C-17

# Spatial Data Infrastructures

# "The Marine Dimension"

## Guidance for Hydrographic Offices

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# Contents

# 1 Introduction and Background - The Current Landscape

## 1.1 Overview

The purpose of this Publication is to explain why and how Hydrographic Offices (HOs) should develop, support, and promote Marine Spatial Data Infrastructures (MSDI), the marine domain of a Spatial Data Infrastructure (SDI). The content is not exhaustive, rather it provides guidance on how to engage in MSDI through practical advice, systematic processes, useful links to reference materials, and examples of good practices.

The C-17 is primarily intended to serve as guidance to HOs at any stage of MSDI development and management. In recognition of the increasing value, demand and uses of geospatial data, this Publication could also be relevant to a wider target audience linked to the marine spatial data ecosystem beyond custodians of MSDIs; for example, other marine data providers and users, including governments, industries, citizens, and other stakeholders.

HOs are encouraged to consult this Publication to make informed decisions regarding whether they wish to take a leading role in MSDI development, seek to support an existing MSDI initiative, or work with others to develop a MSDI. Further information regarding MSDI can also be accessed through the IHO MSDI Working Group (MSDIWG) Body of Knowledge[1] (BoK). With expertise in hydrographic data management, HOs are likely best positioned to develop robust and reasonable MSDI capabilities to support the increasing demand for marine spatial data and be viewed as the competent authorities concerning the provision of authoritative hydrographic and other marine-related data under any national and/or regional MSDI.

This publication is structured into five Chapters. The first Chapter covers introductory concepts regarding geospatial data, SDI/MSDI, and data management lifecycle. The second Chapter describes the role of HOs and the importance of MSDI. The third Chapter presents a systematic approach towards MSDI development. The fourth Chapter details the Integrated Geospatial Information Framework (IGIF) from the HO and MSDI perspective. The fifth and final Chapter sets out the emerging trends in MSDI.

## 1.2 What is a SDI?

Geospatial information is information that describes objects, events, or other features at a location on the surface of the Earth. Geospatial data typically combines location information (coordinates on the Earth, for example latitude, longitude, depth/height) and attribute information (the characteristics of the object, event, or phenomena concerned) with temporal information (the time or life span at which the location and attributes exist). The location provided may be static in the short term (for example coastline, bathymetry) or dynamic (for example a moving vessel). Geospatial data typically involves large datasets gathered from different sources. Its usefulness is enhanced when it can be discovered, shared, analysed, and used in combination with other data to generate insights.

The importance of geospatial information in decision-making and addressing growing national, regional, and global issues was highlighted at the 1992 Rio Summit[2] and by a special session of the United Nations (UN) General Assembly in 1997 to assess Agenda 21[3] implementation. It was identified as a clear need, at all scales, to be able to access, integrate, and use geospatial information from different data sources in guiding decision-making. The ability to make sound decisions collectively at the local, regional, and global levels is dependent on the implementation of SDIs because they provide for compatibility across jurisdictions and promote information access and use.

Only through common conventions and technical agreements is it possible for local communities, nations, and regional decision-makers to discover, acquire, exploit, and share geospatial information vital to the

[1] https://iho.int/en/body-of-knowledge [accessed 14 October 2022].
[2] United Nations Conference on Environment and Development (UNCED): https://www.un.org/en/conferences/environment/rio1992 [accessed 14 October 2022].
[3] https://sustainabledevelopment.un.org/outcomedocuments/agenda21 [accessed 14 October 2022].

decision process. The use of common conventions and technical agreements also makes sound economic sense by limiting the cost involved in the integration of information from various data sources as well as eliminating the need for parallel and costly development of tools for discovering, exchanging, and exploiting spatial data. The greater the limitation on available resources for SDI development, the greater the incentive for achieving alignment between initiatives to build SDI[4].

SDI is usually defined as "the relevant base collection of technologies, policies, and institutional arrangements that facilitate the availability of and access to spatial data"[5]. SDIs provide a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, industry, commerce, non-profit sectors, academia, and by citizens in general. The term "infrastructure" is used to promote the concept of a reliable and supportive environment that facilitates access to geographically-related information using a minimum set of standard practices, protocols, and specifications.

A SDI must be more than a single dataset or database. It hosts geospatial data and attributes, sufficient documentation (metadata), means to discover, visualise, and evaluate the data (catalogues and web mapping), and methods to provide access to the geospatial data. Beyond this, there are additional services or software to support data applications. In order to become functional, a SDI must also include the organisational agreements needed to coordinate and administer it on a local, regional, national, or transnational scale. A SDI also provides the ideal environment to connect applications to data. It influences both data collection and application construction through minimal appropriate standards and policies.

### 1.2.1 Types of SDI

A SDI's hierarchy is usually structured from Global SDI (GSDI), Regional SDI (RSDI), National (NSDI), State SDI (SSDI), Local SDI (LSDI), and Corporate SDI (CSDI)[6] .

Depending on the scale or scope of implementation, another designation may be used. For example, Thematic SDI, Marine SDI (MSDI), Federated (Marine) SDI, Organisational (Marine) SDI, Internal MSDI, and External MSDI.

## 1.3 MSDI and the value of open marine geospatial data

A MSDI is the element of a SDI that focuses on the marine input in terms of data content, governance, standards, and technologies.

Typically, hydrographic information has been used primarily for navigation. However, it has gained wider applications in other areas, including: maritime trade, environmental protection, sustainable fishing, resource development, infrastructure construction, defence, search and rescue, and scientific research. The combination of hydrographic data with other marine spatial data for efficient analysis can also support some of the major challenges: blue economy, e-navigation, emergency planning and response, climate change and sea level rise, and marine spatial planning (MSP). The value of MSDI and open marine geospatial data and information can be assessed through Section 2.3 of this IHO C-17 document and the UN Committee of Experts on Global Geospatial Information Management (UN-GGIM) Operational Framework for Integrated Marine Geospatial Information Management-Hydro (IGIF-H), Part One and Part Two documents[7].

The broader use of marine spatial data requires that it be held and managed in a holistic approach rather than for a particular product, a limited user group, or a specific purpose. A MSDI is not a collection of hydrographic products, but an infrastructure that promotes interoperability of data at all levels. Hence, involving a broad range of stakeholders.

[4] http://gsdiassociation.org/images/publications/cookbooks/SDI_Cookbook_GSDI_2004_ver2.pdf [accessed 14 October 2022].
[5] http://gsdiassociation.org/images/publications/cookbooks/SDI_Cookbook_GSDI_2004_ver2.pdf [accessed 14 October 2022].
[6] https://www.researchgate.net/publication/242276273_Diffusion_of_Regional_Spatial_Data_Infrastructures_with_particular_reference_to_Asia_and_the_Pacific [accessed 14 October 2022].
[7] https://ggim.un.org/UNGGIM-wg8 [accessed 10 April 2023].

HOs are a major source for marine spatial information. However, in tailoring data for specific products, the extended use and user base is drastically constricted. Therefore, a shift must occur from a product-based approach to a data-centric approach, where data is placed at the centre of the organisation and specifically designed for re-use by a broader community of stakeholders. This increases the hydrographic data value and gives a more prominent role to HOs. These concepts are further developed in Chapter 2.

## 1.4 MSDI architecture

A MSDI typical architecture is flexible, and its emerging technologies are further detailed in Chapter 5 and in the IHO MSDIWG BoK.

A MSDI is frequently associated with web access and uses a client-server architecture, where several clients access a server. Data is stored on the server and requested by the client. These requests are satisfied using standardised and interoperable web services (for example Web Map Service[8] (WMS), Web Feature Service[9] (WFS) or an Application Programming Interface (API)).

A MSDI usually comprises the following physical components: a spatial database to store marine geospatial data, a map server for publishing that geospatial data on the web, a data catalogue to manage marine geospatial metadata and assure its findability, and a web portal for users to access data. To safeguard the MSDI, cybersecurity should also be considered in its architectural design.

## 1.5 DIKW (Data, Information, Knowledge, Wisdom) hierarchy

The DIKW pyramid (Figure 1-1) demonstrates the relationship between data, information, knowledge and wisdom. **Data** are facts, signals or symbols that have no meaning outside of the human mind. **Information** (or meaning) emerges through cognitive processing of data, arranged and ordered in a consistent way, the products. **Knowledge** constitutes a collection of information with its associated context, giving a specific human understanding, which is reached through services. **Wisdom** is shared understanding, and it is reached through judgement[10]. Wisdom has more value than data, but is also more difficult to transmit.


***Figure 1-1 – Data-Information-Knowledge-Wisdom pyramid***

[8] https://www.ogc.org/standards/wms [accessed 14 October 2022].
[9] https://www.ogc.org/standards/wfs [accessed 14 October 2022].
[10] https://www.researchgate.net/publication/279942958_Data_Information_Knowledge_Wisdom_DIKW_A_Semiotic_Theoretical_and_Empirical_Exploration_of_the_Hierarchy_and_its_Quality_Dimension [accessed 28 November 2022].

The principle of data being the foundation of knowledge and wisdom for data-driven decisions is well known in the hydrographic community. In essence, a broad base of data is required to extract a smaller volume of information, knowledge and wisdom. The conversion of detailed bathymetric surveys into digital maps, maritime services and decisions though a full spectrum of hydrographic geospatial data is a good example of this. Thus, knowledge transfer is only a small part of the potential of the original data, while wisdom is a very dense concentration of value and purpose. Many hydrographic datasets have the potential to convey a range of very different knowledge and wisdom applications, from safety of navigation to blue growth and sustainable development. This becomes especially true when their analysis within a knowledge theme is integrated with the necessary and complementary scientific, administrative, and legal marine geospatial information.

**Data quality** is usually associated with the difference between the measurement or the model and the reality, weighted by its purpose. Geospatial inherent data quality principles are described in ISO 19157 and structured into six categories: completeness, logical consistency, positional, temporal and thematic accuracy, and usability[11]. While describing the inherent data quality is an important component of the metadata that HO should strive to provide, making the data 'fit for purpose' to a broad range of users can be a challenge. In many cases poor quality data is better than no data and may be acceptable if the metadata includes sufficient information on its quality.

