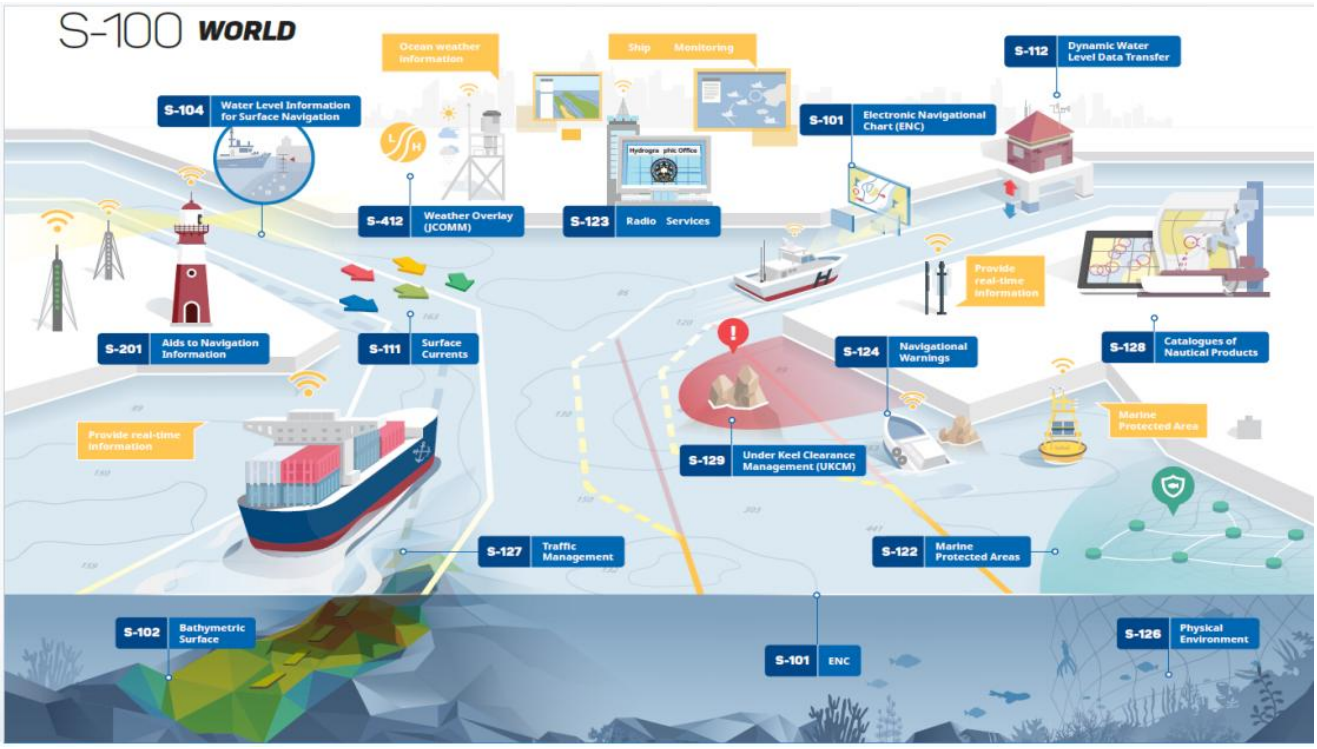


Figure 8: The S-100 World[38]

The main stakeholders involved in the defining of S-100 WORLD are:

- Flag state administration via IMO,
- IHO,
- data providers (HOs) and data service providers,
- ECDIS manufacturers,
- classification societies,
- standardization organisations (e.g. IEC),
- Type Approval Authorities (e.g. Notified Bodies)
- IALA

4.2 Concept and implementation

The S-100 implementation, particularly the S-101 ENC Product Specification, represents the next step in ENC development, driven by the maritime electronic industry, hydrographic offices (HOs), and ship navigation equipment manufacturers. Stakeholders face a complex regulatory environment, with international rules set by IMO, national implementations, and EU regulations like the Marine Equipment Directive (2014/90/EU). ENC adoption began with S-57 in the 1990s but required manual updates and hardware replacements for major Presentation Library (PresLib) changes, leading to the development of S-100 for better digital integration and flexibility.

[38] International Hydrographic Organization (2024)

S-100 aligns with IMO's e-Navigation Initiative, promoting data exchange between ships and shore-based stakeholders. The IHO GI Registry now supports IMO's Common Maritime Data Structure (CMDS) for interoperability. Unlike S-57, the S-100 framework enables semi-dynamic data updates, reducing the need for software upgrades and improving forward compatibility. This impacts type approval and flag state acceptance for S-100 ECDIS compliance.

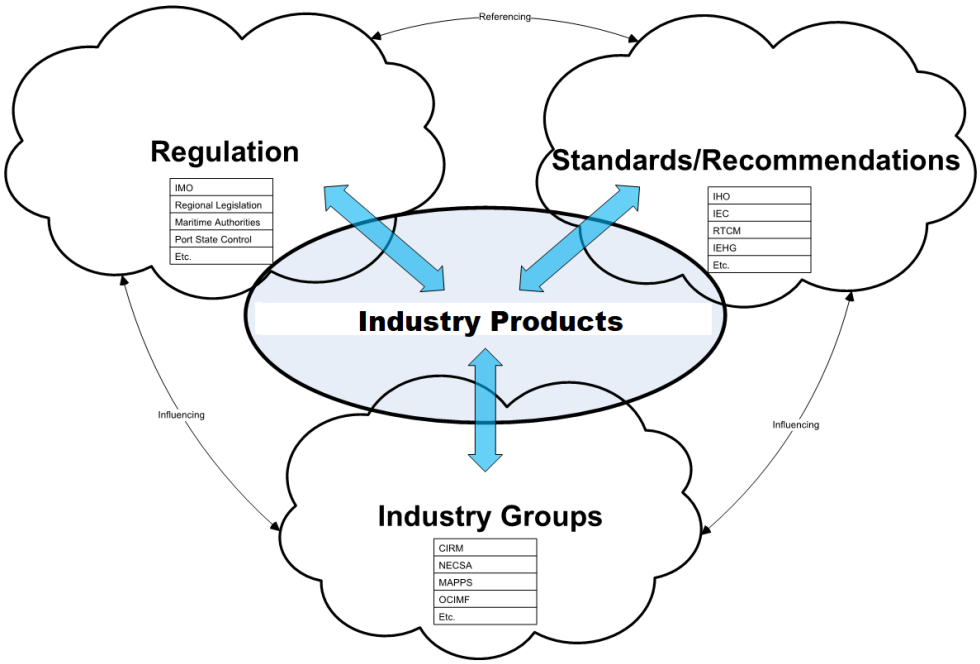


Figure 9: Environment of S-100 framework for marine electronics

4.2.1 Types of data within S-100

The terms „dynamic data" and „semi-dynamic data" are used in this document in the following way.

„**Dynamic data**" is sensor data received and processed by ECDIS cyclically, mainly data exchange of ECDIS with other navigational equipment on the navigation bridge.

„**Semi-dynamic data**" is data like ENCs, portrayals and other data which needs to be updated in the ECDIS to have all IMO and IHO required environmental data up to date. This may not apply to IMO and IHO required data only it may also include data for manufacturer proprietary additional layers as well.

Semi-dynamic data can be distinguished into two different types:

Type A: Libraries like ENCs, ENPs, symbols for portrayals (former PresLib)

Type B: Data which enables ECDIS to apply new portrayal and interoperability rules.

Such Type B data may comprise e.g. XSLT-stylesheets or Lua scripts which can be interpreted and processed by EDCIS, and which enables ECDIS to apply new (required) portrayal rules. Interpreters of such programming languages are commonly used in browsers. It allows for modification and adaption of portrayal rules without the need to change the ECDIS software and re-type approve it. Such semi-dynamic data Type B is used for Conditional Symbology Procedures (CSPs), which are defined to adjust the portrayal to selections made by the user, like own ship safety contour, four shades, etc. (Lua stands for "moon" on Portuguese).

4.2.2 Semi-dynamic data within S-100

S-100 Part 9/9a defines the portrayal model for organizing symbols and portrayal rules in S-100 products. These rules are included in the Portrayal Catalogue (PC), delivered with the Feature Catalogue (FC) and ENC data to ECDIS.

The Portrayal Model with the Portrayal Engine is defined in S-100 Part 9 as follows.

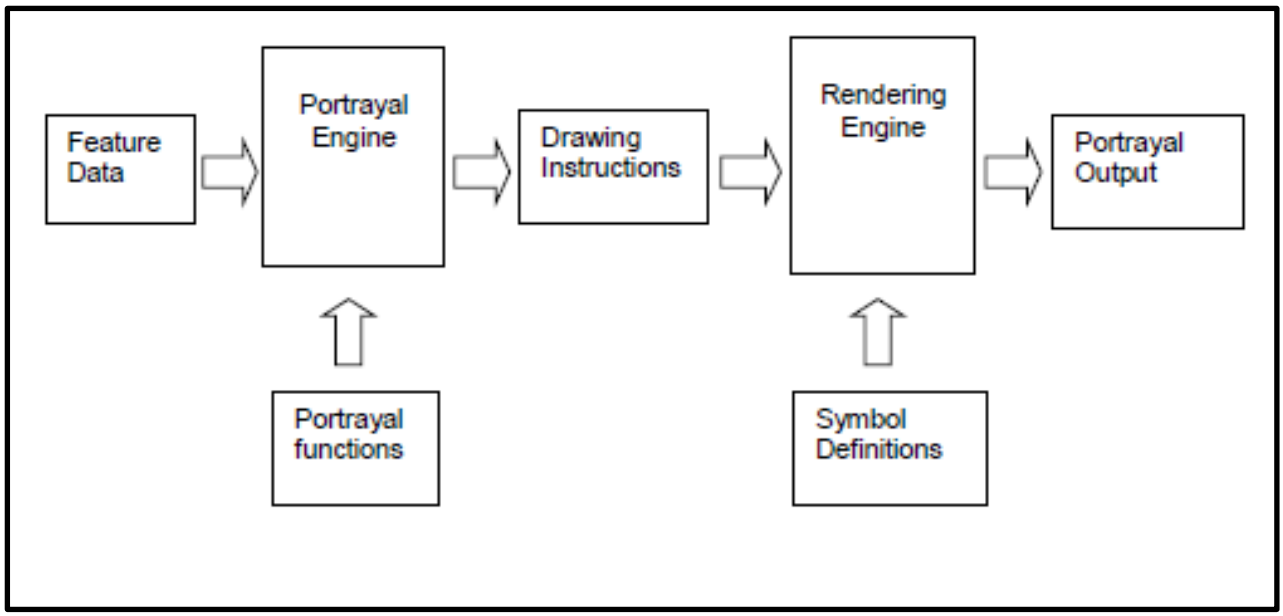


Figure 10: General Portrayal Model

In S-52, portrayal rules (CSPs) were hard-coded into ECDIS software, requiring software updates and re-approval for changes. In S-100, approval focuses on verifying the XSLT- and Lua-interpreter, requiring a new test procedure. S-98 interoperability rules were intended to be machine-readable, but for the initial Dual-Fuel ECDIS phase, rules for water level adjustment must still be hard-coded.

Semi-dynamic portrayal data enables display and alerting updates without ECDIS software changes, enhancing flexibility. However, testing must ensure ECDIS can correctly interpret received code. The threshold for new type approvals remains undefined. With Type B semi-dynamic data (e.g., XSLT stylesheets, Lua scripts), functionality is added online without dedicated functional checks. Since domain owners (e.g., IHO for S-101) control data quality, a single error could impact all ECDIS systems. High-level quality management is essential to prevent failures. Beyond type approval, procedures for crews, flag states, and port authorities must be developed to ensure S-100 ECDIS compliance with SOLAS and safe navigation.

4.2.3 Concept of interoperability and independency of product specifications

General independency

S-100 generated a doctrine and a concept which in general tries to keep the different S-xxx product specifications independent of each other.

This means, that the requirement for S-xxx specifications under the umbrella of S-100 requires independency of the S-xxx product specifications and its interoperability i.e., the requirements laid down in the S-xxx product specification shall only have impact of e.g. the additional presented layer of its own specification. There shall be no dependency between different layers (S-xxx specifications). They all should work independently of each other together with their semi-dynamic data. That is the goal and the theory. The independency is defined in S-100 Part 16 and 16a.

S-100 Part 16 and 16a describe, among other things, which rules must be applied when data products are displayed together. Part 16a is a guideline for harmonized presentation and distinguishes between three categories of systems (INS/ECDIS according to SOLAS, ECS/PPU as an aid with chart data as essential information, other applications).

Rules for the harmonization of symbols and colors and for the avoidance of ambiguities and contradictions are laid down there.

This means that, in principle, each data product is independent and describes the presentation functions and alerts as well as data queries (pick report) for this product, but as soon as it is foreseeable that several products are displayed simultaneously on a target system or are to interoperate, further aspects/rules must be taken into account when designing the products.

Within the IHO, this is regulated by the relevant committees and working groups; if it goes beyond this, joint expert groups are set up. The exact form is individual, depending on the requirements.

The IHO is the coordinator for ensuring harmonization and appropriate presentation of the required information on ECDIS as defined by the IMO SOLAS carriage requirements.

S-98 describes the interoperability of S-100 products. Changes in interoperability lead into a new version of S-98. In case S-98 is changed and the change downloaded by new semi-dynamic data cannot be processed by the ECDIS (and its software) based on the previous version of S-98, this is causing a re-type approval as a consequence. This circumstance has a large impact and should be avoided as far as possible.

Independence of portrayals of data products

Different data products are to be independent via S-100 definition. There is no general rule of priorities or an order in which different data products are to be displayed. The order of the presentation of the data products on the display is defined by the ECDIS manufacturer or by the mariner depending on the way of implementation in the ECDIS system. The mariner is able to switch the presentation of data products on and off as specified by the ECDIS standards. Any overlay or partly coverage over the ENC content should be “temporary”. Presently the term “temporary” is not defined in more depth and no automatic switching off after a certain timeout is required. Special cases for the independence of portrayals of data products are defined by the applicable S-100 product specifications.