## 1.6 FAIR principles

Marine spatial data has great value if it can outreach to all of its potential users[12]. To increase data benefits and make the data accessible and transparent, it should be managed in accordance with the FAIR (Findable, Accessible, Interoperable, Re-usable) data principles[13].

FAIR principles describe features, attributes and practices that will move a digital resource closer to a state of "FAIRness", maximising the data lifespan. It fundamentally enables machine-readability which supports knowledge discovery, distribution, integration, and reuse of data by enabling data harvesting and analysis of multiple datasets and for artificial intelligence (AI) ingestion. It is noteworthy that FAIR principles should be applied not only to (meta)data, a community-endorsed word that identifies both data and metadata, but also to many other non-data assets such as software, algorithms, tools, workflows, and protocols[14]. This "fractal FAIRness"[15] encompasses all the MSDI components, which means that high-technology-based services and infrastructures, including registry cataloguing, are needed.

In order to make resources and key components findable, accessible, interoperable and reusable, it is encouraged to comply with the following guiding principles.

- **Findable**: The first step towards the FAIRification process concerns the need to describe (meta)data fully and unambiguously in order to make them discoverable for both humans and machines;
- **Accessible**: Once the (meta)data have been found, it is needed to know how they can be accessed, possibly including authentication and authorization;
- **Interoperable**: Once the (meta)data are accessed, suitable tools are required to move from non-cooperating resources to integrate or work together with minimal effort;
- **Reusable**: To achieve the reuse of (meta)data, it should be well-described so that they can be replicated and/or combined in different settings.

Three additional principles, also relevant in the marine domain, may be added to the FAIR principles. These are: traceability, licensure, and connectedness (FAIR-TLC), also referred to as FAIR+.

[11] ISO 19157:2013 - Geographic information - Data quality: https://www.iso.org/standard/32575.html.
[12] https://data.europa.eu/sites/default/files/analytical_report_15_high_value_datasets.pdf [accessed 28 November 2022].
[13] https://www.nature.com/articles/sdata201618; https://www.go-fair.org/fair-principles; https://ec.europa.eu/info/sites/default/files/turning_fair_into_reality_1.pdf [accessed 28 November 2022].
[14] https://www.nature.com/articles/s41586-022-04501-x [accessed 28 November 2022].
[15] https://zenodo.org/record/203295#.Y1_ku2mZPIU [accessed 28 November 2022].

- **Traceability:** Provenance and much richer information, well documented and clearly declared, is required to understand how, why, when and by whom the digital assets were created. This enables potential (re)users to assess the accuracy, reliability and quality of the data, and to determine whether these data meet their needs;
- **Licensure:** Data should be accompanied by a clear and accessible usage license that dictates how digital resources can be accessed, re-used, and redistributed by licensees (the end users). The conditions under which data are licensed should be transparent to both humans and machines. Even when data resources are publicly funded and seemingly publicly available, not all of them are free to use. For the purpose of referring to any legally binding instrument that grants permission to access, re-use, and redistribute resources with few or no restrictions, the term "Open License" is frequently used[16];
- **Connectedness:** The development of a "data centric" concept entails a radical shift in how information is handled and research performed. Combining extensive data collections from different repositories and new methods of data analytics, open great opportunities for making digital assets inherently more usable, integrated, connected, and linked.

It should be noted that many relevant values, correlated with the FAIR principles, are likely to have ethical, legal and social implications[17] including, but not limited to the following:

- **Interdependency** by encouraging scientific communities and private and public organisations to collaborate and reinforce one another;
- **Transparency** about provenance, data processing, management, stewardship and costing;
- **Sustainability** by avoiding unnecessary duplication and reducing costs of data acquisition/ production;
- **Efficiency** by investing strategically and making technologies/ innovations more affordable;
- **Legitimacy** of (meta)data and digital assets as a whole;
- **Reciprocity** through recognition received by the scientific communities and/ or the general public for the multiple allowed uses of data;
- **Reproducibility** by facilitating the use of technical verifiable solutions that add a plus and avoid time and monetary waste;
- **Accountability** by organising a fair and clear distribution of responsibilities along the data re-use chain;
- **Public debate facilitation** by raising public awareness and involvement in FAIR strategy implementation;
- **Non-discrimination principle** must be guaranteed. Accessibility, interoperability, and licensing must not discriminate against any person, group, or field of scientific research, in this way enhancing distribution of benefits and opportunities.

There are many data principles that would help guide HOs to provide open marine spatial and hydrographic data for a broad range of use-cases. However, it can be a challenge to apply all the principles into a HO system, workflow or programme. Some HOs have prioritised certain principles in order to enable the shift towards data-centric HO. HOs may refer to the IHO MSDIWG BoK for the latest guidance materials towards achieving FAIR+ principles.

## 1.7 The 7 Quality Management Principles

HOs, along with academic research centres and authoritative national and international Organisations, promote a marine spatial data culture that results in the behaviour, attitudes, activities and processes that

[16] https://resources.data.gov/open-licenses/#:~:text=U.S.%20Government%20Works [accessed 28 November 2022].
[17] https://faircookbook.elixir-europe.org/content/recipes/introduction/FAIRplus-values.html [accessed 28 November 2022].

deliver value through fulfilling the needs and expectations of customers and other relevant interested parties.

The term "quality" identifies the degree to which a set of inherent characteristics of an object fulfils requirements. The object can be material (for example an engine, a sheet of paper), non-material (for example conversion ratio, a project plan) or imagined (for example the future state of the Organisation); the adjective "inherent" means existing in the object, therefore it is opposed to "assigned"; requirements are needs or expectations that are stated, generally implied or obligatory[18].

The 7 Quality Management Principles (QMPs) are defined in the International Organization for Standardization (ISO) Publications and Standards (ISO 9001:2015)[19]. They can be used to certify and guide the quality of HOs processes[20], for instance, MSDI development and implementation.

The seven QMPs and a possible use of them from a MSDI perspective (Table 1-1) are as follows:

- **QMP 1 – Customer focus:** The primary focus of quality management is to meet customer requirements and to strive to exceed customer expectations.

  MSDI perspective: All possible users are MSDI customers.

  Benefits: Increasing use of data, wider community of users, enhanced reputation.

  Actions: Plot direct and indirect users; understand users' current and future needs, satisfaction and expectations; manage relations with users.

- **QMP 2 – Leadership:** Leaders at all levels establish unity of purpose and direction and create conditions in which people are engaged in achieving the organisation's quality objectives.

  MSDI perspective: MSDI needs a strategic vision, aligning policies, processes and data.

  Benefits: Better communication of MSDI levels; data-centric and not only data-driven HO; fit for purpose.

  Actions: Encourage an Organisation-wide commitment to quality and trust founded on MSDI; provide people with the required resources, training, and authority to act with accountability to release authoritative MSDI services; guide the future of the HO through an MSDI perspective.

- **QMP 3 – Engagement of people:** Competent, empowered and engaged people at all levels throughout the Organisation are essential to enhance its capability to create and deliver value.

  MSDI perspective: Focusing people enables a people centric and not only data centric MSDI.

  Benefits: Motivation; initiatives and creativity to change; shared MSDI vision.

  Actions: Empower people to develop MSDI skills; open discussion and sharing of knowledge and experience around MSDI topics; focus on the importance of individual contribution.

- **QMP 4 – Process approach:** Consistent and predictable results are achieved more effectively and efficiently when activities are understood and managed as interrelated processes that function as a coherent system.

  MSDI perspective: MSDI data management workflow is composed of several individual trusted processes.

  Benefits: Focusing key processes; predictable outcome; optimised performance.

  Actions: Manage risks of data quality management in the full MSDI spectrum; define necessary data and metadata for each data package; analyse interrelations among different processes.

- **QMP 5 – Improvement:** Successful Organisations have an ongoing focus on improvement.

  MSDI perspective: MSDI is a long-term change of view and not an objective to achieve or a web portal.

[18] ISO 9000:2015(en) Quality management systems — Fundamentals and vocabulary

[19] https://www.iso.org/publication/PUB100080.html; https://www.iso.org/standard/45481.html; https://www.iso.org/standard/62085.html (accessed 28 October 2022).

[20] https://www.iode.org/index.php?option=com_oe&task=viewDocumentRecord&docID=12661 (accessed 28 November 2022).

Benefits: Focus on route causes investigation; being more reactive and proactive; drive for innovation.

Actions: Establish measurable MSDI Key Performance Indicators (KPI); structured education; use improvement to update data services.

- **QMP 6 – Evidence-based decision making:** Decisions based on the analysis and evaluation of data and information are more likely to produce desired results.

  MSDI perspective: MSDI links data and information to policy and governance.

  Benefits: Improved decision making; data driven decisions; easier change of past decisions.

  Actions: Establish measurable MSDI KPI; curate a lessons learned repository, make data available for all decision-makers; make data and information more reliable and quality flagged.

- **QMP 7 – Relationship management:** For sustained success, an Organisation manages its relationships with interested parties, such as suppliers.

  MSDI perspective: Networking enables MSDI shared knowledge.

  Benefits: Common understanding of goals; focus more valuable data; long term stability.

  Actions: Determine relevant MSDI players; prioritise relationships; create relationships sharing data.

***Table 1-1 – 7 Quality Management Principles from MSDI perspective***

| QUALITY MANAGEMENT PRINCIPLES (QMPs) | MSDI PERSPECTIVE |
|---|---|
| QMP 1 – Customer focus | All possible users are MSDI customers |
| QMP 2 – Leadership | MSDI needs a strategic vision, aligning policies, processes and data |
| QMP 3 – Engagement of people | Focusing people enables a people centric and not only data centric MSDI |
| QMP 4 – Process approach | MSDI data management workflow is composed of several individual trusted processes |
| QMP 5 – Improvement | MSDI is a long-term change of view and not an objective to achieve or a web portal |
| QMP 6 – Evidence-based decision making | MSDI links data and information to policy and governance |
| QMP 7 – Relationship management | Networking enables MSDI shared knowledge |

## 1.8 IHO Implementation Status

MSDI is critical to increasing the use of marine data for the benefit of society, and to raise marine data value and give a more important role to HOs. Therefore, the IHO encourages all member States to develop, support and promote MSDI. The IHO Secretariat maintains a web map of national geoportals that shows the implementation status across the coastal States[21].

[21] https://iho.maps.arcgis.com/apps/webappviewer/index.html?id=6225e69a6d424b38b46dd2b59e7ca722. [accessed: 14 April 2023]

## Portugal's Open Source MSDI Case Study - Hidrografico Plus MSDI

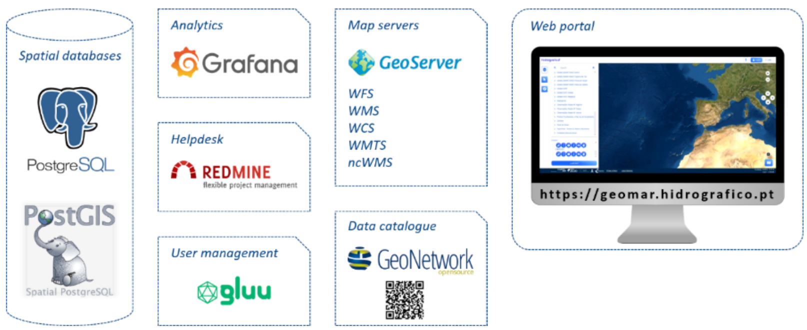
### 1. Background

The Portuguese Hydrographic Institute (IH) has long recognized the importance of SDIs and, specifically, MSDIs, maintaining since early 2000s, a CSDI (IDAMAR). However, the adaptation to the new geospatial tendencies, and the upgrade of processes, technologies and services, was beyond the internal pool of resources. Therefore, IH developed a project called "Hidrografico Plus", integrated into the program to support digital transformation in public administration (SAMA2020). The project started in 2018 and ended in 2020. It comprised several phases: mapping of processes and workflows, compilation of case studies and best practices, definition of requirements, outsourcing and contracting services, quality control and acceptance. One of the main goals of the MSDI development was that it should use open source technologies and its architecture should be interoperable, modular and scalable. Since the project ended, the Hidrografico Plus MSDI has been constantly improved under other projects or funding sources.

### 2. Architecture

Hidrografico Plus architecture is composed by:

- Spatial databases to store marine data;
- Map servers to publish geospatial data on the web;
- Data catalogue to manage marine metadata;
- Additional modules for analytics, helpdesk and user management;
- Web portal for visualizing data.




### 3. Components

#### 3.1. PostgreSQL

PostgreSQL is an open source object-relational database system that uses and extends structured query language (SQL) combined with many features that can store and scale complex data workloads. It comes with many features aimed to help developers build applications, administrators to protect data integrity and build fault-tolerant environments, and help you manage your data no matter how big or small the dataset.

#### 3.2. PostGIS

PostGIS [2] is a spatial database extender for PostgreSQL object-relational database. It adds support for geospatial objects, for instance, allowing location queries to be run in SQL.

#### 3.3. GeoServer

GeoServer[3] is an open source server for sharing geospatial data. It is designed for interoperability, allowing publishing data from any spatial source using open standards. GeoServer implements OGC (Open Geospatial Consortium) protocols such as Web Feature Service (WFS), Web Map Service (WMS), and Web Coverage Service (WCS). Additional formats and publication options are available as extensions including Web Processing Service (WPS), and Web Map Tile Service (WMTS).

##### 3.3.1. ncWMS

ncWMS[4] is a WMS for geospatial data stored in CF-compliant NetCDF files. The intention is to create a WMS that requires minimal configuration: the source data files should already contain most of the necessary metadata. ncWMS is developed and maintained by the Reading e-Science Centre at the University of Reading, UK.

#### 3.4. GeoNetwork

GeoNetwork[5] is a catalog application to **manage** geospatial data. It provides powerful metadata editing and search functions as well as an interactive web map viewer. It is currently used in several SDI initiatives across the world and it is compliant with multiple metadata formats, e.g., European INSPIRE Directive[6].

[1]https://www.postgresql.org.
[2]https://postgis.net.
[3]https://geoserver.org
[4]https://reading-escience-centre.gitbooks.io/ncwms-user-guide/content.
[5]https://geonetwork-opensource.org
[6]https://inspire.ec.europa.eu

*Figure 2-2 – Portugal open source MSDI – case study*

# 2 Role of the Hydrographic Office and MSDI

## 2.1 Traditional role of the Hydrographic Office

Traditionally, most HOs operate in terms of product and require data provided by multiple sources both internally and externally from third parties. The creation of nautical products for example requires an assessment of source information for product relevance. Having determined source information is relevant, the information, or data, is decomposed into an appropriate data model, perhaps into different features with associated attributes or metadata. Oftentimes, HOs will even use a common centralized hydrographic database to store the source information. However, the output is still a generalized product, albeit provided as data sets. The delivery of these data sets is on a cell-by-cell basis, characterized by scale or spatial extent, therefore restricted in use by their design.

Most HOs focus on supplying products to a narrow sector of navigational users. The driving force is navigational safety, often via governmental mandate, with any additional use, being an opportunistic spin-off. The opportunity to service a wider user community (outside of navigation) was overlooked in the past but now - in alignment with the IHO Strategic Goals 2 and 3[22] - needs to be seriously considered as an important HO service. The imperative to engage with this much wider community of users has grown with the demand for access to marine and maritime geospatial data from commerce, government, industry, academia and the citizens.

## 2.2 Why is MSDI important to Hydrographic Offices?

### 2.2.1 Why is a MSDI needed?

HOs are key curators and custodians of marine spatial data. These data can be collected by them or deposited by others through partnerships and agreements. Traditionally, the data are used for creating nautical or navigational products, but in doing so, HOs are not exploiting their full potential. Widening the user base is a way of increasing marine data value and possibly revenue, as data are acquired once but used many times.

Figure 2-1 illustrates this paradigm in the traditional HO workflow, from hydrographic data acquisition to product generation. A product like an Electronic Navigational Chart (ENC) which is built for a particular purpose has limited use and a narrow user base. Going backwards in the processing workflow, a bathymetric surface has a broader use than the ENC (while the ENC is used almost exclusively for navigation, the bathymetric surface can be used, for instance, for marine spatial planning (MSP) or tsunami and flood modelling). Going further backwards in the processing workflow, the original sounding data points have wider applications than the bathymetric surface, as they preserve the original data resolution without applying any gridding method.


***Figure 3-1 – Traditional Hydrographic Office workflow - data acquisition to product***

[22] IHO strategic plan 2021 - 2026
https://iho.int/uploads/user/About%20IHO/Strategic%20Plan/IHOSP2021_2026_final.pdf

To implement this paradigm, HOs must migrate from a traditional product-based approach to a data-centric approach (Figure 2-2). This potentiates marine data use, as it can be applied in broader domains and by a larger number of stakeholders. The intensification of marine data use is beneficial for HOs, as it increases marine data value and reinforces the role of HOs in ocean knowledge.


***Figure 2-2 – Data centric approach to maximise data value***

MSDIs are used by HOs to successfully provide marine spatial data to a wider user base. Currently, spatial data are critical for decision-making processes and to achieve effective solutions. Data relevant for marine spatial planning purposes are often stored in different formats and in different online locations. The combination of data, their possible interoperability and the derivation of geospatial solutions require an infrastructure which connects different storages and harmonized data formats at the minimum. Geographic Information Systems (GIS) and geospatial technologies are frequently being used to integrate and analyse data from multiple sources, and to obtain insights.

MSDIs are solutions for both HOs to manage the data and stakeholders to find, access and use the data in adequate and interoperable formats. The key aspects collected in Section 2.3 demonstrate the need for better utilization of marine data, such that more informed decision making can lead to effective solutions.

### 2.2.2 Hydrographic Offices and authoritative and non-authoritative data

HOs are usually associated as producers of authoritative data with expertise and experience in authoritative data management. There is no one definition of authoritative data, but elements of it were discussed within the UN-GGIM Authoritative Data Paper[23]. An obvious element of authoritative data is those that are legislated or regulated and have legal value because they are defined by a competent authority such as depth values in nautical charts produced by HOs. However, non-authoritative data that have gone through validation and certification can also be classified as trusted data and still be useful for integration, analysis and, ultimately, societal benefit. In such a way, a MSDI can be employed by HOs to provide third-party marine data that have undergone quality assurance processes and that can be used with some degree of confidence. This reinforces the role of HOs as the primary marine data providers and/or custodians. The policy and legal components of MSDI are further discussed in Clause 4.1.2.

## 2.3 MSDI development – demanding aspects

There is an increasing demand for marine spatial and hydrographic data from diverse users seeking MSDIs. Some examples of prominent environmental and socio-economic, operative, and administrative aspects are elaborated in this Section.

[23] UNGGIM Authoritative Data Paper: https://ggim.un.org/meetings/GGIM-committee/13th-Session/documents/