Adding implementation of new S-100 features

An ECDIS shall be able to manage different versions of catalogues (FC, PC, IC) for the different data products to handle amendments in a catalogue of a data product even if some data producers use a former version with their data. There is the possibility to create new features based on the S-100 General Feature Model

(GFM) and Application Schema implemented in the ECDIS. For those features and portrayals may no test data set exist at the time of its development.

Such cases need a case-by-case decision whether an integration check/Re-type Approval is required or not. Today it is undefined how such cases are handled and who decides about the necessity of a Re-type Approval.

4.3 Administrative and coordination tasks

As described above there is a big variety of standards and specifications to be considered. The synchronisation between the standards and specifications today are manually coordinated. A process to be kept is not defined. Although today there is a big interest in a good manual coordination and cooperation, a misunderstanding, a lack in knowledge may cause pain for all other stakeholders.

The more standards and specifications to be applied – and the number will increase – the more communication between committees is necessary to avoid unsynchronized specifications which cause problems in unsynchronized requirements/tests, contradicting requirements/tests or unnecessary often re-certification of equipment. Re-certification of equipment is expensive and leads to unnecessary administrational burden for all involved stakeholders mainly for ship owners to be sure to keep their ECDIS up to date, further on

- for manufacturers generating software releases on high frequency,
- for Notified Bodies to provide enough resources for such high frequent re-certification and
- at least the administration to keep the list of standards and specifications to be considered up to date to guarantee a set of standards and specifications for a full functioning and IMO compliant ECDIS i.e. MED IR.

This all asks for a well-defined process in which it is clear for each stakeholder, how is the process and who is involved with which duties and rights in the synchronisation process for keeping the number of necessary re-certifications to a minimum.

4.4 Maintenance of S-100 based product specifications

A product specification is a precise technical description, which defines a geospatial data product. It comprises a description document, a data classification and encoding guide (DCEG), a feature catalogue (FC, see also Feature Catalogue Builder (FCB) below) and a portrayal catalogue (PC). All these parts may have different versions – the versioning rules for such product specification parts are not yet finally defined.

Safety related aspects

Technical standard/specification may need editorial corrections, bug fixes, changes or additions. Depending on the change made within a release of a technical standard/specification, it must be decided whether this is an important/mandatory change and/or an urgent change. This leads to the question „From which level of change in the revision or in the clarification numbering a re-type approval of ECDIS equipment is necessary? “ Current IMO decision is, that for a change in the Edition of the version number a re-type approval is necessary.

Product Specifications generally follow this format:

• New Editions denoted as n.0.0
• Revisions denoted as n.n.0
• Clarifications denoted as n.n.n

The same format for versioning has also being adopted for most of IHOs other Standards.
In the case of major changes to the product specification, an impact study must be carried out, in which the OEMs are involved. Test data for the main changes could be provided. Depending on the results of the study, proposals can be made to the IMO as to whether the changes have safety-relevant effects and therefore also need to be implemented on existing systems. Corresponding information will be posted on the IHO website.

There is within IMO and IHO a common approach that there is a need to develop a fixed procedure to address implementation of changes with safety-relevant effects and therefore also need to be implemented on ECDIS equipment already installed and in operation on SOLAS ships.

Check of independency

When the PTs provide a new version of their S-xxx product specification it has to pass a formal check by HSSC. HSSC requires a formal „impact study“ from the PT regarding the changes made.

The S-100 concept allows for a variety of options, therefore guidelines and rules specifically for ECDIS provided. It should be kept in mind that the S-100 concept is made for ECDIS but not limited to it. Since everything is managed via the GI registry and registry entries the processes of accepting, changing and deleting registry entries are specified in S-99 and S-100 Part 2, a certain degree of control is ensured.

General definitions and concepts are stored in the Concept Register and basic data constructs that are to be used or supplemented when creating product specifications are stored in the Data Dictionary Register. This ensures that the required features/attributes from the existing data in the data dictionary register can be used in a new product specification or newly developed ones can be added. The tasks/duties of the Registry Manager, Register Manager, Register Domain Control Body and Register Executive Control Body are regulated in S-99 clause 3,

Synchronisation of dependent S-1xx specifications

S-100 has product specifications which are used in combination to provide the navigator online with the correct information and presentation of semi-dynamic data. One example is the dependency of S-101, S-102 and S-104, This may require that editions of those product specifications need to be synchronized e.g. S-101 data (former ENC) and S-102 bathymetric data. Such synchronization is simple in case the data is provided by the same source e.g. a HO. In those cases, the data is synchronized, or data is rejected by cancellation notice. In case there are different data sources, synchronization must be ensured by the relevant stakeholders, which might be data provider, RENCs and others.

There is a quite big challenge to check and write down the consequences in changes in S-100 product specifications and its downstream processes, means the consequences at all involved stakeholders and its processes. To cover all those related aspects and consequences sufficiently IHO requires an impact study for substantive changes in product specifications. Guidance for this study and stakeholder participation is given in S-100 Part 12. Within the IHO, it is regulated by the relevant committees and working groups; if it goes beyond that, joint expert groups are set up. A further challenge is that the exact form is individual, depending on requirements it must be described in a general form or in detail. Complex is in addition the risk analysis of relevant consequences for the stakeholders affected.

Feature Catalogue Builder (FCB)

The purpose of the FCB is to produce S-100 conformant Feature Catalogues that contain all relevant data model elements such as feature types, attribute bindings or associations that are required for a product specification. The FCB interfaces with the GI Registry to allow feature catalogue developers to take advantage of common concept definitions and recommended attribute bindings. Functions for defining local types or draft types are also provided. Through experience, it was decided that also associations and roles should be defined

in the FCB and not be contained in the Registry. This is mainly due to the individual nature of these elements as observed through the development of several product specifications[39].

The S-100 Toolkit containing the Feature Catalouge Builder can be downloaded from the IHO Webside:

https://iho.int/en/feature-catalogue-builder

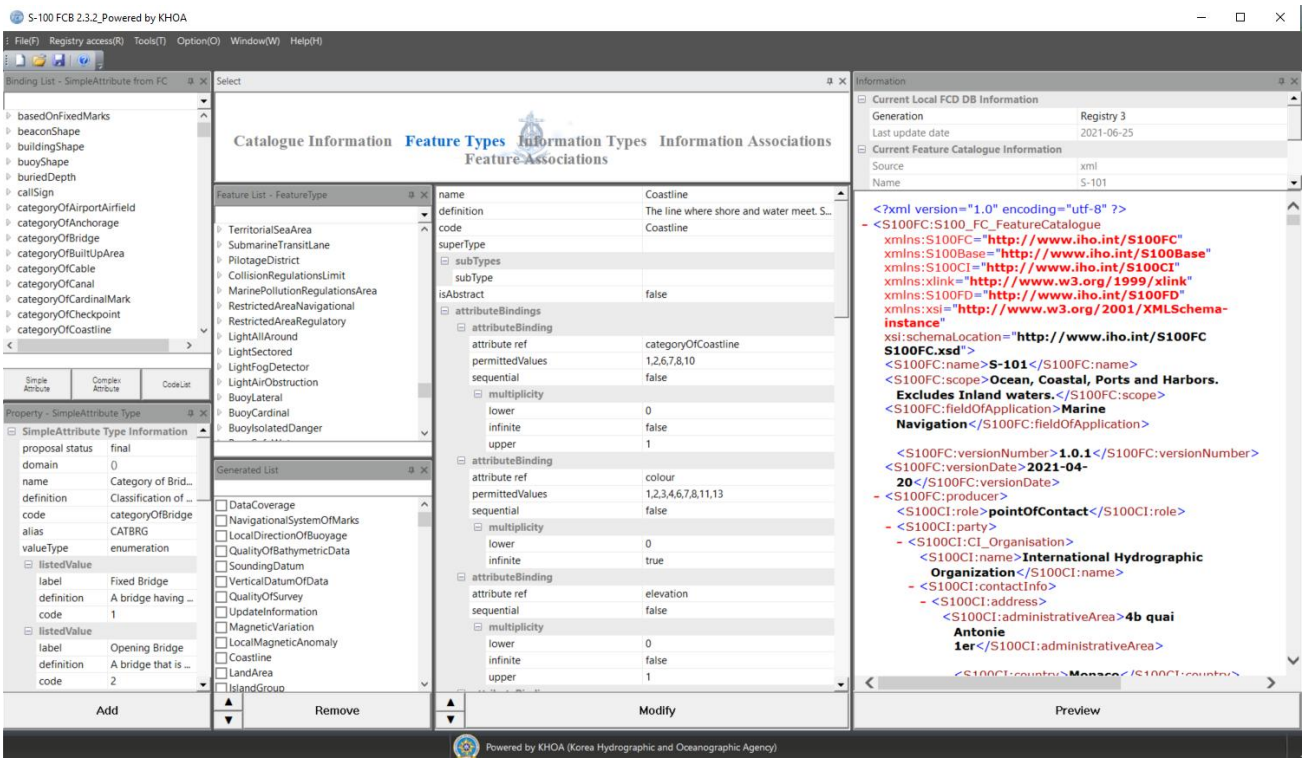


Figure 11: IHO Feature Catalogue Builder

4.5 S-100 based product specifications

At IMO the Common Maritime Data Structure (CMDS) is defined and maintains S-100 based product specifications. The following tables give an overview of the present status.

IHO Domain: S-100 – S-199

IHO S-101	ENC
IHO S-102	Bathymetric Surface
IHO S-103	Sub-surface Navigation
IHO S-104	Tidal Information for Surface Navigation
IHO S-111	Surface Currents
IHO S-112	Dynamic Water Level Data

[39] INTERNATIONAL HYDROGRAPHIC ORGANIZATION (o. J.)

IHO S-121	Maritime Limits and Boundaries
IHO S-122	Marine Protected Areas
IHO S-123	Marine Radio Services
IHO S-124	Navigational Warnings
IHO S-125	Marine Navigational Services
IHO S-126	Marine Physical Environment
IHO S-127	Marine Traffic Management
IHO S-128	Catalogues of Nautical Products
IHO S-129	Under Keel Clearance Management (UKCM)
IHO S-130	Polygonal Demarcations of Global Sea Areas
IHO S-131	Harbour Infrastructure
IHO S-164	IHO Test Data Sets for S-100 ECDIS
IHO S-1xx	Digital Navigator Routeing Guide
IHO S-1xx	(Social/Political)

Figure 12: IHO domain

IALA Domain: S-200 – S-299

IALA S-201	Aids to Navigation Information
IALA S-210	Inter-VTS Exchange Format
IALA S-211	Port Call Message Format
IALA S-212	VTS Digital Information Service
IALA S-230	Application Specific Messages
IALA S-240	DGNSS Station Almanac
IALA S-245	eLoran ASF Data
IALA S-246	eLoran Station Almanac
IALA S-247	Differential Loran Reference Station Almanac

Figure 12: IALA

IOC/WMO Domain: S-300 – S-399

	Currently no product specifications planed

Figure 13: IOC/WMO domain

General Domain: S-400 – S-499

IEHG S-401	Inland ENC
IEHG S-402	Bathymetric Contour Overlay for Inland ENC
JCOMM S-411	Sea Ice Information
JCOMM S-412	Weather Overlay
JCOMM S-413	JCOMM Weather Overlay
JCOMM S-414	Weather and Wave Conditions
IEC S-421	Voyage Information System

Figure 14: General domain

NATO GMWG (Geospatial Maritime Working Group): S-501 – S-525

	Currently no product specifications planed

Figure 15: NATO-GMWG

4.6 S-100 Implementation phases

For the first edition of S-98, addressing interoperability between different data products in the future S-100 ECDIS, priority will be given to product specifications used in route monitoring mode. In the next step layers used in route planning mode will be included. To achieve usage of S-100 products in future S-100 ECDIS it is essential to develop the supporting framework in accordance with the S-100 timeline. The essential S-100 framework consists of:

- the IHO Geospatial Information (GI) Registry,
- the S-100 Universal Hydrographic Data Model,
- the Interoperability Specification (S-98),
- the Catalogue of Nautical Products (S-128) and
- the Test Data Set for S-100 and ECDIS Type Approval (S-164).

It should be noted that priorities given to the products used in route monitoring mode and the essential S-100 framework does not prevent route planning products from being developed. In addition to the route monitoring products, S-122, S-127 and S-131 should be operational in the year 2026.

Table A – IHO list of S-100 products with special focus	
Phase 1 / Route monitoring	
S-101	Electronic Navigational Chart (ENC)
S-102	Bathymetric Surface
S-104	Water Level Information for Surface Navigation
S-111	Surface Currents
S-124	Navigational Warnings
S-129	Under Keel Clearance Management

Critical Framework	
	IHO Geospatial Information Registry
S-98	Interoperability Specification
S-100	Universal Hydrographic Data Model
S-128	Catalogue of Nautical Products
S-164	Test Data Set for S-100 and ECDIS Type Approval
Phase 2 / Route planning	
S-122	Marine Protected Areas
S-123	Marine Radio Services
S-125	Marine Aids to Navigational (AtoN)
S-126	Marine Physical Environment
S-127	Marine Traffic Management
S-131	Marine Harbour Infrastructure
S-411 (WMO)	Ice Information
S-412 (WMO)	Weather and Wave Hazards

Figure 16: The S-100 Implementation Priorities

The current version of the roadmap is provided on the IHO website:

https://iho.int/en/s-100-implementation-strategy

The first step encompasses product specifications for Route Monitoring which are supported by the Critical S-100 Framework. Product specifications for Route Planning will be developed as the second step.

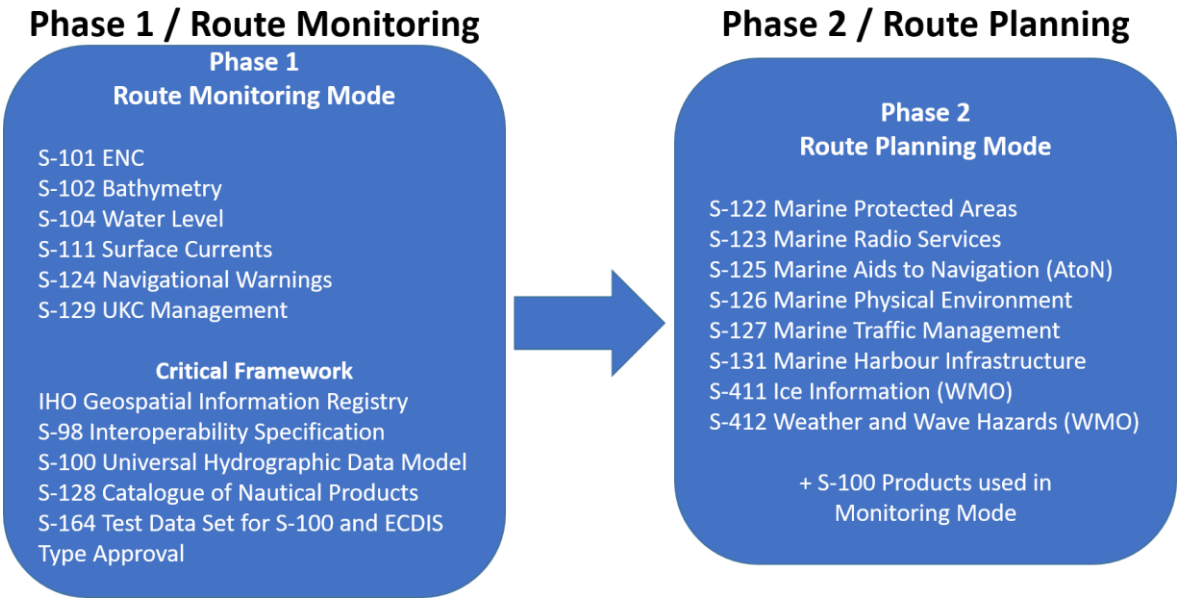


Figure 17: The IHO Navigational Package to be handled by the Interoperability Specification S-98[40]

[40] International Hydrographic Organization (2024a)

4.7 S-122(Marine Protected Areas)

S-122 is a product specification developed by the International Hydrographic Organization (IHO) for encoding Marine Protected Areas (MPAs) within the S-100 Universal Hydrographic Data Model. It aims to provide a standardized method for representing MPA data, which is essential for ensuring navigational safety and environmental protection. This specification is part of the S-100 framework, which aims to enhance the standardization and interoperability of hydrographic data. S-122 supports the integration of MPA data into Electronic Chart Display and Information Systems (ECDIS) and other GIS.

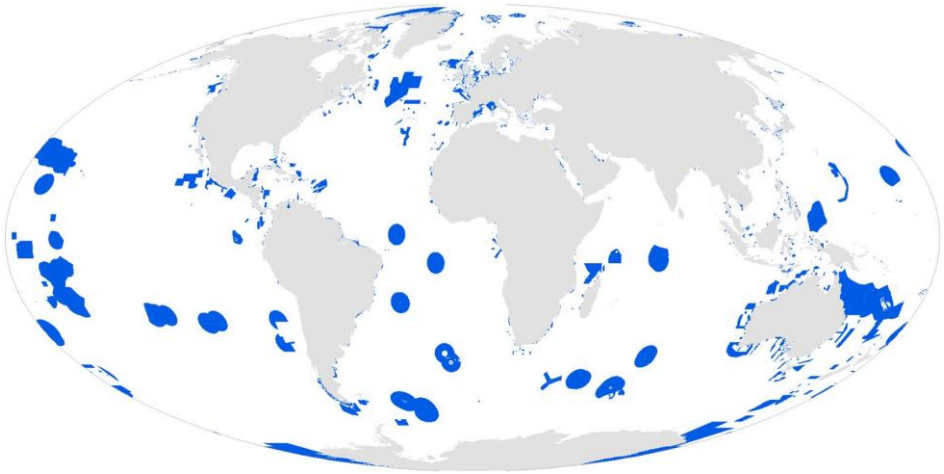


Figure 18: World MPAs (authors with data from UNEP-WCMC and IUCN 2021)

S-122 Product Specification

Purpose	to encapsulate all navigationally relevant information about MPAs, helping mariners navigate while respecting environmental regulations.
Components	The specification includes a feature catalogue, portrayal catalogue, and application schemas, all of which are essential for integrating MPA data into Electronic Navigational Charts (ENCs). - (Feature Types) These include various types of MPAs and related areas such as Navigational Restricted Areas, Regulatory Restricted Areas, and Vessel Traffic Service (VTS) Areas - (Information Types) These encode regulations, restrictions, recommendations, and other relevant information in text or graphical form. - (Application Schema) This details the structure and relationships of features and information types, ensuring standardized data representation and interoperability
Implementation and Testing	The first edition (1.0.0) was released for implementation and testing in January 2019. This phase is crucial for refining the specification based on real-world feedback and ensuring it meets operational needs
Data Management	The data includes vector datasets representing the boundaries and regulations of MPAs. These datasets are managed through the IHO Geospatial Information Registry, ensuring they are up-to-date and standardized globally.
Coordinate reference system	The specification uses the World Geodetic System 1984 (WGS 84) for horizontal data and supports various vertical datums. Coordinates are expressed in decimal degrees for latitude and longitude.

Data quality	S-122 datasets must undergo specific quality checks before release to ensure data accuracy and reliability. These checks include data format validation, standard conformance, and logical consistency.
Data delivery	Data products are delivered primarily in Geography Markup Language (GML) format. Exchange sets may include multiple MPA datasets and support files, which are structured and named according to defined conventions.
Meta data	Metadata is crucial for identifying and describing datasets, including details about data sources, production processes, and update histories

Figure 19: S-122 Product Specification

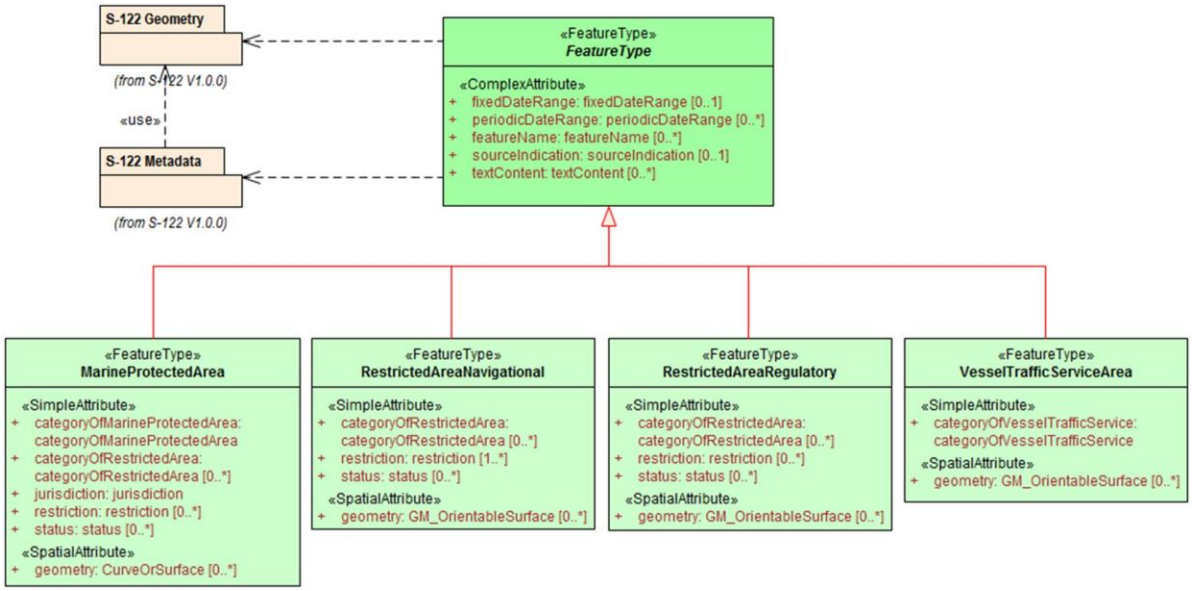


Figure 20: S-122 feature types (Reproduced from IHO 2019b)

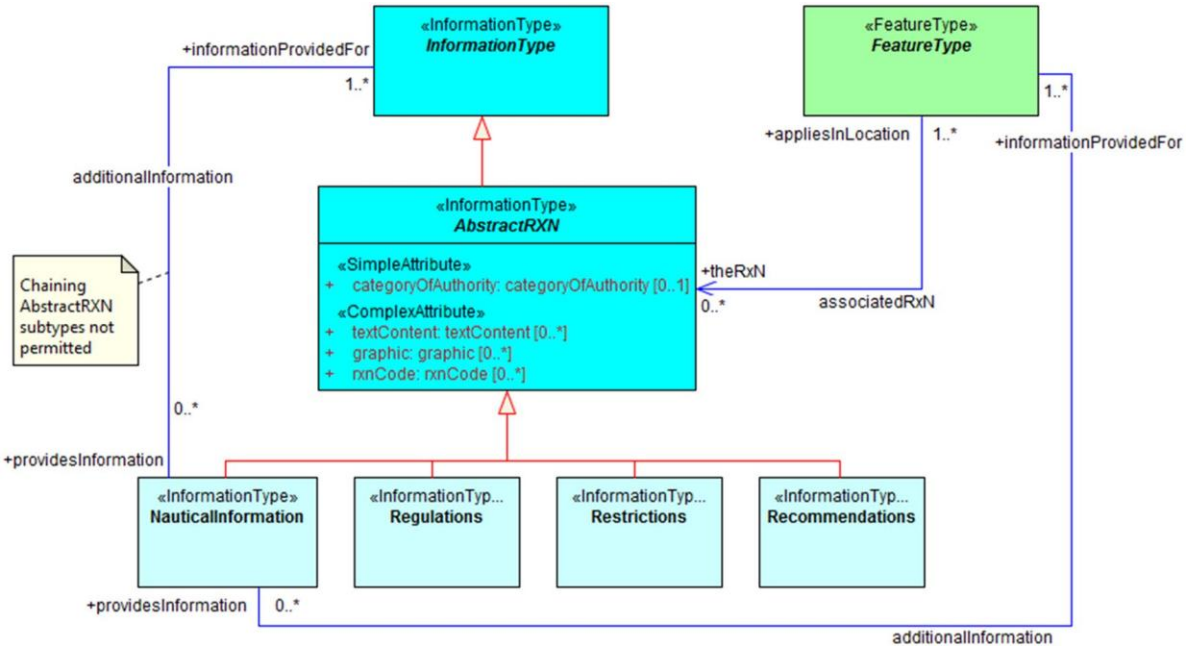


Figure 21: S-122 restriction types (Reproduced from IHO 2019b)

Development progress of S-122

Global research efforts have been concentrated on integrating S-122 with other S-100 specifications to improve data interoperability and usability in marine navigation systems. The S-100 Working Group, led by NOAA, oversees the development and implementation of these standards, ensuring that they meet the needs of modern maritime operations. The ongoing development includes creating intuitive symbols for MPAs to facilitate user comprehension and integration into existing electronic chart systems.

Technological advancements associated with S-122 include the development of new symbology and mapping techniques for MPAs. These advancements aim to improve the visualization and understanding of MPAs on digital charts, aiding in better decision-making for both environmental protection and navigation. The IHO's S-100 Test Bed supports the testing and validation of these product specifications, ensuring their reliability and effectiveness.

The following table shows the progress of S-122 development from 2017 to the present.

2017	- Initial development of S-122 begins. The focus is on defining the application schema and identifying the necessary feature and information types. - Release of the first draft (Draft 3) of the S-122 specification. - Release Candidate 1 (RC1) is made available for review and testing.
2018	- Refinement of the application schema and incorporation of feedback from the review process. Efforts are made to ensure alignment with the S-100 Universal Hydrographic Data Model.
2019	- Publication of the first official edition of the S-122 Marine Protected Area Product Specification (Edition 1.0.0). This edition includes a detailed application schema, data content and structure guidelines, and a feature catalogue. - Initiation of data validation checks and the development of guidelines for data quality assurance. - Initial implementations of S-122 data sets begin, focusing on integration with Electronic Chart Display and Information Systems (ECDIS)
2020	- Development of enhanced data validation checks to address data coverage, attribute consistency, and geometric correctness. This includes more stringent quality control measures for S-122 datasets. - Collaboration with international hydrographic offices and environmental agencies to facilitate data exchange and improve the management and enforcement of MPAs globally.

2021	- Introduction of new portrayal and symbology efforts to develop intuitive symbols for MPAs, aimed at enhancing user understanding and operational efficiency on ECDIS - Launch of pilot projects to test the integration of S-122 data with other S-100 based products, such as S-101(ENC) and S-104 (Water Level Information for Surface Navigation).
2022	- Significant progress in refining the application schema to improve the accuracy and utility of MPA data. This includes the standardization of feature types and the addition of attributes to capture complex MPA characteristics. - Implementation of automated alert systems utilizing S-122 data to enhance maritime safety and environmental compliance, particularly in Vessel Traffic Service (VTS) areas.
2023	- Further improvements in data validation checks and the introduction of new metadata standards to ensure the integrity and reliability of S-122 datasets. - Expanded collaboration with stakeholders to enhance the global management of MPAs, including more comprehensive data sharing and interoperability efforts.
2024	- (Ongoing) Continuous updates and refinements to the S-122 specification based on user feedback and technological advancements. Focus remains on improving data quality, portrayal, and integration with other hydrographic and environmental data products.

Figure 22: Progress of S-122 development from 2017 to the present

As of 2024, the development of S-122 has seen significant progress, with key updates including:

1. **Application Schema Refinement**: Enhancements have been made to the schema to improve the accuracy and utility of MPA data, including the standardization of feature types and the addition of attributes to capture complex MPA characteristic.
2. **Enhanced Data Validation Checks**: New validation checks have been introduced to ensure the integrity and reliability of S-122 datasets, addressing issues such as data coverage, attribute consistency, and geometric correctness.
3. **Portrayal and Symbology**: Although the current edition of S-122 does not include a portrayal catalogue, efforts are ongoing to develop intuitive symbols for MPAs, enhancing user understanding and operational efficiency on ECDIS.