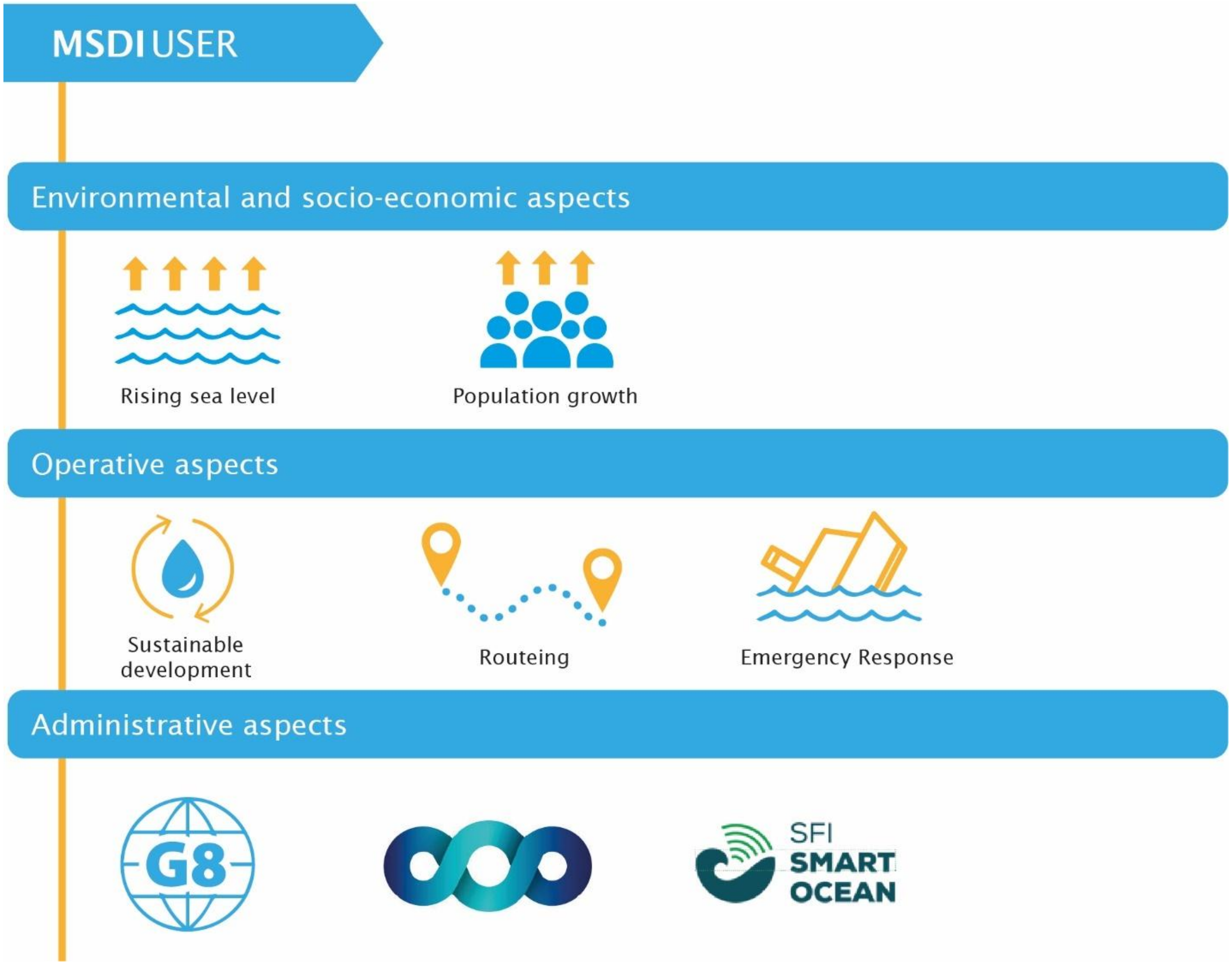



***Figure 2-3 – Aspects seeking MSDIs***

### 2.3.1 Environmental and socio-economic aspects

#### 2.3.1.1 Rising sea levels

Evidence of climate change is leading to raised concerns for the coastal zone both in terms of rising sea levels and the increasing occurrence of extreme weather patterns leading to greater coastal flooding. Sufficient spatial planning in coastal areas should consider coast erosion and effects inter alia on all infrastructure elements, human settlements, agriculture.

#### 2.3.1.2 Population growth

With over 50% of the world's population now living within 50km of the sea, the drive for additional infrastructure development in the coastal zone is growing year on year. Overall population growth is putting great pressure on energy generation, food production and other resources as well as on both the marine environment and seaborne trade. This in turn puts pressure on HOs to provide suitable support to marine spatial planning.

### 2.3.2 Operative aspects

#### 2.3.2.1 Integrated Coastal Zone Management (ICZM)[24]

Each coastal State should develop an ICZM structure reflecting its unique characteristics, including institutional arrangements, traditions, environmental and economic conditions considering that all

[24] https://documents1.worldbank.org/curated/pt/754341468767367444/pdf/multi-page.pdf

components are dynamic and will evolve over the time. It should become an integral part of economic development plans both at the national and local level requiring sufficient support of politics, legal administration, planning and other official agencies.

The ICZM spatial covers usually the area between a zone extending inland to the upper reaches of the coastal watersheds and seaward to the limit of national jurisdiction; generally, the limit of the territorial sea (up to 12 nautical miles from the relevant baseline depending on coastal State declarations and agreements). The ICZM should, if possible, use a holistic ecosystem approach which will take all components into account, especially those which are democratically agreed. The complexity of the tasks requires an iterative approach.

#### 2.3.2.2 Sustainable development

Each coastal State should bear in mind that natural resources are limited. Some resources can only be used once in a life. Therefore, the responsibility of HOs to support decision making processes in providing detailed hydrographic information is essential. The decision to develop a nation sustainably is not only a political question; it is everyone's daily life or business decision. Detailed hydrographic information may support this decision-making process.

The following example, having a navigational context, could be seen as one foundation of sustainability:

Every piece of information helpful for route planning purposes is crucial. Either hydrographic information on tidal streams or information based on regulatory framework may have effects on route planning. An improved route planning could reduce fuel consumption, greenhouse gas emissions and carbon footprint. It can also save flora and fauna by reducing underwater noise or other man-made disturbances in certain sea areas.

#### 2.3.2.3 Map once, use several times

Official nautical charts (paper or digital) content is a compilation of data provided by many sources; inside and outside the marine domain. The portrayal of the content is standardised by IHO and fit to support safe navigation. However, the content is not easily compatible with the tools and systems used by non-marine agencies. Therefore, it is of great importance to store the information in standardised IHO formats. This allows a greater interoperability between data and involved stakeholders and supports multiple use of the data.

#### 2.3.2.4 Routeing

A growth in the use of cross-polar routes as the Arctic ice sheet melts may put environmental pressure on developing new sea routes in that region as well as increasing the challenges of disaster response. These new initiatives will require interoperable spatial data.

#### 2.3.2.5 Emergency response

Independent of being natural or man-made, devastating events and emergencies around the globe require the development and provision of improved plans and a far more proactive way of responding. The response requires a multi-disciplinary approach including immediate emergency response, environmental protection and longer-term regional planning.

### 2.3.3 Administrative aspects

Administrative aspects seeking MSDIs could be from national, regional and international levels.

#### 2.3.3.1 UN-GGIM[25]

UN-GGIM is now playing a leading role in setting the agenda for the development of global geospatial information and to promote its use to address key global challenges. It provides a forum to liaise and coordinate among Member States, and between Member States and international Organizations.

[25] http://ggim.un.org

The IHO currently has observer status at UN-GGIM and has stated that in the marine space, the future role of the IHO and its Member States will be crucial to enabling the wider reach and use of HO data as part of the framework of work activities such as:

- Development of the global geodetic reference frame;
- Development of a global map for sustainable development;
- Geospatial information supporting sustainable development;
- Adoption and implementation of standards by the global geospatial information community;
- Development of a knowledge base for geospatial information;
- Identification of trends in national institutional arrangements in geospatial information management;
- Integrating geospatial statistics and other information;
- Supporting the development of legal and policy frameworks, including support in resolving critical issues related to authoritative data;
- Development of shared statement of principles on the management of geospatial Information[26];
- Determining fundamental data sets.

#### 2.3.3.2 G8 Open Data Charter[27]

In June 2013, the G8 Group of major economic nations signed the Open Data Charter. The world is witnessing the growth of a global movement facilitated by technology and social media and fuelled by information; one that contains enormous potential to create more accountable, efficient, responsive and effective Governments and businesses, and to spur economic growth.

Access to data allows individuals and Organizations to develop new insights and innovations that can improve the lives of others and help to improve the flow of information within and between countries. While Governments and businesses collect a wide range of data, they do not always share these data in ways that are easily discoverable, usable, or understandable by the public. People expect to be able to access information and services electronically when and how they want. Increasingly, this is true of Government data as well. People are keen to use open data to generate insights, ideas, and services.

Open data can increase transparency in Government and businesses. Open data also increase awareness on how countries' natural resources are used, how extractive revenues are spent, and how land is transacted and managed. All of which promotes accountability and good governance, enhances public debate, and helps to combat corruption. Transparent data on G8 development assistance are also essential for accountability.

Providing access to Government data can empower individuals, the media, civil society, and business to fuel better outcomes in public services such as health, education, public safety, environmental protection, and governance.

A set of principles will be the foundation for access to, and the release and re-use of data made available by G8 Governments. They are:

- Open data by default;
- Quality and quantity;
- Useable by all;
- Releasing data for improved governance; and
- Releasing data for innovation.

While working within national political and legal framework, implementation of these principles in accordance with the technical best practice and timeframes will need to be set out in our national action plans.

[26] http://ggim.un.org/docs/statement%20of%20shared%20guiding%20principles%20flyer.pdf
[27] https://www.gov.uk/government/publications/open-data-charter/g8-open-data-charter-and-technical-annex

#### 2.3.3.3 Blue economy

The concept of a “blue economy” came out of the 2012 Rio+20 Conference and emphasises conservation and sustainable management, based on the premise that healthy ocean ecosystems are more productive and a must for sustainable ocean-based economies.

To support a shift to this new approach:

- The UN Food and Agriculture Organization (FAO) launched the Blue Growth Initiative[28], through which it will assist countries in developing and implementing blue economy and growth agendas;
- The European Union developed its long-term strategy to support sustainable growth in the marine and maritime sectors as a whole (Figure 2-4). Seas and oceans are drivers for the European economy and have great potential for innovation and growth. It is the maritime contribution to achieving the goals of the Europe 2020 strategy for smart, sustainable and inclusive growth.

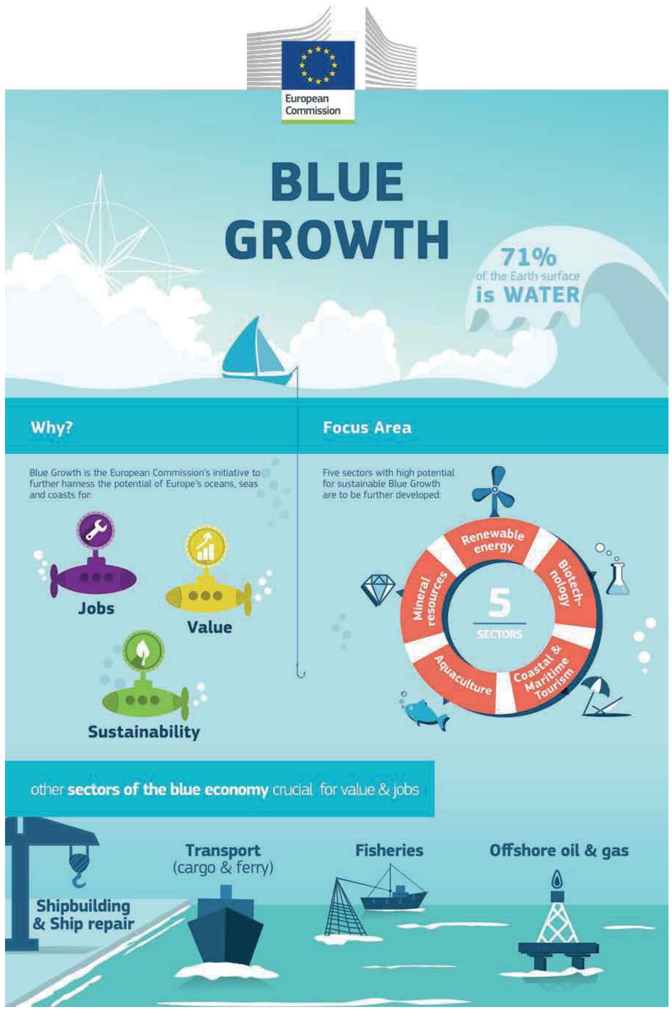



***Figure 2-4 – Blue Growth Schematic***

The blue economy represents roughly 5.4 million jobs and generates a gross added value of almost €500 billion a year. However, further growth is possible in a number of areas which are highlighted within the strategy.