Figure 23: Sample ENC symbols for MPAs types (S-122 Portrayal and integration concepts and services, NTUA)

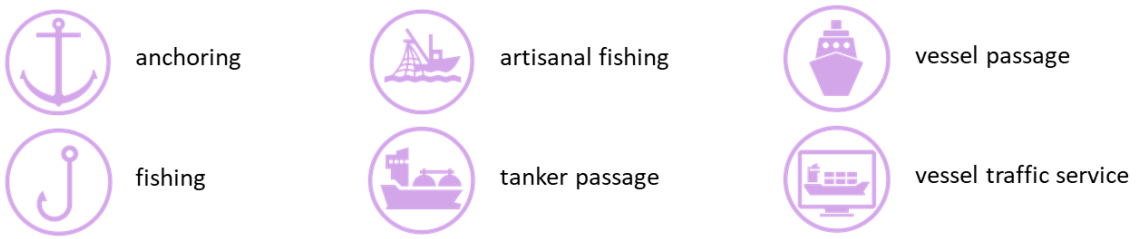


Figure 24: Sample ENC symbols for MPAs permitted activities s (S-122 Portrayal and integration concepts and services, NTUA)

Implementation Example of S-122

S-122 has been implemented in various contexts to support maritime navigation and environmental protection:

1. **Integration with ECDIS**: S-122 data is used to overlay MPA information on electronic charts, providing mariners with critical information about restricted areas and environmental regulations. This integration aids in route planning and compliance with MPA regulations.
2. **Data Exchange and Collaboration**: The standardized format of S-122 facilitates data exchange between hydrographic offices, environmental agencies, and other stakeholders, enhancing the management and enforcement of MPAs globally.
3. **Automated Alerts and Monitoring**: Systems utilizing S-122 data can generate automated alerts for vessels entering restricted areas, improving maritime safety and environmental compliance. This functionality is particularly useful in VTS areas, where real-time monitoring and management are critical.

Figure 25: Combined ENC symbols for MPAs categories and regulations (Euro-Mediterranean Journal for Environmental Integration 2023)

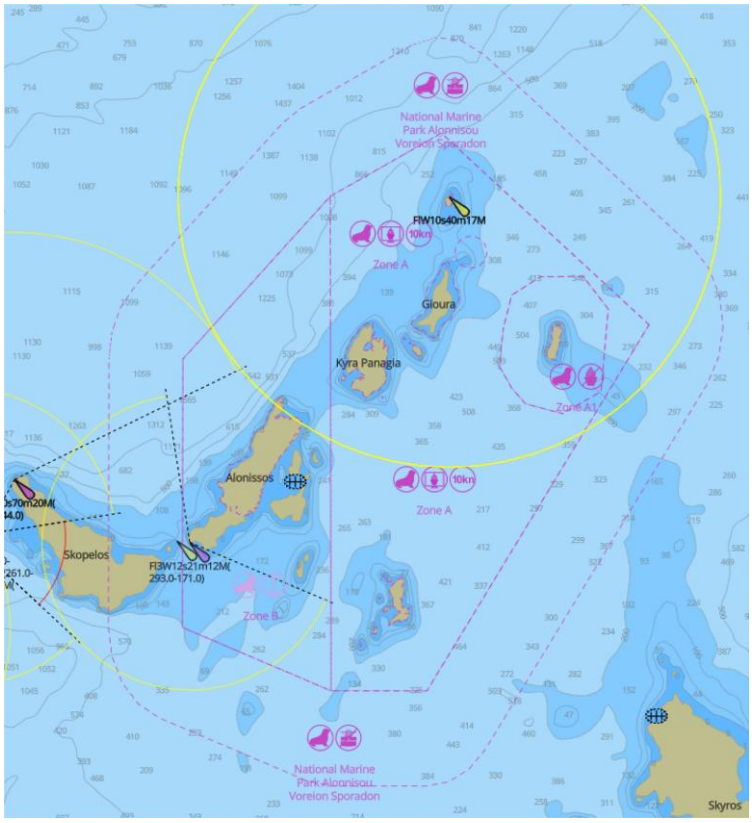


Figure 26: Monachus turtle (Zakynthos) MPA charting testbed (NOAA)

References of service development

Services using S-122 data are designed to display the boundaries and regulations of MPAs on ENCs. These services are crucial for enforcing environmental regulations within protected areas and for promoting safe navigation practices. The World-Wide ENC Database Working Group (WENDWG) actively evaluates the readiness of regional hydrographic commissions to provide S-1xx datasets, including S-122, by 2026.

Developing services based on S-122 data involves several key examples. These services focus on visually representing the boundaries and regulations of Marine Protected Areas (MPAs) on Electronic Navigational Charts (ENCs), helping mariners comply with regulations within protected zones and contribute to environmental protection.

1. **UKHO's Trial Data Set :** The United Kingdom Hydrographic Office (UKHO) released a trial data set for S-122 on April 22, 2022. This data set was designed to test the practical application of S-122 data in real-world scenarios. The trial involved displaying the boundaries and regulations of Marine Protected Areas (MPAs) on Electronic Navigational Charts (ENCs). Feedback from this trial was essential in identifying areas for improvement in data accuracy and usability. The results showed how S-122 data could be effectively integrated into navigation systems to enhance maritime safety and environmental protection.

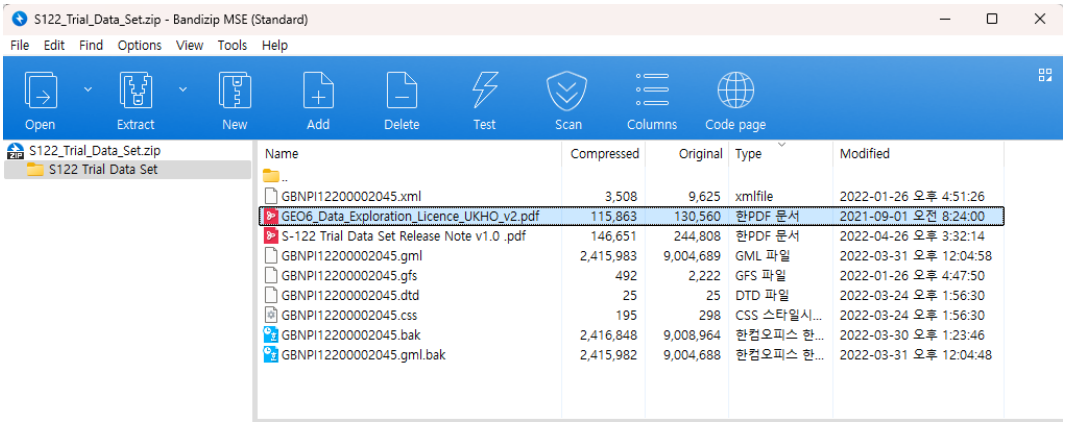


Figure 27: S-122 Trial Data Set

2. **Canadian Research on MPA Portrayal:** In Canada, a significant study focused on addressing the la ck of portrayal standards in the existing version of S-122. Researchers developed intuitive symbols fo r different types of MPAs, such as endangered species habitats, historical or cultural submerged sites, and Vessel Traffic Service (VTS) areas within MPAs. These symbols were designed to be easily und erstood by end-users and included representations for various marine activities and restrictions, such as slow zones, anchoring regulations, and fishing limits. This work aimed to provide a foundation for future versions of S-122 that might include a portrayal catalogue, enhancing the visual representation of MPAs on navigational charts

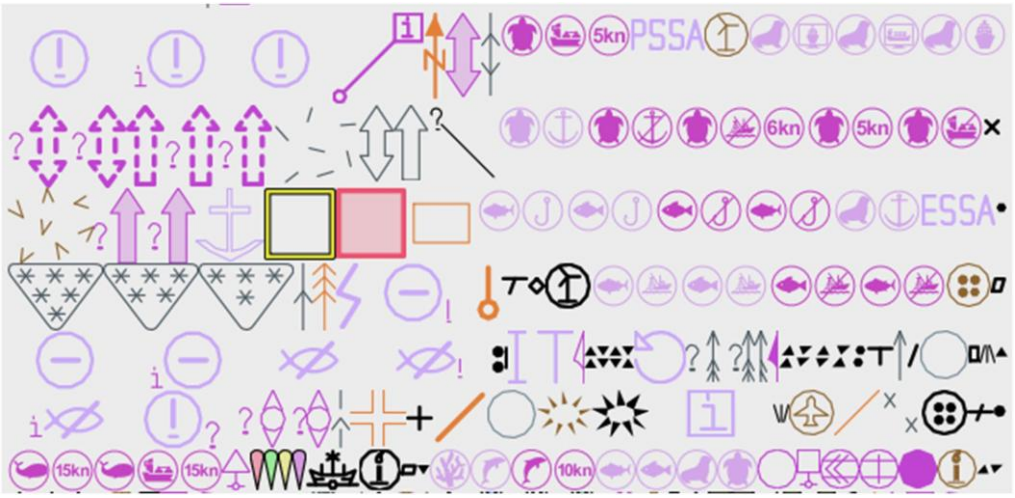


Figure 28: New S-122 symbols along with existing S-101 ENC portrayal symbols

3. **NOAA and International Collaboration:** The National Oceanic and Atmospheric Administration (NOAA), alongside the UKHO and the Canadian Hydrographic Service, has been working on harmonizing S-122 data through S-100 sea trials. This project integrates high-resolution bathymetry, safety contour calculations, and surface current information into a cohesive system. By using international standards, these efforts ensure that the hydrographic community worldwide can develop and use harmonized products, making it easier for system implementers to use data across different regions without worrying about national variations.

4.8 S-124(Navigational Warnings)

Based on the S-100 Timeline published by the IHO, the product specification for S-124 data is currently in the preliminary implementation phase, having been completed to version 1.0.0, with development of ed 2.0.0 nearing completion. Final approval is expected by 2025, with full implementation starting in 2025.

S-124 Product Specification

Name	S-124 Service Specification
Version	1.0.0
Description	Implements the IHO geospatial standard for navigational warnings, used as an overlay to ENC within a navigation system
Status	Provisional
Current regime	Manual processes and non-standardized system interfaces for NW dissemination.
Future scenario	Standardized structured NW format for seamless exchange across compatible systems, supporting both local and national levels of NW dissemination.
Functional requirements	Include the handling of new datasets, cancellation datasets, in-force bulletins, and more.
Non-functional requirements	Interoperability, confidentiality, authenticity, integrity, availability, performance, and operability.
Service interface	Get Interface: Pulls navigational warnings from a service producer
	Get List Interface: Returns a list of accessible information objects
	Subscribe Interface: Requests subscription to specific information.
	Remove Subscription Interface: Removes subscriptions.
	Subscription Notification Interface: Handles notifications for created or removed subscriptions
Data Model (data structure)	Logical data structures for NW features and information types, described in XML schema format.

Figure 29: S-124 Product Specification

Development of S-124 product focuses on Navigational Warnings(NW) as part of the Maritime Safety Information(MSI) service, aiming to modernize the dissemination and display of navigational warnings using the IHO's S-100 framework. This involves the creation and integration of new data models and interoperability standards to ensure the accurate and timely delivery of critical safety information to mariners. The S-124 product specification includes features such as S124_Text Placement and S124_Navigational Warning Feature Part, which help in structuring the navigational warnings efficiently.

Based on data products, S-124 is being developed to be compatible with current and future maritime communication technologies, including traditional radio broadcasts, NAVTEX, and enhanced EGC services. These services aim to create datasets from safety information provided through wide-area broadcasts like radio, NAVTEX, and SafetyNET messages, which can be widely transmitted to various devices, ensuring real-time, standardized safety information integration with ENC overlays within ECDIS.

The IHO's S-124 standard is part of the broader S-100 framework, which provides a universal hydrographic data model for various maritime data products. The standard is being developed by the S-124 Correspondence Group, which includes representatives from various national hydrographic offices and industry stakeholders.

The goal is to create a machine-readable, interoperable standard that enhances the efficiency and accuracy of maritime safety information dissemination.

The development of S-124 involves several key activities, including the creation of data models, the establishment of interoperability rules, and the development of service specifications. Currently, efforts are focused on finalizing the S-124 product specification, integrating it with existing systems, and conducting extensive testing to ensure its functionality and reliability.

So far, the leading S-124 service development and implementation references are from Republic of Korea and Canada. Korea developed an S-124-based MSI service as part of its e-Navigation project in 2019, which focused on integrating maritime safety information with ECDIS using the MCP. Through the project, Korea has developed and tested an S-124 prototype to ensure that the S-124 service meets the needs of navigators and is consistent with international standards. The development of the S-124 has also included the utilization of advanced data models to provide accurate and timely safety information. As a result, since 2021, Korea established an e-Navigation operation system and is currently providing S-124 services to approximately 10,000 small vessels using MCP.

Figure 30: S-124 product provision of Korea

Canada, particularly through the Canadian Coast Guard (CCG), is actively involved in the development and implementation of S-124 services. The CCG's implementation efforts include the development of a NAVWARN Issuing System (NIS) that integrates S-124 processes, utilizing tools such as the JAXB library for XML content creation and SECOM-compatible technical services for distribution. Canada's approach emphasizes the use of open-source libraries and innovative projects to enhance the service's capabilities and user experience.