The strategy consists of three components:

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[28] http://www.fao.org/zhc/detail-events/en/c/233765/

a) Develop the sectors with potential for sustainable jobs and growth;
b) Provide knowledge, legal certainty and security in the blue economy;
c) Sea basin strategies to ensure tailor-made measures and to foster cooperation between countries in the following sea basins.

#### 2.3.3.4 e-Navigation

The IMO e-Navigation initiative also has a vision beyond current navigational products. The Strategy Implementation Plan (SIP) states that *'as shipping moves into the digital world, e-Navigation is expected to provide digital information and infrastructure for the benefit of maritime safety, security and protection of the environment; reducing administrative burden; and increasing the efficiency of maritime trade and transport*'. e-Navigation relies on the IHO S-100 Framework as an enabler, but also on data not currently held by HOs. Thus, in sympathy with MSDI, e-Navigation requires interoperability of data.

The description of Maritime Services in the context of e-Navigation is the foundation of a digital information network connecting ship to ship, ship to shore, shore to ship and shore to shore by a maritime digital infrastructure.

#### 2.3.3.5 Digital twins (of the ocean and of coastal zone areas)

Certain high-level initiatives aim to develop digital twins of the ocean to support sustainable developments of nature and human interactions. Digital twins are considered to be crucial tools as they can reflect all aspects related to the oceans. However, digital twins are not limited to the water area. They are also digital replications of the coastal zones and consequently, of land areas. These two aspects are relevant for HOs. They have a core competence in providing all hydrographic data comprehensively, covering deep and shallow waters as well as coastal areas. Therefore, it is important for HOs to support all digital twin initiatives with their core expertise and to provide the data needed in a sophisticated MSDI (see Clause 5.2.1 for more details).

## 2.4 Third party data incorporation methods

Much of the data that are used by HOs to create and maintain nautical products and services are provided by third parties, for example Lighthouse Authorities or Port Authorities. The method by which these data are transferred from the third party to the HO varies depending on the type of dataset, the status and capability of the third party and how the third party chooses to make the data available. Often one or several copies of the data are maintained by the HO, for example within different products, charts or cells; with the information being updated manually each time the third party notifies the HO of a change, by the HO scanning public documents or the HO being informed of a change by the mariner.

Where there is an agreement between the HO and the third-party, change notifications can be provided in the form of a written or sometimes a verbal statement; a paper or electronic, for example PDF report; or by the transfer of a data file, for example text file containing the changes, the format having been agreed beforehand. Traditionally, these disparate methods are underpinned by some form of Source Data Receipt and Assessment (SDRA) workflow which ultimately validates and accepts the changes prior to their inclusion in the next update or edition of the nautical chart or other publication. Where the change is considered important or urgent enough then a temporary or provisional 'Notice to Mariner' may be issued.

The above approach is at best slow, inefficient, and increasingly archaic when compared to being able to utilize the new technologies that are readily available, such as the Internet and World Wide Web. In other words, these technologies allow us to create an information or data infrastructure which, for information with a geographical component, is commonly known as a SDI that facilitates the exchange of information between different parties, including from third party sources of data to HOs and ultimately from HOs to the Mariner.

Figure 2-5 below illustrates the steps from exchanging text-based information verbally, in reports or in non-editable electronic (for example PDF format (1 Star Data)); to exchanging datasets in editable but proprietary formats (2 Star Data); then editable open formats (3 Star Data) via Data or Web Services (4

Star Data); and ultimately as Linked Data (5 Star Data), the latter utilizing Internet based technologies such as Resource Description Framework (RDF).

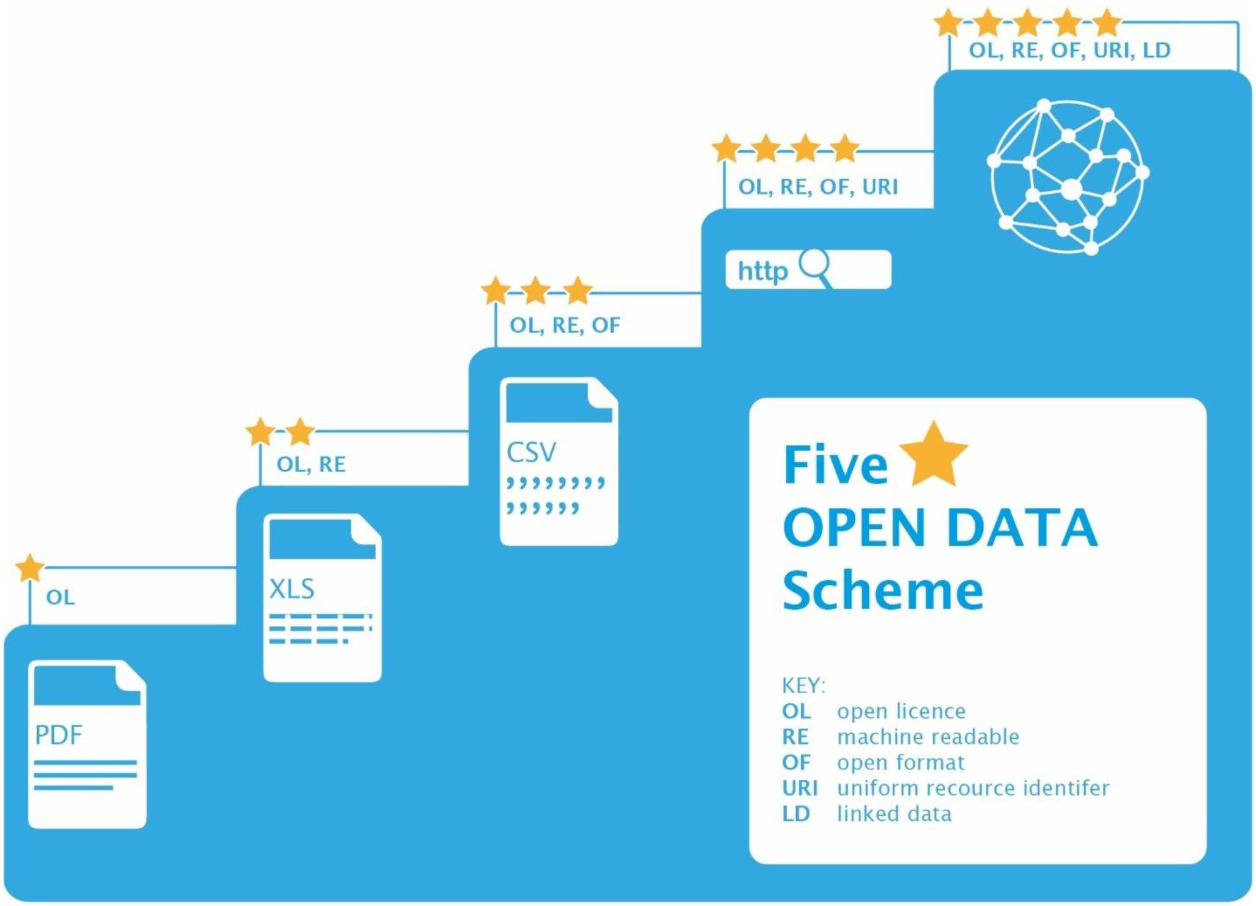


***Figure 2-5 – Five Star scheme for data exchange. Adapted and adopted from: https://5stardata.info/en***

While 4- and 5- Star data are the goal, much can be achieved by first agreeing on how to exchange datasets at the 3 Star level, such as utilizing S-100 based datasets to transfer aids to navigation or maritime boundary datasets over FTP between different authorities. Editable proprietary formats, such as Excel or ESRI Shapefile, should be avoided if possible due to their limitations; and of course some form of policy or governance framework is required to ensure licensing, warranties and other commercial and legal requirements are covered appropriately.

# 3 MSDI Maturity

This Chapter provides a step-by-step approach towards the development of MSDI and a means by which HOs can assess its MSDI and/or IGIF-MSDI maturity to plan its development roadmap and enhancements to remain relevant. The approach considers how geospatial data is managed to support these products and services but also whether and how HOs are involved in the wider geospatial data ecosystem.

The Chapter addresses MSDI 'maturity' in terms of the policies and procedures the HO has in place to:

1) Manage the geospatial data for which it is solely responsible (internal datasets);
2) Ingest data from third parties that is used in (navigational) products and services;
3) Licence its data or data products to value added providers or directly to end users;
4) Engage with national and wider SDI and regional / international MSDI initiatives.

A HO that has a high level of maturity with regard to MSDI will almost certainly have a data governance framework that contains the policies and procedures for each of the above areas. Although not strictly necessary, this framework should ideally run parallel with other governance frameworks such as for Quality, HSE, Human Resources and Finance. The latest ISO business management standards (for example ISO 9001, 14001, 27001 and 45001) encourage this integrated business management system approach.

## 3.1 Maturity criteria and assessment

1) Manage the geospatial data for which it is solely responsible (internal datasets):
   i) Data is held in product, for example Anchorage Areas within an ENC cell; the data is optimized for a specific product and can only be 'repurposed' with difficulty;
   ii) As i) but data is held outside a product in non-editable format, for example paper or reports;
   iii) As ii) with the data being held in an editable form, such as in a file store or relational database; the dataset is still product focused, for example shoalest soundings only;
   iv) The data is held in a file store or relational database and the data is maintained agnostically, for example application specific (for example navigational aspects are added at the product level, for example a navigational bathymetric surface is created or an abandoned pile becomes an obstruction (that is, the form of the feature is maintained not its function));
   v) As iv) but the data is available internally – and potentially licensed externally – as a web service to be utilized in products or value-added services.
2) Ingest data from third parties that is used in navigational products and services:
   i) HO gathers third party data from published reports etc or 'closed' applications, for example GeoCable; and maintains a copy of the data as an internal dataset or directly in product, for example ENC cell;
   ii) HO has an agreement with a third party data holder but receives this data in a non-editable format and transcribes data to an internal dataset or directly in product, for example ENC cell;
   iii) As ii) but data is transferred in non-open digital format, for example Excel or Shapefile;
   iv) As iii) but data is transferred in open digital format, for example GML;
   v) Data is made available as a web service and ingested (or better accessed) as when and required. No permanent copy of the dataset is held by the HO.
3) License its data or data products to value added providers or directly to end users;
   i) Data is used by the HO in navigational products alone, usually in encrypted form and is otherwise inaccessible to third-parties, who historically have scanned or digitized navigational products to gain access to the data;
   ii) Navigational datasets, for example Raster Charts in GeoTIFF format or ENCs in unencrypted S-57 format, are made available to third-parties under license;
   iii) Source datasets are made available in non-editable formats under license;

iv) Source datasets are made available in proprietary editable formats;
v) Source datasets are made available in open formats or as web services.

4) Engage with national and wider SDI and regional / international MSDI initiatives:
   i) The HO has no interest in MSDI and retains traditional workflows for publishing navigational products and services;
   ii) As i) but the HO understands the benefits of MSDI (and the parallel improvements in data governance) and is seeking assistance;
   iii) The HO is engaged in national SDI and/or regional or international MSDI initiatives and is working on a plan to implement data governance and MSDI;
   iv) The HO has a plan and is implementing MSDI. It is working with other HOs within the IHO and Regional Hydrographic Commission(s) (RHCs) to address boundary and other data quality issues;
   v) The HO has an established role in its country's national SDI for identified hydrographic datasets and makes these available to end users either directly or via licensed third-party Value Added Resellers (VARs), ideally but not necessarily as web services.

An IHO MSDI Maturity Assessment questionnaire was previously completed[29].

The above could be presented as a graph such as in Table 3-1 below for each of the maturity areas (based on the DAMA functional/environment matrix).

***Table 3-1 – Data Governance Framework***

| Environmental Factors | + | - | RAG |
|---|---|---|---|
| **Vision & Strategy** | **Strong recognition of the need for DG** | **No clear alignment between DG and the goals of the organisation** | |
| **Organisation & People** | **Widespread recognition that ownership of data is required** | **DG is not seen as business as usual therefore there is a lack of awareness** | |
| **Culture & Communications** | **Access to shared platforms to help communicate DG messages** | **No communications plan or ownership of DG communications** | |
| **Processes & Workflows** | **Elements of DG methodology in place in parts of the business** | **No overarching and consistent approach to DG** | |
| **Data Management & Metrics** | **Some validation of data formats** | **Insufficient focus on verification of data** | |
| **Tools & Technology** | **Distributed data sources allow user flexibility and independence** | **Complex, disjointed and unplanned infrastructure** | |

## 3.2 Step-by-Step Approach

MSDIs can operate at the Organization level (as an enterprise SDI) or at the country/state level or at the regional level across borders (for example Arctic SDI).

The following steps below provides some guidance on steps to establishing, developing and sustaining relevance of a MSDI across maturity stages:

[29] IHO MSDIWG MSDI Maturity Assessment Questionnaire: https://iho.int/uploads/user/Inter-Regional%20Coordination/MSDIWG/Body%20of%20Knowledge/DRAFT_23MAR2021MSDIMaturityAssessment_GoogleForms.pdf

### 3.2.1 Establishment

1. Prepare and define the HO policy and role for MSDI (if not done already);
2. Establish a governance structure along with any necessary national or regional initiatives or legislation;
3. Identify MSDI "champion(s)" to influence, lead and gain support for MSDI at the highest levels of leadership (this may need to be at Ministerial and/or Senior Management level) and can be linked to prevailing national, regional or global agendas;
4. Identify key HO stakeholders and their requirements;
5. Build support for engagement at Senior Management level;
6. Join the IHO MSDIWG[30] ;
7. Identify other marine spatial data providers to the MSDI:
   a. Who are they and what is their data?
   b. Who are the key people in that Organization to engage with?
   c. What support do they expect from the HO by way of data content, skills and knowledge?
   d. How do they interact with other Organizations in the MSDI?
   e. What are their data sharing and exchange protocols and mechanisms?
8. Plan engagement with stakeholders and all other data providers and work to get stakeholder support (e.g. users, influencers, enablers);
9. Promote the benefits and opportunities to be derived from MSDI to all non-HO stakeholders;
10. If the MSDI is new and the HO is the lead Organization, consider developing a "White Paper" for discussion and comment by Senior Management, decision makers and politicians across all stakeholders. The White Paper could include the benefits of MSDI for the country and be used to promote the benefits of MSDI. The IHO MSDIWG produced White Paper[31] could be referred to;
11. Gain necessary HO approvals for involvement;
12. Scope out a work plan or "road map" (including timescales);
13. Engage, respond, and communicate with all stakeholders.

### 3.2.2 Development

14. Develop the MSDI system with systems integrator and GIS experts. Typically, this involves 3 components: The sources, the MSDI database and a web portal for users' access to the data and metadata, whether as a catalogue or a visualised online chart viewer - or both;
15. Depending on data exchange protocols and mechanisms within the HO and with external stakeholders, prepare the API, web services or datasets for migration.

### 3.2.3 Sustain relevance

16. Consistently evaluate emerging trends and consider enhancements to MSDI features, functions and/or architecture;
17. Actively participate in the IHO MSDIWG and/or appropriate IHO RHCs to keep abreast on the latest trends and materials.

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[30] International Hydrographic Organization Marine Spatial Data Infrastructures Working Group: https://iho.int/en/msdiwg

[31] IHO MSDIWG White Paper – Realising the benefits of Spatial Data Infrastructures in the Hydrographic Community (https://iho.int/uploads/user/Inter-Regional%20Coordination/MSDIWG/Body%20of%20Knowledge/MSDI_white_paper-2017.pdf )

## 3.3 Evolution from MSDI Four Pillars to Nine Pathways – tips on how to do it right and better

The MSDI Four Pillars (Figure 3-1) and IGIF Nine Pathways (Figure 3-2) can synergise with or complement each other and are not mutually exclusive approaches and frameworks. Generally, the MSDI Four Pillars: People; Standards; Information and Communication Technologies (ICT); and Data can be mapped to the IGIF Nine Pathways matrix[32]. Besides Standards, Data and Innovation (for ICT) pieces of the framework, the remaining 6 IGIF pathways could be viewed as a detailed approach to the People (policy and governance) MSDI pillar. This is naturally a simplification that may miss other connections between MSDI and IGIF but is useful as a guiding concept where the Four Pillars can be taken as a HO's specific "lens" on the Nine Pathways, which encompasses a nation's All-Domain NSDI across Land, Sea, Air, Space, and Cyberspace (where applicable).

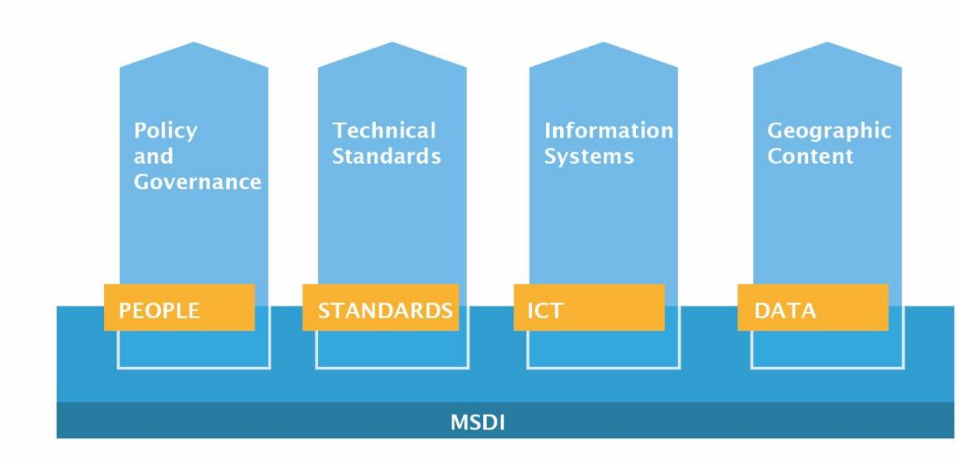


***Figure 3-1 – The MSDI Four Pillars***

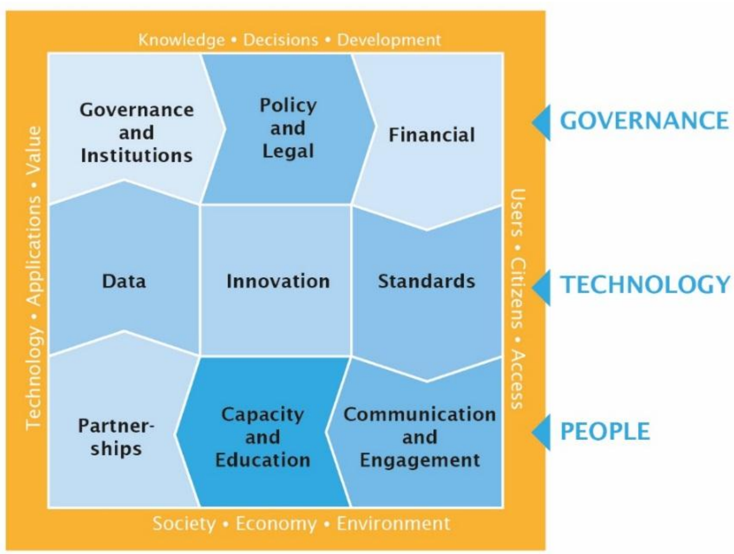


***Figure 3-2 – The UN-GGIM Integrated Geospatial Information Framework (IGIF) Nine Strategic Pathways***

[32] International Hydrographic Review (24) 2020, article on Singapore's National Marine Spatial Data Infrastructure "GeoSpace-Sea": Enabling Hydrospatial Context, provides example of how the MSDI four pillars and IGIF 9 strategic pathways can be complementary (https://ihr.iho.int/wp-content/uploads/2021/06/IHR_November2020.pdf)

The broader range of users and demands from HOs' MSDIs include interdisciplinary users within the diverse marine community, and from land to sea and sea to air. The evolution from the MSDI Four Pillars to the IGIF Nine Pathways would be beneficial in aligning HOs' efforts with the global geospatial community and enabling integration of MSDIs to an even broader marine and geospatial ecosystem and/or national, regional and global geospatial programs in order to effectively respond to the various aspects seeking MSDIs.