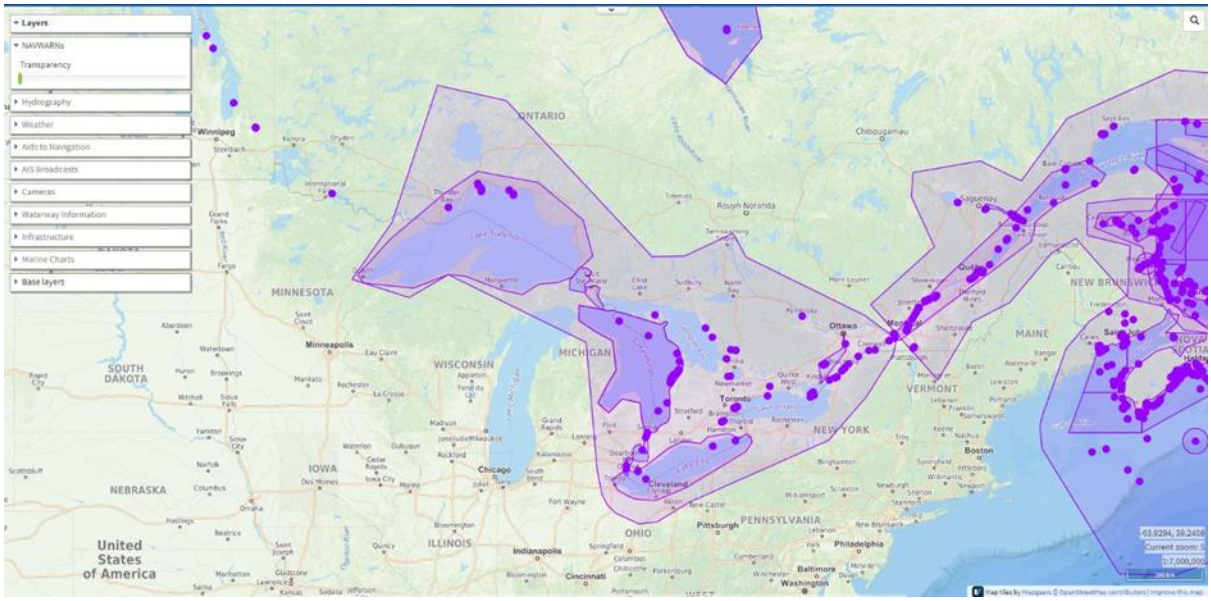


Figure 31: S-124 product provision of Canada

4.9 S-412(Weather Overlay)

Based on the S-100 Timeline published by the IHO, the product specification for S-124 data has been completed up to version 1.0.0 and is currently in the preliminary implementation stage, with the development of edition 2.0.0 nearing completion. S-412 is a product specification designed to overlay marine weather information in ECDIS. This standard is being developed based on the S-100 Universal Hydrographic Data Model. It is expected to receive final approval by 2025, with full implementation beginning from 2025 onwards.

The S-412 product aims to integrate marine and atmospheric weather data and provide it as an overlay to ENC, designed to support safe navigation by providing mariners with highly accurate real-time weather information. Although ECDIS currently does not include weather information, it has been designated as a mandatory requirement with approval from the IMO (International Maritime Organization). The S-412 product is designed to be seamlessly integrated with other S-100-based product specifications accessible in ECDIS. Real-time Water Level (S-112), Surface Current (S-111), Bathy Grid (S-102), Digital Tide, and Bathy ENC information will be overlaid with the S-412 Weather data layer, allowing all these layers to be viewed simultaneously on the ECDIS screen. Additionally, these overlaid layers will be updated in real time, contributing to the safe navigation of mariners. The data in S-412 is in vector format, represented as polygons. Polygons represent the extent of the disaster area, with the color of the polygons varying depending on the intensity of the disaster. The system targets alerts not only for disasters that are currently occurring, but also for potential disasters that could occur within the next 24 hours.

The S-412 warning polygon is not a static image, but rather a dynamic representation. They are displayed in continuous motion over a 24-hour period, allowing you to pinpoint where disasters are occurring in real time. These S-412-format representations will last for 48 hours, after which they will transition to S-413-format data displayed on top of the Electronic Chart Display System (ECDIS).

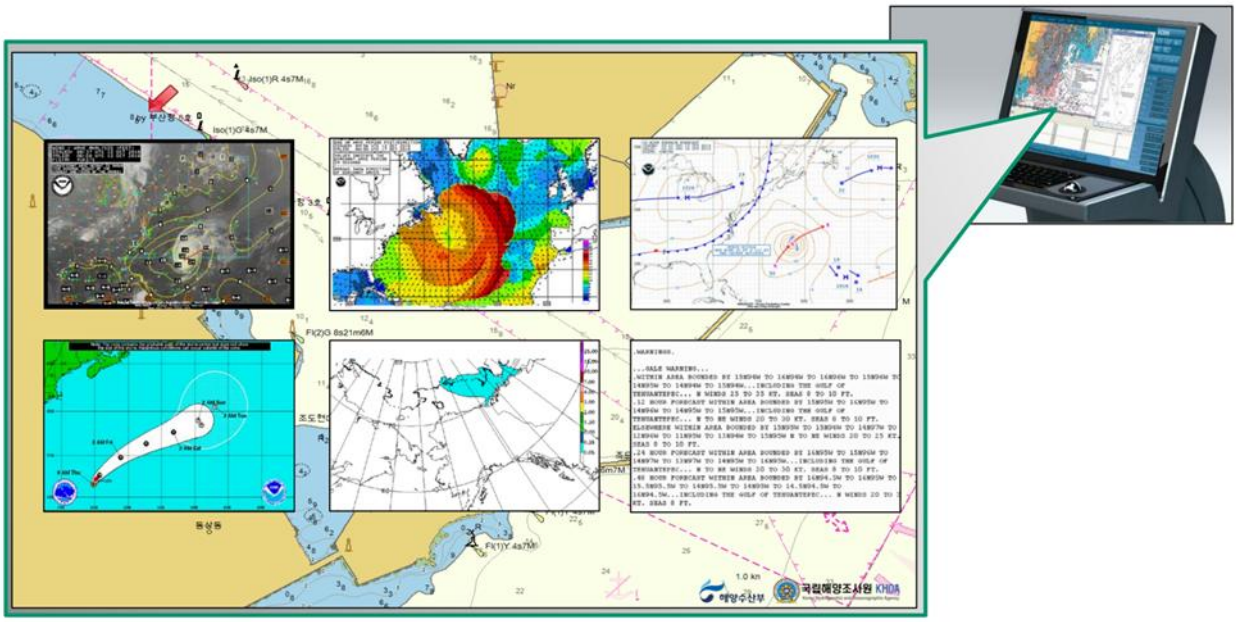


Figure 32: Weather Overlay Goal

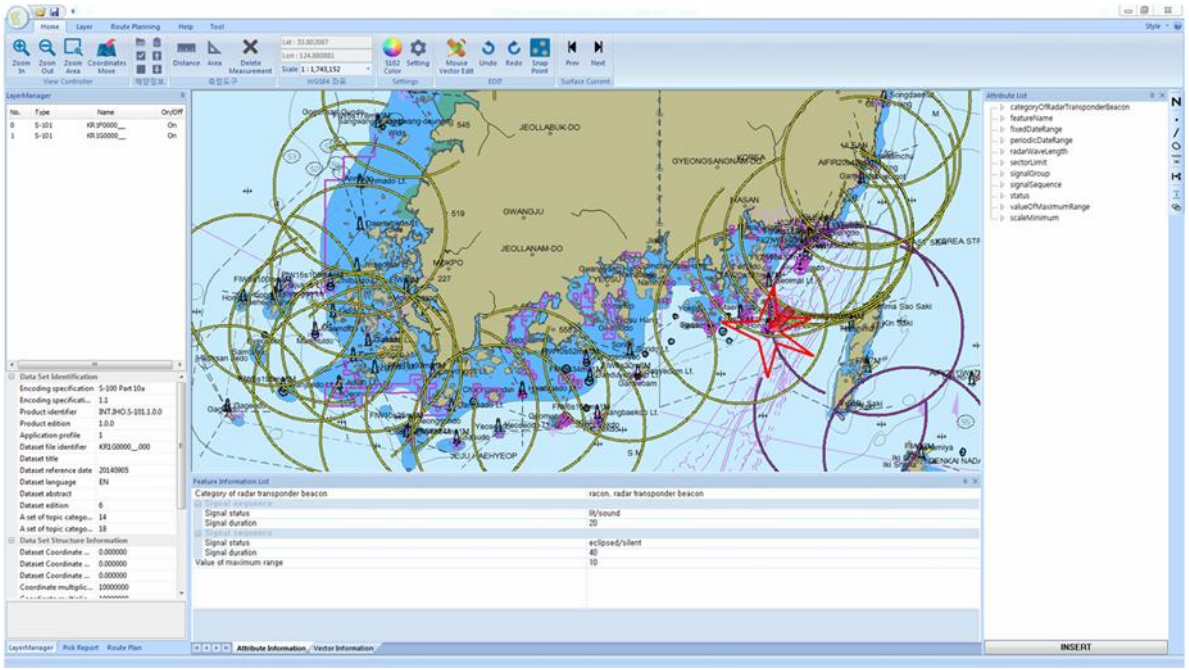


Figure 33: S-viewer Testing

The S-412 Weather Overlay product specification is part of the IHO S-100 framework and is specifically designed to standardize the encoding of meteorological and oceanographic information. This specification aims to ensure the interoperability and harmonization of weather overlay products used in Electronic Navigational Charts (ENC) and other marine information systems. By establishing an integrated standard for encoding weather-related data, it facilitates the seamless integration of these overlays with various maritime navigation and safety systems. This enhances the ability of different systems to consistently interpret and display weather information, promoting safer navigation. Additionally, it provides a flexible framework that can be adjusted to integrate new types of meteorological and oceanographic data as they become available. The S-412 standard is

structured to define various objects and associated attributes used to represent a wide range of meteorological phenomena and related information.

S-412	S-413	S-414
Wave and Weather Hazards	Wave and Weather Conditions	Wave and Weather Observations
Polygons	Features (e.g. fronts) Graphics & Gridded Data	Point Based Data

Figure 34: S-41x Series

The S-412 standard is developed in accordance with the IHO S-100 framework, ensuring compliance with international standards for hydrographic and oceanographic data. This standard references key documents and guidelines from organizations such as the World Meteorological Organization (WMO). The S-412 Weather Overlay product specification is a comprehensive standard designed to improve the representation and interoperability of meteorological and oceanographic data in maritime navigation systems, thereby contributing to safer and more efficient maritime operations.

Name	S-412 Weather Overlay Product Specification
Version	1.0.0
Description	A standard for providing real-time meteorological and oceanographic information, implemented as an overlay for ENC
Status	Preliminary
Current regime	-
Future scenario	Access to standardized weather symbol data and support for seamless navigation
Functional requirements	Implementation of portrayal forms for Point, Curve, and Surface; use of ISO 8211 format, etc.
Non-functional requirements	Real-time capability, interoperability
Data Model (data structure)	Logical data structure for meteorological information described in XML schema format.

Figure 35: Weather Overlay Product Specification

The S-412 includes the following key components: it defines and represents objects and attributes for meteorological messages, meteorological systems, weather conditions, and more. The data formats used include GML (Geographic Markup Language) 3.2.1 and HDF5 (Hierarchical Data Format 5). There are plans to add future weather condition features, and there is a proposal to separate the product specification into S-412 (Weather and Wave Hazards), S-4xx (Weather and Wave Conditions), and S-4xx (Weather and Wave Observations).

Main	Specifies what is needed to build a complete product • Feature Types • Geometry • Data formats and file size • Metadata

Feature Catalogue	• Features • Attributes • Enumerations • Bindings • Point, Curve or Surface - Combine features, attributes, and enumerations in XML format - As of February 2017, version 2 of the encoding guide was completed, defining 37 objects and 135 attributes (representative objects include pressure, wind speed and direction, precipitation, sea surface temperature, and significant wave height) - Resolution of warning messages and other modeling issues is needed
Portrayal Catalogue	•Symbols, Line Styles and Area Fills •Rule for how the feature attribute combination must be portrayed
Data Classification and Encoding Guide	•Contains the guidance for how the data should be encoded by the data producer •Useful as a template for building the feature catalogue
Exchange Format	•Data format that is used for data exchange Exchange Format •ISO 8211 – normally used for ECDIS

Figure 36: S-412 Weather Overlay Product Specification components

The S-412 product specification outlines the content, structure, and metadata necessary to create fully compatible S-41X data sets that are compatible with future electronic navigation systems, including ECDIS, and their overlays. The S-41X is being developed within the framework specifications defined by the International Hydrographic Organization (IHO) S-100 Universal Hydrographic Data Model and the International Organization for Standardization (ISO) 19100 series standards. These product specifications are primarily intended for encoding maritime weather and sea state analyses and forecasts for situational awareness, planning purposes, and risk mitigation.

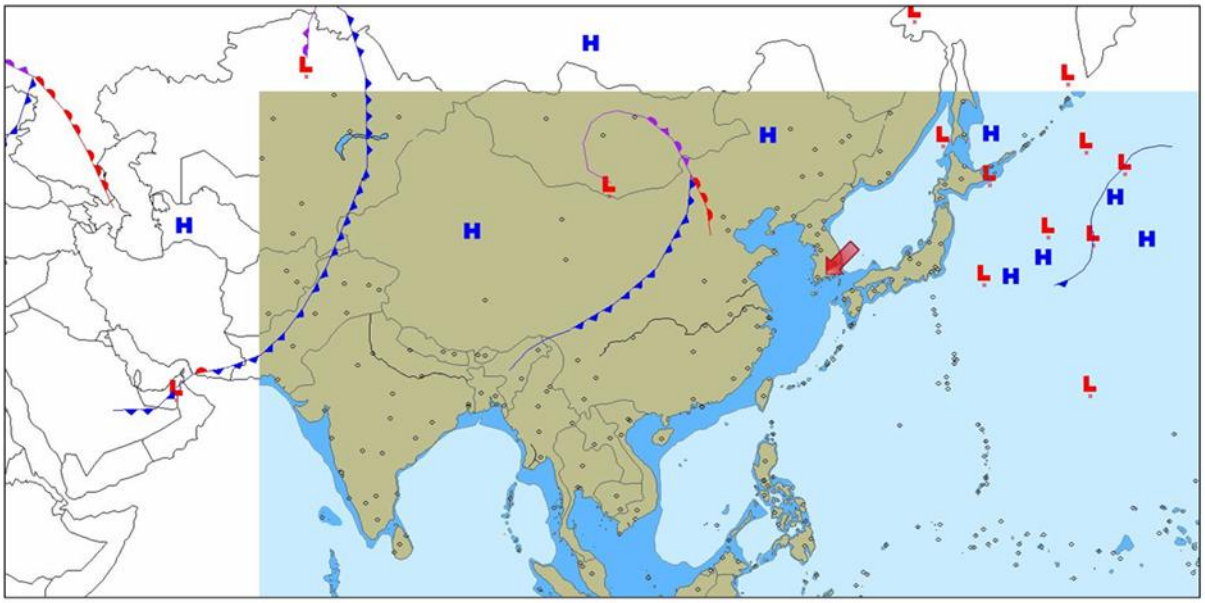


Figure 37: Examples of S-412 symbols

Additionally, as the S-412 is a standard for visualizing weather information within ECDIS, each piece of information has its own symbol. These symbols are categorized as Point, Curve, and Surface, and they are implemented in the ENC layer. Currently, 13 point symbols and 30 line symbols have been reviewed and are under testing, while area symbols and graphic files are currently in development.

S-413 (Marine Weather Conditions)

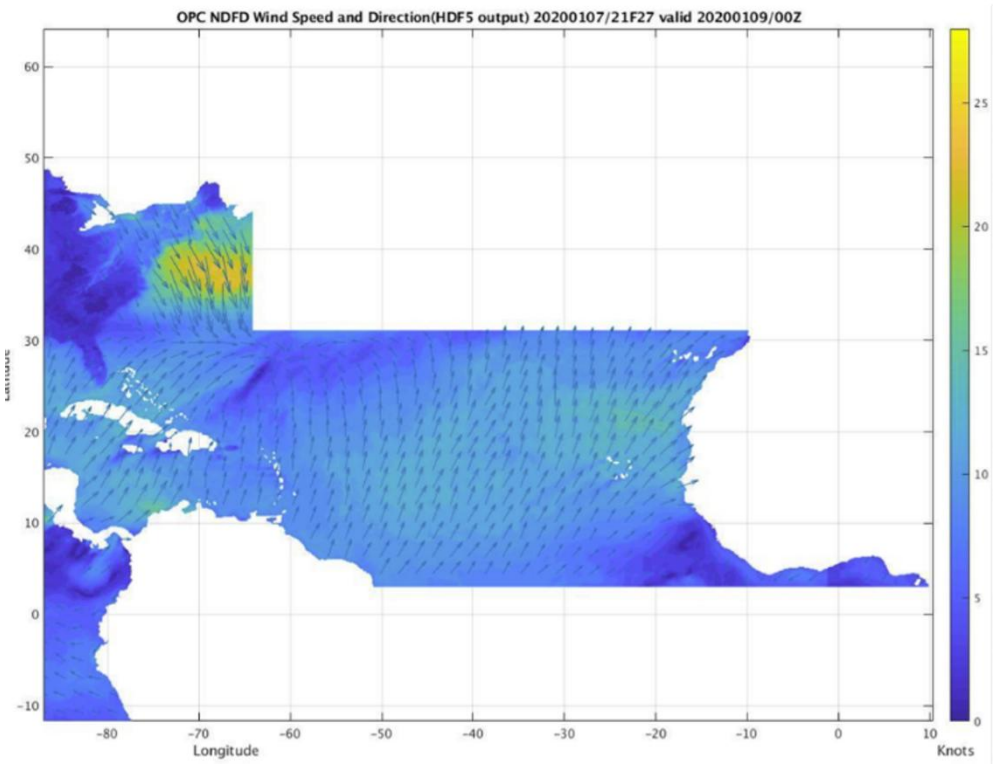


Figure 38: HDF5-wind speeds, dir (from NDFD)

S-413 (Marine Weather Conditions) is a product specification that covers comprehensive marine weather conditions. Like S-412, S-413 is part of the International Hydrographic Organization's (IHO) S-100 family of standards. S-413 focuses on providing more detailed and longer-term information about marine weather conditions.

- As for the data format, it uses the Hierarchical Data Format 5 (HDF5) format when dealing with forecast data. This format allows you to efficiently store and manage large amounts of complex data.
- When dealing with forecast features, we use the Geographic Markup Language (GML) format. This format is ideal for representing data that will be posted to the Electronic Chart Display System (ECDIS).

S-413 provides a broader range of weather condition information than S-412. This can include air temperature, barometric pressure, humidity, precipitation, cloud cover, sea surface temperature, and more. Whereas the S-412 focuses on short-term forecasts up to 48 hours, the S-413 covers medium- to long-term weather conditions beyond that. It can typically provide forecast information for 7 to 14 days. S-413 can provide information in the form of gridded data, which is useful for visualizing changes in weather conditions over large areas of water. This data can be utilized for a variety of purposes, including long-term voyage planning, marine work scheduling, and marine environmental monitoring.

S-414 (Marine Weather Observations)

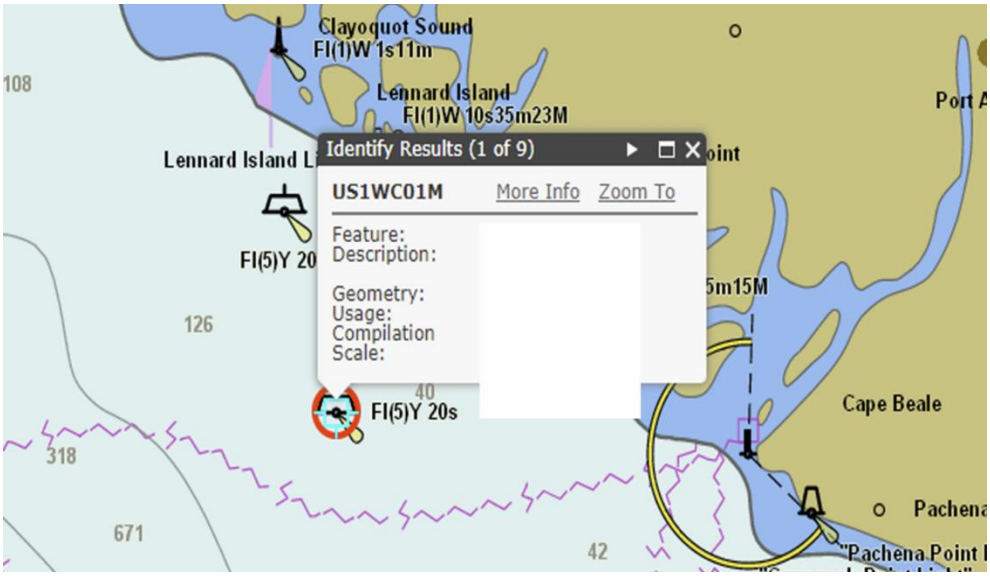


Figure 39: Example of S-414 ECDIS Representation Method

S-414 (Marine Weather Observations) is another important component of the International Hydrographic Organization's (IHO) S-100 family of standards. It specializes in covering meteorological and wave observation data collected by in-situ and remotely sensed observations. S-414 data is stored in GML 3.2.1 (Geographic Markup Language) format. This format is an XML-based representation of geographic information and is widely used for the exchange and storage of spatial data. S-414 collects data from two main observational sources.

- in situ observational sources: These include data collected from measurement equipment installed directly at sea, such as buoys, ships, and oceanographic stations. They provide accurate weather and ocean conditions at a specific location.
- remote observational sources: Includes data collected from remote measurement equipment such as satellites, aircraft, and radar. They provide comprehensive observations of weather and ocean conditions over large areas.

The S-414 observes and records a variety of marine weather elements. These can include wind speed, wind direction, barometric pressure, air temperature, humidity, wave height, wave direction, wave period, current speed and direction, water temperature, and more. S-414 primarily deals with observational data collected in real-time or quasi-real-time. This is important to provide an accurate picture of current marine weather conditions.

4.10 S-124/S-125 Sea Trial

S-124/S-125 Service Overview

Service types	Concepts	Service Operation	Test Summary
S-124 Service	- When a user requests the service, it responds with anomaly messages (S-124 dataset) related to the waypoints adjacent to the route.	- Anomaly messages responded to by the S-124 service are displayed as Warning symbols on waypoints in the electronic nautical charts. -The message remains for a period of time and is cleared when the waymark facility is restored. - If the facility is delayed, it switches to the waypoint data responded to by the S-125 service and is displayed on the electronic nautical chart.	- The S-124 service ensures that the S-124 dataset can be sent to ECDIS as requested by the user. - ECDIS checks for updates to the S-124 service when new datasets are issued or old ones are canceled.
S-125 Service	- When a user requests the service, it responds with waypoint data (S-125 datasets) related to the status of waypoints adjacent to the route.	- The data returned by the S-125 service is displayed as waypoint status on the electronic nautical chart. - If anomaly messages responded to in the S-124 dataset are retained and there is a delay in facility restoration, they are switched to the S-125 dataset and displayed on the nautical chart.	- The S-125 service ensures that the S-125 dataset can be sent to ECDIS as requested by the user. - Ensure S-124 datasets are converted to S-125 datasets

Figure 40: S-124/S-125 Service Concepts and Testing Summary

S-124/S-125 Service Scenario

Based on the proposal from the Singapore MPA, we prepared for the sea trial project for the AtoN (Aids to Navigation) information service and summarized the verification results of the AtoN information service. When

a user on a ship in Singapore waters requests S-124 or S-125 services using ECDIS (Electronic Chart Display and Information System) equipment through a 4G/5G network environment, the information management system installed in Korea processes the request. The information management system receives the user's request, generates the S-124 or S-125 dataset, and sends it in response. The user can view the updated AtoN symbols on the ECDIS screen with the received dataset. Additionally, the information management system installed in Korea is used to create S-124 and S-125 datasets, providing real-time AtoN information to ships in Singapore waters.

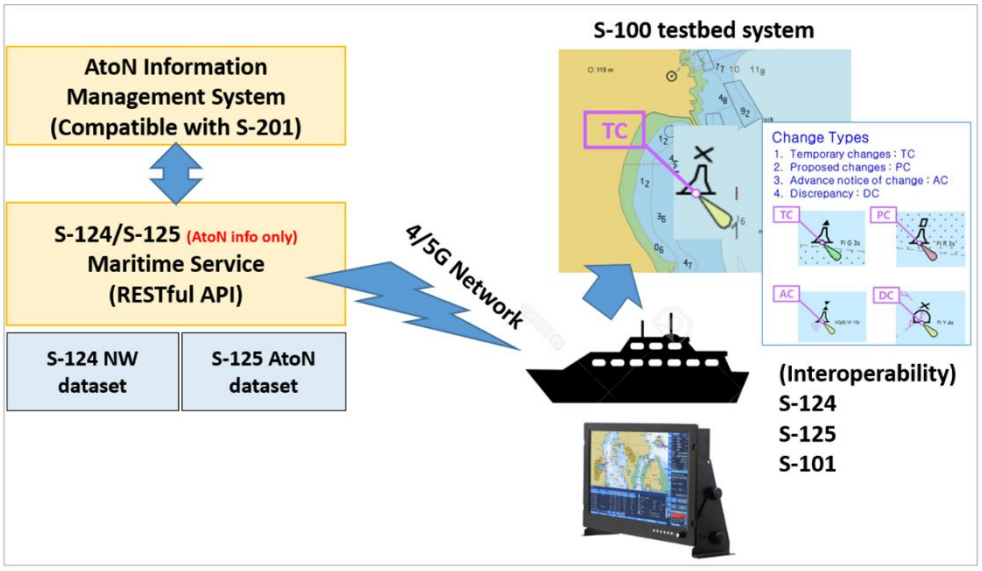


Figure 41: S-124/S-125 Service

S-124/S-125 Sea Trial Overview

The S-124 / S-125 Sea Trial tests were conducted on April 19-20, 2023, including equipment installation, service communication, and pre-test activities. The real sea trial was based on a pre-prepared and agreed scenario. Test plans and result reports were prepared for this trial, and this document is based on those references. It includes the sea trial route, test items, summary, environment, and detailed scenarios. The test objectives are as follows:

- Verify the response to user requests for S-124 and S-125 services.
- Confirm the update of received information on the ship's navigation system (ECDIS) during operation.
- Check the data transmission process between different services during the service life cycle.

S-124/S-125 Sea Trial Route

The real sea trial is conducted in Singapore waters, starting from Marina South Pier and passing through Buran Channel and Jong Fairway, covering a distance of 19.3 km. The route image and waypoints are as follows.

Route Image			
			
Route waypoints			
1. 1.271, 103.864	2. 1.273, 103.868	3. 1.269, 103.871	4. 1.265, 103.872
5. 1.26, 103.868	6. 1.252, 103.857	7. 1.248, 103.851	8. 1.243, 103.846
9. 1.24, 103.843	10. 1.238, 103.841	11. 1.237, 103.839	12. 1.235, 103.835
13. 1.235, 103.83	14. 1.238, 103.826	15. 1.242, 103.822	16. 1.245, 103.818
17. 1.248, 103.815	18. 1.25, 103.811	19. 1.253, 103.808	20. 1.255, 103.805
21. 1.256, 103.804	22. 1.256, 103.803	23. 1.254, 103.798	24. 1.25, 103.792
25. 1.241, 103.783	26. 1.234, 103.78	27. 1.23, 103.781	28. 1.228, 103.782
29. 1.226, 103.784	30. 1.222, 103.788	31. 1.217, 103.793	32. 1.213, 103.797
33. 1.208, 103.8	34. 1.207, 103.802	35. 1.204, 103.805	

Figure 42: S-124/S-125 Service Test Plan – Sea Trial Route

S-124/S-125 Sea Trial Overview

- Environment setup: A ship in Singapore waters equipped with a 4G/5G network.
- Service request: The user requests the service through ECDIS equipment on the ship.
- Response: The service installed in Korea responds with S-124/S-125 datasets.
- Result verification: The user confirms the update of AtoN symbols on the ECDIS screen based on the service data received.

This experiment is a sea trial of S-124 (Maritime Safety Information) and S-125 (AtoN Update Information) services in Singapore, conducted on April 19-20, 2023. During the preparation stage, ship equipment installation and pre-tests for service communication and operation were carried out. The test environment consisted of a

land server, a laptop, and ECDIS (Electronic Chart Display and Information System), using the test ship named PANDUAN. The actual sea trial was conducted on a 10.4 nautical mile route from Marina South Pier, passing through Buran Channel and Jong Fairway. The test consisted of four main items: requesting and receiving S-124 datasets before departure, requesting and receiving S-125 datasets before departure, updating S-124 during operation, and transitioning from S-124 to S-125 during operation.