A good principle or vision for a HO's digital transformation efforts is to ensure an "IGIF-aligned MSDI implementation"; first and foremost a MSDI that serves marine and maritime geospatial requirements, but additionally contributing to a nation's NSDI development or implementation. For nations beginning their IGIF and MSDI transformation journeys, introducing the MSDI Four Pillars (HO specific) for a period before the full IGIF Nine Pathways (all of nation) may ease institutional acceptance and engagement longer-term.

Although there are undoubtedly many ways to encapsulate the IGIF Nine Pathways, two useful statements of intent are helpful for considering before and during an MSDI development programme. These are that an IGIF-aligned MSDI implementation should seek to "Drive Technology, not be Driven by Technology"; and it should "Make the Data Count, not just Count the Data". There are likely many other such statements that may be crafted and tailored to a nation's hydrographic vision, but these are useful starting points if not directly applicable already. The 'IGIF-MSDI Maturity Roadmap' produced under the OGC's Federated MSDI (FMSDI) project includes a Diagnostic Assessment Tool[33] for an IGIF-aligned MSDI implementation that offers robust organisational baselining.

[33] IGIF-MSDI Maturity Roadmap: https://www.ogc.org/igif-msdi-maturity-roadmap/

## Arctic SDI/ARMSDIWG Case Study

**International Hydrographic Organization (IHO)**
**Marine Spatial Data Infrastructures Working Group (MSDIWG)**
MSDI Case Study Summary Information Sheet

**Case Study**
Arctic Regional Hydrographic Commission's Arctic Regional Marine Spatial Data Infrastructures Working Group

**Case Study Type:** Other (MSDI-related Activity)

**Summary**
This case study is about the activities of the Arctic Regional Marine Spatial Data Infrastructures Working Group (ARMSDIWG) under the Arctic Regional Hydrographic Commission (ARHC).
The ARMSDIWG is the key coordinating body, under ARHC, for facilitating the access to Arctic marine geospatial data produced by the ARHC Members States and Associate Members, the International Hydrographic Organization (IHO), General Bathymetric Chart of the Oceans (GEBCO), and other networks throughout the Marine domain in order to allow broader use of hydrographic data.
The ARMSDIWG analyzes how its participating Hydrographic Offices, and the Marine domain in general, can make Arctic marine spatial data findable, accessible, interoperable and reusable, following the FAIR data principles. The ARMSDIWG accomplishes this by investigating best practices for leveraging currently available technologies, identifying applicable open geospatial standards from the IHO and the Open Geospatial Consortium (OGC), and addressing policies & governance for the participating nations to provide users discoverable, accessible, and interoperable marine geospatial data for the Arctic.
The ARMSDIWG also maintains a collaborative partnership with the Arctic Spatial Data Infrastructure cooperation (Arctic SDI), a cooperation based on a Memorandum of Understanding between the National Mapping Agencies of the eight Arctic countries, to provide both the terrestrial and marine foundations in a regional SDI. Together, Arctic SDI and the ARHC's ARMSDIWG will facilitate an infrastructure that connects users, across domains, to the spatial data valued to support research, planning and decision making in the Arctic.
Currently, the ARMSDIWG is facilitating the reuse of data that has already been made available, but with an Arctic-regional focus. The limitations/restrictions of data reside at the original producer/distributor of the data.
The ARMSDIWG facilitates marine spatial data for the broadest use. The intended users are anyone with interest in accessing or using marine spatial data in the Arctic.
Increasing ocean accessibility in the Arctic yields a growth in maritime/marine activities for the region. Marine geospatial data is a valuable asset to enable those activities to advance the applicable sectors of society (e.g., academic/scientific research, natural resource exploration, fisheries management, emergency management, marine spatial planning). Hydrographic Offices (HOs) collect and store marine geospatial data for use on Safety of Navigation products. This source, marine geospatial data (e.g., bathymetry) maintained by the HOs, when made available, can benefit these Arctic activities for the greater advancement of society.

**Sources:** https://iho.int/en/arctic-rhc
https://arctic-sdi.org/

**Submitted by:** Click here to provide name.
Click here to provide title.
Click here to provide affiliation.
Click here to provide contact information (e.g. email address).
**Date Submitted:** Click here to enter a submission date.

**Data Governance & Infrastructure Components Exemplified by Case Study:**
(Checked ☑ components apply.)

| | |
|---|---|
| ☑ Access, Data Sharing & Exchange | ☑ Policy & Organization, Strategy |
| ☐ Data Assurance | ☐ Quality Control Procedures |
| ☐ Data Quality | ☐ Standards |
| ☐ Documentation | ☐ Storage |
| ☐ Information Control Technologies | ☑ User Needs & Response |
| ☐ Interoperability | |

***Figure 3-3 – Arctic SDI/ARMSDIWG – case study***

# 4 IGIF 9 Pathways from the HO Perspective

## 4.1 Governance

*"Governance is the framework of authority and accountability that defines and controls the outputs, outcomes and benefits from projects, programmes and portfolios. Governance is the mechanism whereby organisations exert control over the deployment of work (effort) and the realisation of value." (**Association of Project Management-APM- Body of Knowledge 7th edition**)*

A useful guiding vision for Governance is balancing focus on hard Technology with that of softer aspects such as People, Partnerships, and Policies (effectively the *top* and *bottom* layers of the IGIF matrix that *sandwiches* Technology) (Figure 4-1). Although there are many other ways of encapsulating effective Governance, this concept is agnostic of Technology and more inclusive of constraints around IGIF-aligned MSDI development, either due to financial or other limitations. Driving the use of Technology to meet genuine sovereign requirements, however modest or expansive, whilst ensuring appropriate Governance, allows national HOs to participate in the global drive for digitalisation whatever their level of resourcing.

HOs are key players of marine spatial data governance. Given this governance's complexity and desired adaptability to local, national, regional and international priorities, a general definition below borrows from the work of researchers in the field (Sutherland and Nichols, 2006[34], Edwards and Evans, 2017[35]). It is proposed for practical purposes:

*Marine Spatial Data Governance consists in an effective framework of leadership, policies, laws, directives, regulations, agreements, partnerships, processes and procedures focussing on marine data to oversee and ensure the continuity of good decision-making prioritized based on scientific evidence and authoritative data in order to oversee sustainable social, economic, environmental protection and scientific human activities in marine space.*

This simplified definition must take global priorities and trends into consideration. It requires more development in this section to expand on the different aspects of data governance over marine spaces. Note that elements of governance and proposed steps to achieve it for a HO have been presented earlier in the perspective of Quality Management Principles (Clause 1.5.3) and attaining a national or regional MSDI maturity at a level that is sustainable (Chapter 3). The steps necessary to establish a MSDI presented in Chapter 3 can be mapped as actions to achieve Marine Spatial Data Governance following the UN-GGIM IGIF model for governance and institutions. These actions also articulate the strategies towards marine spatial data governance that the HO will adopt.

[34] Sutherlands, Michael and Sue Nichols.- Issues in the Governance of Marine Spaces; International Federation of Surveyors (FIG), Article of the month, September 2006

[35] Edwards, Rosemary and Alan Evans.- The challenges of marine spatial planning in the Arctic: Results from the ACCESS programme; *Ambio volume 46* (Supplement 3), December 2017; pp 486-496


***Figure 4-1 – Diagram modified from UNGGIM IGIF SP1 Governance and Institutions remapping the steps from the MSDI maturity section under the 6 IGIF Strategic path 1 actions.***

### 4.1.1 Challenges

For coastal States, establishing Marine Spatial Data Governance is an ongoing endeavour that faces many challenges. HOs are one of the many participants in this national or regional effort. They have to integrate with the wider governance structure existing in their country, regionally, and globally. Sutherland and Nichols (2006)[36] have divided known marine spaces governance issues into categories of:

[36] Sutherlands, Michael and Sue Nichols.- Issues in the Governance of Marine Spaces; International Federation of Surveyors (FIG), Article of the month, September 2006

1) Stakeholder Issues:
   - Not meeting users and stakeholders' requirements;
   - Decisions unsupported by scientific or commercial evidence;
   - Lack of consultation and inclusion;
   - Vision and Strategy is lacking where Data Governance is not clearly aligned with the goals of the organisation (Chapter 3, Table 3-1);
   - Lack in Culture and Communications where there is no communication plan or where data governance communications have no owner (Chapter 3, Table 3-1);
   - Lack in Organisation and People: Data Governance is not seen as business as usual, thus generating a lack of awareness (Chapter 3, Table 3-1).
2) Legal Issues:
   - Fragmented marine legal framework;
   - Conflicting overlapping legislations;
   - Gaps in legislation;
   - Lack of jurisdictional clarity;
   - Non-compliance.
3) Technical Issues:
   - Uncoordinated use of or lack of interoperable Standards;
   - Isolated unsustainable solutions and applications: Complex disjointed, and unplanned infrastructures (Chapter 3, Table 3-1);
   - Major technological evolution away from traditional methods;
   - Lack of consistency in processes and workflows: No overarching and consistent approach to Data Governance (Chapter 3, Table 3-1).