S-124/S-125 Sea Trial Demo

a) Pre-departure S-124 dataset request and reception test:

- Receiving S-124 datasets within the route+buffer
- Not receiving unrelated S-124 datasets
- Receiving S-124 datasets that intersect with the visibility distance and route

b) Pre-departure S-125 dataset request and reception test

- Receiving S-125 datasets within the route+buffer
- Not receiving unrelated S-125 datasets

c) S-124 update test during operation

- Receiving new S-124 datasets during operation
- Receiving cancellation data for S-124 during operation

d) Transition test from S-124 to S-125 during operation

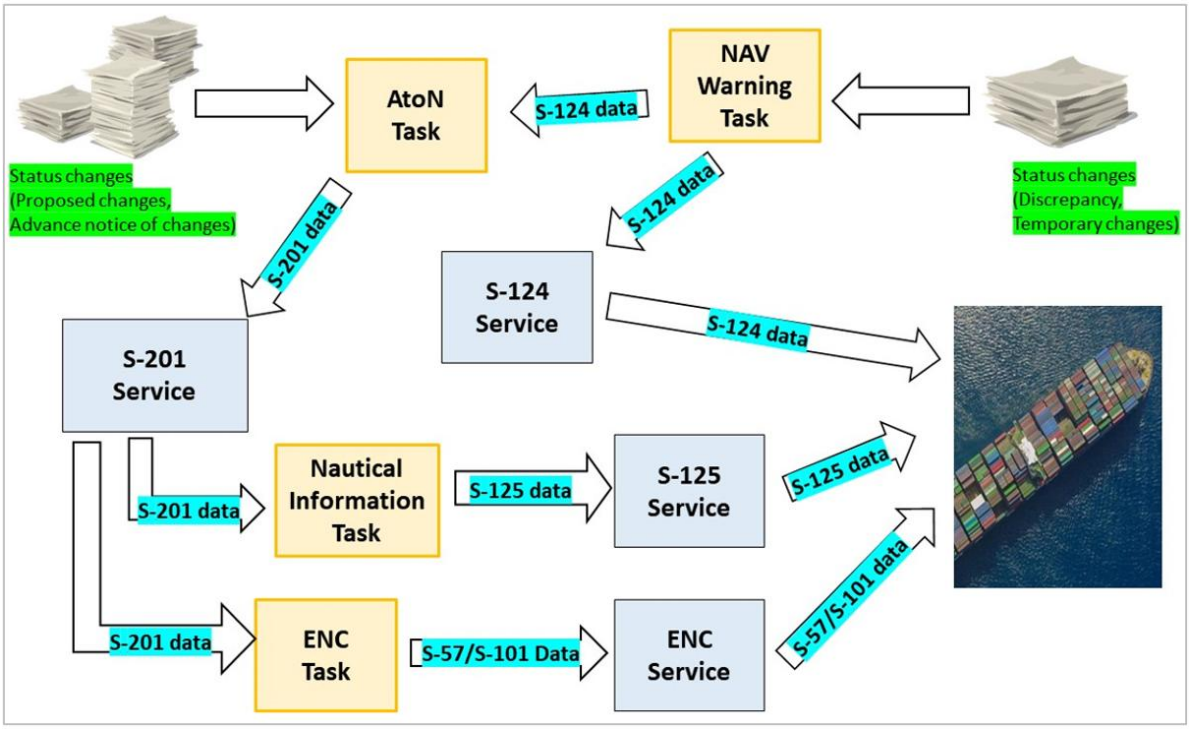


Figure 43: Data flow of S-201/S-125/S-124

The S-124 navigational warning data model and service concept, as well as the S-125 AtoN data model and service concept, were defined. We developed the capability to automatically generate S-124 data through the information management system that manages domestic AtoN based on major data changes classified as navigational warnings and notices. It was confirmed that S-124 data is generated as the coordinates, characteristics,

and visibility distances of each AtoN change. For this Singapore sea trial, we created sample data for the trial by incorporating S-122 MPA AtoN data.

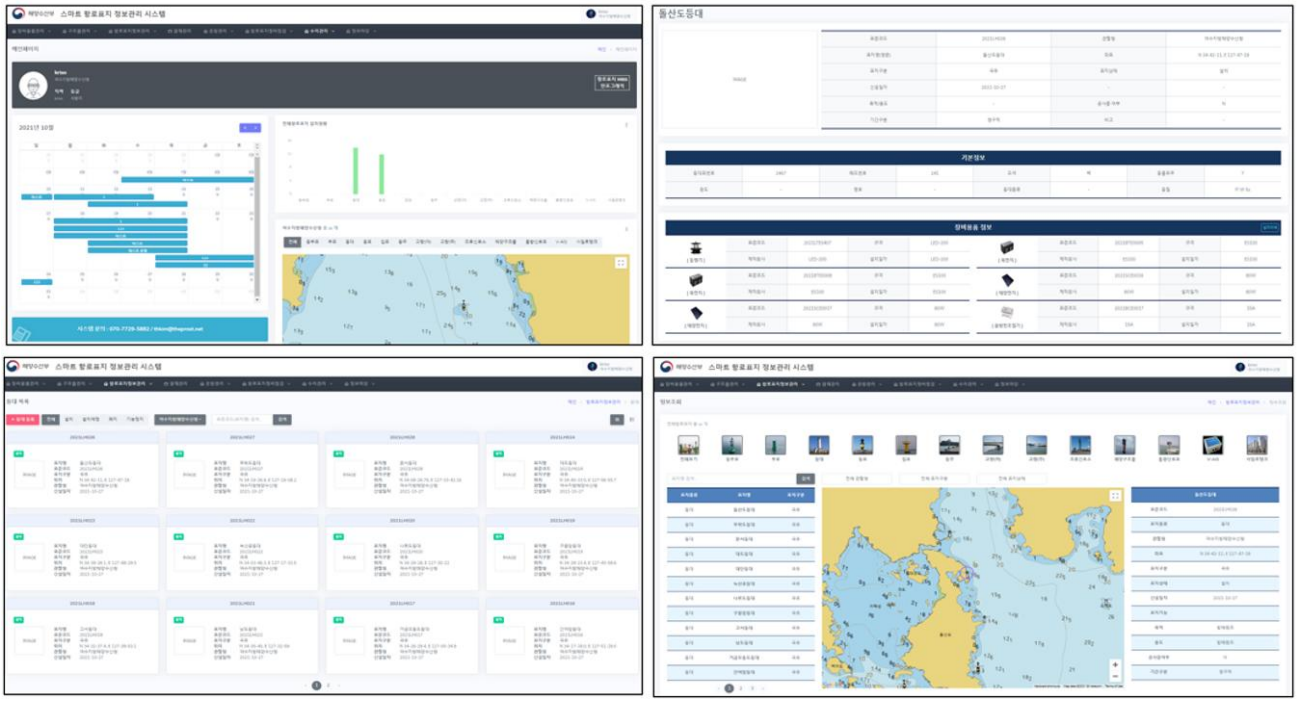


Figure 44: ROK-Aton Information Management System

To prepare for the Sea Trial Demo, we defined pre-scenarios for generating S-124 data for each case using the information management system and verifying the data displayed in the ENC for each S-125 type. The AtoN information service verification scenario involves the first process of registering, modifying, and deleting individual AtoN data applying the MRN issuance system in the domestic AtoN management system, the information management system. The registered, modified, and deleted data in the information management system are loaded into the AtoN Database, and the S-124 and S-125 data are produced through the Mapping/Convert process. Each generated data can be viewed in gml format. Finally, in the user system, the S-100 ECDIS, we monitored and checked the process of sending and receiving data as the ship moved along the predefined sea trial route.

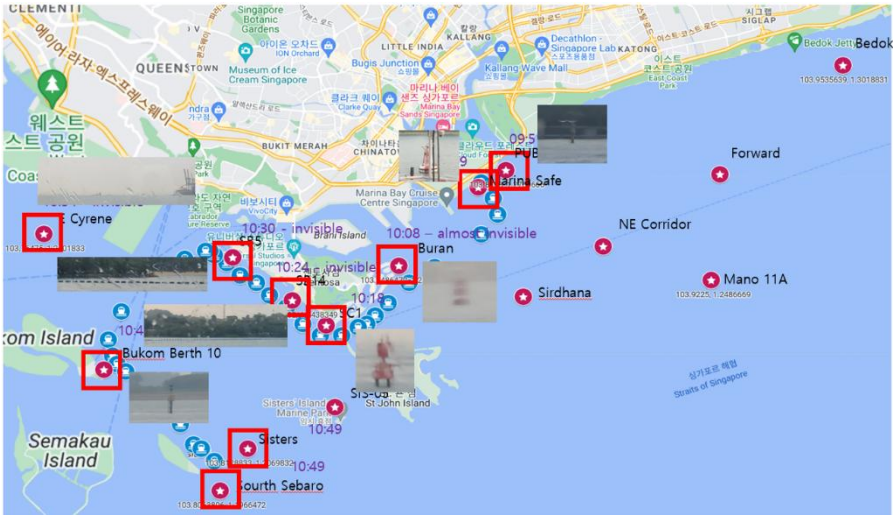


Figure 45: Targeting Atons

S-124/S-125 Sea Trial Test Results

As a result of the experiment, all test cases were successfully performed. The S-124 service accurately transmitted datasets within the route + buffer to ECDIS and did not transmit unrelated datasets. It also correctly received datasets for visibility distance changes and processed new dataset reception and cancellation data during operation. The S-125 service also accurately transmitted datasets within the route + buffer and did not transmit unrelated datasets. The transition from S-124 to S-125 was also successfully performed. The ECDIS screen accurately updated AtoN symbols based on the received datasets, including displaying and removing warning symbols and transitioning to S-125 data.

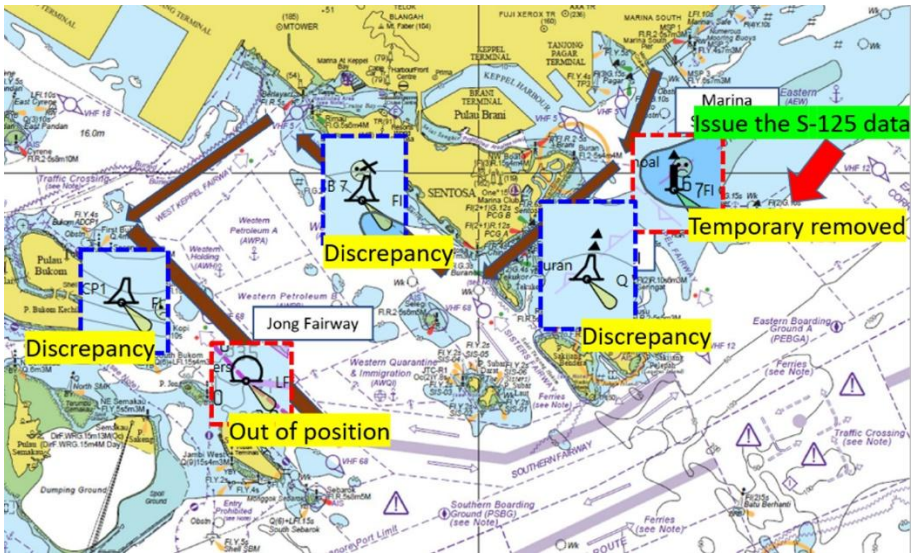


Figure 46: Transit from S-124 to S-125

Test success rate:

- All eight test cases were successfully performed, which represents a 100% success rate.

S-124 service validation:

- The correct S-124 datasets within the route + buffer were sent to ECDIS.
- S-124 datasets not related to the route were not sent, avoiding unnecessary information.
- Receipt of S-124 datasets following a change in light-distance was done correctly.
- Receipt of new S-124 datasets and processing of cancellation data during the flight was performed correctly.

S-125 Service validation:

- S-125 datasets within the route + buffer were correctly sent to ECDIS.
- S-125 datasets not related to the route were not sent.

Service transition verification:

- The transition from S-124 to S-125 was successful, which means that the change in information delivery in the event of a delay in the restoration of a waymarking facility is seamless.

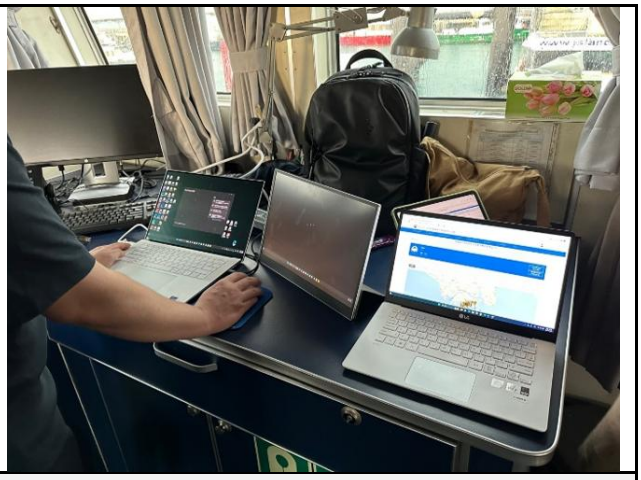
ECDIS display validation:

- The waymarking symbols on the ECDIS screen were updated correctly according to the received S-124 and S-125 datasets.
- Warning symbols were displayed, removed, and switched to S-125 data correctly.

Real-time update performance:

- The S-124 update test during the voyage confirmed that new information was delivered and displayed to the ship in real time.

Sea Trial Vessel



Sea Trial Process

Figure 47: Test Vessel and Process

Through this experiment, it was confirmed that the S-124 and S-125 services work effectively in the actual maritime environment. Additionally, it was verified that the digitalization and real-time provision of maritime safety information are feasible. This is expected to greatly contribute to improving maritime safety and efficient marine information management in the future.

4.11 Roadmap for S-100 Product Specifications

The S-100 timeline is maintained by the IHO Secretariat as a version-controlled Gantt Diagram and is updated and reported annually to the IHO Council.

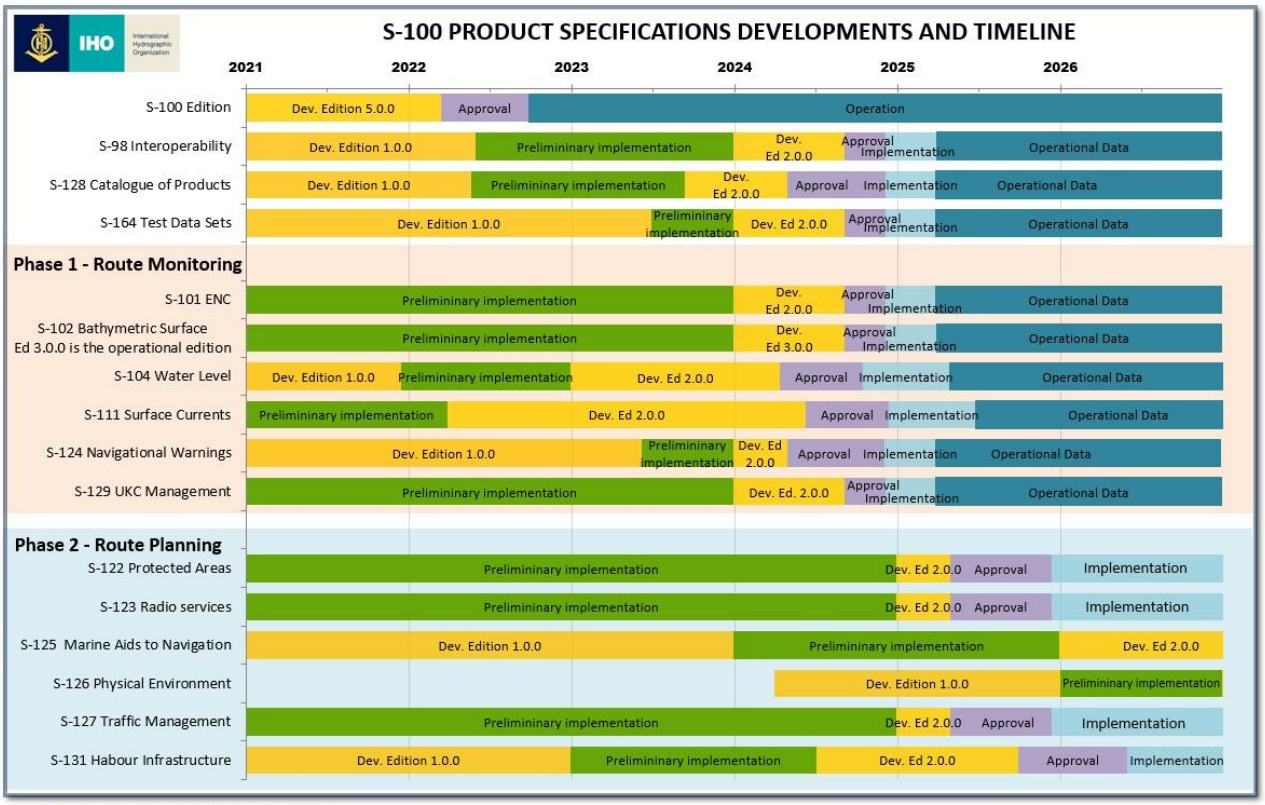


Figure 48: This S-100 timeline is updated: 9 July, 2023

4.12 Data Maintenance of S-100 based ECDIS

For Data Maintenance of ECDIS based on the S-100 data model, particularly for the S-101 ENC Product Specification, procedures similar to the IHO Transfer Standard for Digital Hydrographic Data (S-57) will be used, incorporating encryption and the Data Protection Scheme. Data maintenance will follow the S-100 Security Scheme as outlined in Part 15 of the IHO S-100 document, available at the IHO Publications[41]

The IHO Data Protection Scheme defines security mechanisms (PKI Public Key Infrastructure) and operational procedures for Data Servers (data providers) and Data Clients (data consumers). More details are available on the IHO website. The main goals of the data protection scheme are:

1. **Piracy Protection:** Preventing unauthorized data use by encrypting ENC information.
2. **Selective Access:** Restricting access to ENC data to licensed cells only.
3. **Authentication:** Ensuring the ENC data originates from authorized sources.

The S-100 Scheme (currently in testing) is designed for all S-100-based products (e.g., S-101, S-102). For more information, visit: IHO Data Protection.

[41] International Hydrographic Organization. (2024b).

In the future, satellite and shore-based VDES infrastructure will complement existing update procedures (e.g., email attachments via satellite or mobile data communication such as LTE, 4G, 5G). These technologies will enable direct communication between ECDIS and secure web-based onshore infrastructures, as described in the S-100 document, Part 15, Chapter 8.

For route exchange between ships and between ships and land-based infrastructures (e.g., fleet operation centers, vessel traffic services), the IEC 63173-1 and -2 standards have already been developed. IEC 63173-1:2021 defines an S-100-compliant product specification for route plans (S-421), including the required content, structure, metadata, and portrayal for S-100-based applications. Route transfer has been made mandatory by MSC 108. The revision of MSC.530(106) (Rev.1) will address operational aspects of route transmission via IEC 63173, though details on how routes are processed and additional operational functions are still to be defined and are not part of the current IEC 61174 or IEC 63173 standards.

4.13 “Dual Fuel” ECDIS

“Dual Fuel” is the term which describes that an ECDIS complies with S-57 and S-100 specifications. Such ECDIS can work with S-57 compliant ENCs as well with S-100 compliant ENCs and products. A Dual Fuel ECDIS is type approved as S-57 and as S-100 ECDIS.

Dual Fuel does not describe the process at official ENC providers to produce S-57 and S-100 ENCs. There is a Dual Fuel Concept description in IHO document[42]. The document describes the concept and related HO and data manufacturer’s/HO’s relevant procedures, impacts etc. around the concept. While the mentioned document[43] mainly deals with the data production and its handling by the different stakeholders from IHO perspective in the following paragraphs the focus is more put on the functional approach and the consequences for the administration, type approval authorities (Notified Bodies), ECDIS manufacturers and ship owners.

Necessity for Dual Fuel

It is widely discussed whether Dual Fuel is necessary at all. Currently there is no world-wide coverage of S-100 ENCs available. That means that it is not possible to directly switch over from S-57 to S-100 at a certain point of time₀ when not waiting until world-wide coverage of S-100 ENCs is available. IMO is of the opinion that switching over partly to S-100 data - where available - will provide several advantages for the navigators that the switching over shall not wait until world-wide coverage by national HOs is provided because this may last another 10 to 15 years or more.

Besides the resources to change from S-57 to S-100 it is as well a financial issue and challenging for smaller and development countries to provide complete coverage with data in S-100 format. In addition, there are thousands of ships in service which are not able to switch over from S-57 to S-100 data at a certain point of time otherwise all ships have to have two ECDIS systems on board, one for S-57 data to be used until day x and other equipment compliant to S-100 to be used from day x onwards. That leads into the situation that during an interim phase ECDIS installed on board have to be able to read in and process S-57 ENC data as well as S-100 ENC data in any combination of the cells the ENCs are divided in and data is provided.

IMO requires in MSC.530(106) Dual Fuel starting at 1.1.2029. Start for Dual Fuel is permitted on or after 1.1.2026. The end of the interims period for Dual Fuel ECDIS is currently undefined and needs a new or revised MSC resolution. IHO has offered to provide data on the market penetration of dual fuel ECDIS.

Interoperability within “Dual Fuel”

[42] INTERNATIONAL HYDROGRAPHIC ORGANIZATION (2020 – 2030)
[43] INTERNATIONAL HYDROGRAPHIC ORGANIZATION (2020 – 2030).

For faulty free performance of a Dual-Fuel ECDIS equipment the Dual-Fuel ECDIS has to be able to identify the incoming data whether it is S-57 or S-100 data format and to store them accordingly. So, an interface for both formats have to be available.

The ENC data is divided into so named “cells” for further processing of the data, which means for displaying, used for route planning etc. Presented depth areas are to be displayed continuously at the borderline of those cells. The borderlines of those cells are not allowed to be recognized and be identified in the operation of ECDIS. And that does not only apply to the presentation this applies as well to all provided ECDIS functionality. And the borderlines between cells are not sharp lines. Cells may overlap. One cell may provide full S-100 data and other cells may be limited to S-57 data. Each presentation and use of data for any monitoring or other function of those neighbouring cells have to work as there are no cells with different S-xxx data content.

List of mainly affected functions:

- Route planning
- Route monitoring
- Monitoring functions, no double alerting in case of cell overlapping at XTD, depth contours, spot soundings etc.

4.14 Production of S-101 and S-57 data

The preferred option for Hydrographic Offices (HOs) would be to produce their ENCs from a database driven production system. The information provided by ENC production systems software companies shows that some of the provided production tools will include support for parallel ENC production (S-57 and S-101) when using a database driven system. However, HSSC has prepared a synoptic diagram to show other possible options for HOs in regard to parallel production of S-57 and S-101 data.

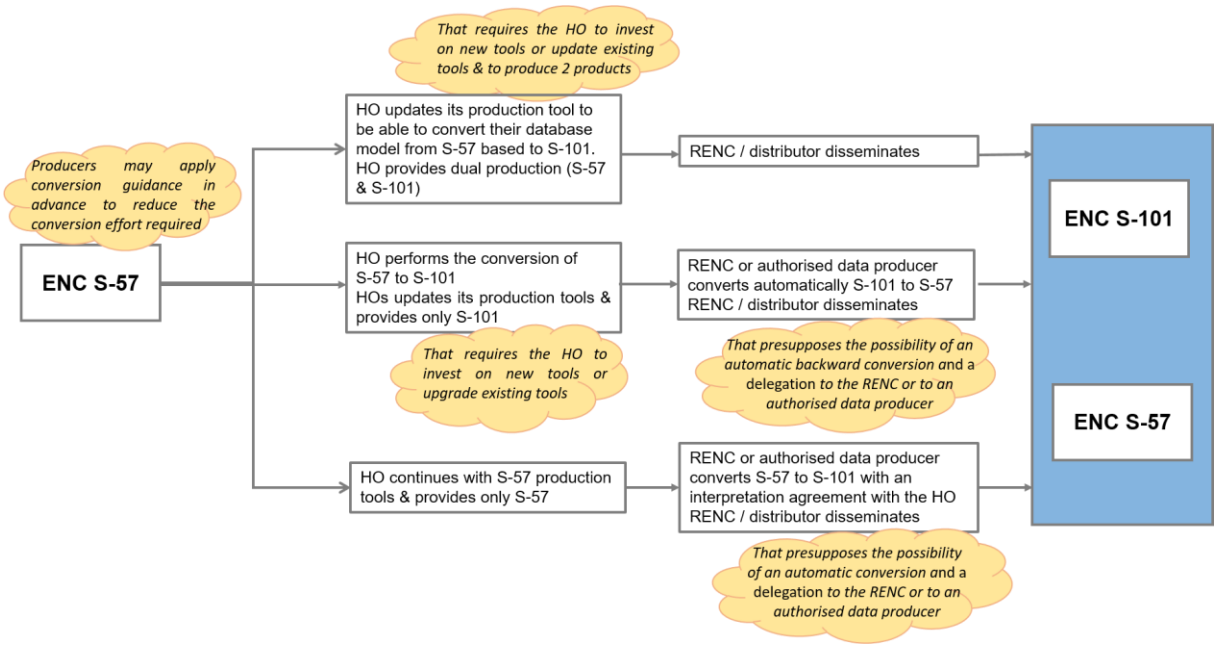


Figure 49: S-101 vs. S-57 production and maintenance phases

This figure illustrates the potential options for HOs for future production of S-101 ENCs in conjunction with S-57 maintenance/production. Production and maintenance phases are currently under discussion as concerns have been raised both from HOs as well as from industry.

It has to be kept in mind, that the ongoing S-57 ENC data availability has to be considered together with the IMO decision of the end of "Dual Fuel" and vice versa.

Outlook until 2031

In 2025 the transfer of the S-57 based ENC production to S-101 based ENC production will start in some Hydrographic Data Providers and Hydrographic Authorities. The parallel provision of S-57 and S-101 ENC must be ensured.

Current plans indicate that by Q1/2026, the Hydrographic Production Database (HPD). will be converted to an S-100 database model. The prerequisite for this is the successful completion of the preparatory work Hydrographic Data Providers and Hydrographic Authorities carried out in 2025.

In a first expansion stage, a service for S-102 data products will be established for selected sea areas from 2025 to 2026.

From 2026, the development of decentralized data storage will be discussed. The basis for this is the concept developed in 2023/2024.

In 2026 the construction of the S-12x data production will start. The prerequisite is the provision of appropriate standards by the IHO.

5 Conclusion

This State-of-the-Art deliverable has outlined the current technological landscape relevant to data exchange in high sea shipping logistics. The increasing complexity of maritime logistics, combined with the need for efficient and secure data sharing, highlights the importance of interoperable data models and standardized frameworks. Data spaces offer a promising approach to enabling trusted and scalable data exchange, but their success relies on well-defined interoperability mechanisms and common standards.

The S-100 framework, developed by the International Hydrographic Organization (IHO), stands out as a key enabler for maritime data interoperability. Its structured approach to geospatial and navigational data ensures seamless integration across diverse stakeholders and systems, facilitating improved situational awareness, optimized routing, and regulatory compliance. In combination with emerging technologies such as cloud-edge computing (compute to data) and AI-driven services, S-100 can play a crucial role in advancing digital transformation in the maritime sector.

Despite its advantages, challenges remain, including technical implementation hurdles, regulatory constraints, and cybersecurity concerns. Addressing these issues will require cross-sector collaboration, continuous refinement of standards, and investment in interoperable infrastructures. By leveraging S-100 within a logistic data space, this research aims to contribute to a more efficient, secure, and connected maritime ecosystem, setting the foundation for the future of digital maritime logistics.

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