These marine domain issues represent challenges to overcome which can be mapped with some overlaps to the UN-GGIM IGIF Strategic Pathways (SP) as interpreted in IGIF-Hydro[37]:

- Stakeholder: Governance and Institutions (SP1), Financial (SP3), Partnerships (SP7), Capacity and Education (SP8) and Communication and Engagement (SP9);
- Legal: Governance and Institutions (SP1), Legal and Policy (SP2);
- Technical: Data (SP4), Innovation (SP5), Standards (SP6), Capacity and Education (SP8);

The guiding principles behind Marine Spatial Data Governance are shared with the IGIF Strategic Pathway 1[38]. These principles are also what a HO would strive to integrate in its MSDI solution: Facilitation, Strategic Outlook, Credibility, Participatory, Open and Transparent, Accountability, Guidance, Clarity, Project Management, Oversight, Communication and Evaluation, Legal Interoperability.

Principles of Marine Spatial Governance have been presented in the literature as part of various infrastructure research projects in marine space. These cover a range of topics such as Marine Spatial Data Infrastructures, Integrated Coastal Zone Management, Marine Cadastre and Marine Spatial Planning. All of these share common elements of governance articulating the coordination between land, coastal and marine interests where the MSDI must be accepted as a fundamental part of the solution.

What is the role of governance in a MSDI?

Marine Spatial Data Governance enables the provision of authoritative reliable data enabling a harmonised and sustainable human use of marine space through collaborative and integrating approaches. It aims at clarifying the situation in marine space, integrating the fragmented information and legal framework and providing certainty for the users while remaining adaptable to the evolution of technology and global

[37] UNGGIM, ISO, IHO, OGC.- IGIF -H, Operational framework for Integrated Marine Geospatial Information Management, Part-2 The Strategic Pathways; draft version accessed on 23 June 2022.
[38] UNGGIM.- IGIF Strategic Pathway 1, January 2022.

practices. The UN-GGIM IGIF-Hydro, for example, is such a guideline to establish global practices in the field of Integrated Geospatial Information Framework for the marine domain. The present document aims at providing similar guidance focussed on the MSDI and HOs.

Considering governance as one of the four pillars of a MSDI, the governance pillar is seen as the main organising force behind all the other pillars (Guay, 2016[39]) because it deals with the actors, the people. There is governance over the data, metadata and applications pillar, the Standards pillar, and the Hardware, software and services infrastructure pillar. Its own Governance pillar is inclusive of directives, agreements, establishing processes, ensuring that enabling laws, directives and regulations are in place and requires a national will to construct and integrate the MSDI into an adaptive and integrated digital ecosystem reaching beyond the HOs traditional marine user-base.

Need to define a governance model in marine space:

The six IGIF actions along the Governance and Institutions Arrangements Pathway consist of: 1) Forming the Leadership; 2) Establishing Accountability; 3) Defining Value; 4) Setting Direction; 5) Creating an Action Plan; and 6) Tracking Success[40]. As far as Leadership is concerned, an integration in existing national geospatial governance structure is mandatory.

The authority over data mapping human activities in marine space is divided between multiple players. A multi-disciplinary approach involving key participants is required to properly coordinate this data. As shown in Chapter 2, HOs' structures and products were originally developed and specialised for safety of navigation. When the MSDI is considered, the user-base expands to the non-navigational users for which the HO will not usually own all the necessary authoritative data. Therefore, HOs cannot do this alone and must become an integral part of the national or regional strategic approach that aims to establish sustainable marine spatial data governance. This implies coordinating their efforts with MSP and Marine Cadastre Services. Among the significant participants and governing factors to interact with we count:

- Data owners with a marine mandate to fulfil as described in regulations, directives and laws;
- IT resources ensuring infrastructure support, maintenance and data management;
- Data and digital policies environment;
- Expert advisors and agencies providing oversight and guidance;
- User needs and stakeholder requirements;
- Financial support.

In order to refine and adapt the governance to the requirements of the targeted MSDI maturity and national situation, inclusive consultations with different stakeholders should be conducted. Inclusion in the governance structure ensures that the best scalable fit-to-purpose solution can be obtained.

### 4.1.2 Governance and institutions

#### 4.1.2.1 Systems supporting marine spatial data governance

Often the roles of the different pieces of infrastructure or systems that enable marine spatial data governance are not well differentiated. This can lead to a misinterpretation of their function and uncertainty on which of their data aspects fit inside the HOs MSDI mandate. Establishing the policies or "rules of the game" for data contribution and sharing is important to avoid duplication of efforts and to make clear what should be shared through the MSDI and who is going to be the audience. When designing these policies, it is important to consider who the "enablers" of the MSDI are; in other words who conforms to the Community of Practice. This Community of Practice is formed of three groups: Data Providers, Data Consumers and a Coordinating Body (Figure 4-2).

[39] Guay, Claude.-Marine Spatial Data Infrastructure for Marine Spatial Planning, in: UNGGIM 9th session, side event of the Working Group on Marine Geospatial Information,05 August 2019. https://ggim.un.org/meetings/GGIM-committee/9th-Session/side_events/Monday/Marine/4-Claude-Guay.pdf

[40] UNGGIM.- IGIF Strategic Pathway 1: Governance and Institutional Arrangements, January 2022

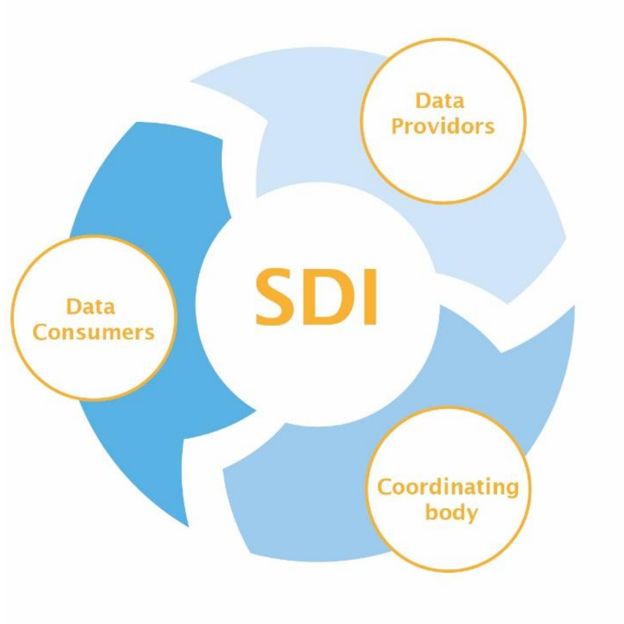


***Figure 4-2 – Three groups making up the Community of Practice of MSDI***

The following definitions of roles aim at demonstrating an example of deconflicting four different system components of marine spatial data governance which must work together: ICZM (see Clause 2.3.2), MSP, Marine Cadastre and MSDI. The following seeks to emphasize an interdependency and complementarity of the marine information and services hosted, used and generated by these systems.

1. MSP: Planning of concurrent marine activities:
   - Marine Spatial Planning (MSP) is an internationally recognized process for managing ocean spaces that guides the sustainable use of ocean spaces to achieve shared ecological, economic, cultural and social objectives in this environment[41];
   - Produces marine spatial plans that consider both economic and conservation aspects: They can identify potential areas for development and/or other marine activities, as well as areas that should be avoided or that may require special protection measures;
   - Coordinates planning partners and stakeholders to build successful governance as an essential element of the MSP process;
   - Utilizes an evidence-based and inclusive approach that draws data and knowledge from different sources to generate additional insights, for example, through the creation of products (for example based on biological, physical, socio-cultural, human use and impact and threat data), including support from Marine Cadastre and MSDI.
2. Marine Cadastre: Geospatial depiction of Marine Regulatory Framework/Georegulations:
   - "Management tool which spatially describes, visualizes and realizes formally and informally defined boundaries and associated rights, restrictions and responsibilities in the marine environment as a data layer in a marine SDI, allowing them to be more effectively identified, administered and accessed (PCGIAP-WG3 2004[42])".
3. MSDI: Infrastructure:
   - Host, enable discovery, work on & distribution of authoritative marine spatial data;

[41] About marine spatial planning (dfo-mpo.gc.ca)
[42] Permanent Committee on GIS Infrastructure for Asia and the Pacific-WG3.- Report of PCGIAP -WG3, in: International Workshop On Administering the Marine Environment – The Spatial Dimensions, 4-6 May 2004, Kuala Lumpur, Malaysia.

- Grouping by theme allowing targeted applications to add value to the data;
- Data governance;
- Provides operational agreements, processes and services to facilitate and support other systems or processes such as Marine Cadastre and MSP;
- MSDI does the heavy lifting that enables Marine Spatial Data Governance.

#### 4.1.2.2 Telling the story to secure the value

Because the MSDI is an infrastructure, there is a danger that it becomes hidden or invisible to the financing agencies. A clear description of its role and goals must be expressed. Once established with operational processes in place, the MSDI becomes an enabler and facilitator of marine information use. It can then feed other systems such as Marine Spatial Planning and a Marine Cadastre (see Clause 4.1.3 – Policy and Legal). Its successes must be communicated and its services maintained. Its governance must include an outreach effort to express the realised value of the MSDI to its stakeholders and users. Ensuring that the marine spatial data governance requirements and challenges are known and communicated helps promote the policies and legislation necessary to support and enable the MSDI as part of a national or regional enterprise solution supporting decision-making for the sustainable management of marine space.

**General Bathymetric Chart of the Oceans (GEBCO) Case Study – Marine Spatial Data Governance**

The General Bathymetric Chart of the Oceans (GEBCO) is a well-established international institution with a mission to map the world's oceans. GEBCO's marine spatial data governance illustrates an example of collaborative international governance with participation from government, commercial, not for profit and academic sectors. In order to address the areas of governance that it needs to map the worlds' oceans, it has established several sub-committees of experts whose work can be related to the UNGGIM IGIF Pathways: Governance, Data, Technology and Innovation, Communications, Education and Training and Partnerships.

***Figure 4-3 – GEBCO Case Study - Marine Spatial Data Governance***

### 4.1.3 Policy and Legal

Whereas marine spatial data governance makes the coordination, engagement and implementation of an MSDI possible, compliance with the national marine and data policy, administrative and legal framework must also be maintained at all times. This framework establishes the legal and regulatory environment where the MSDI will integrate. It gives strength to the Marine Spatial Governance by forcing mandatory contribution, data management obligations, and defining geospatial areas of enforcement. Legislative and administrative gaps as well as marine domain mandates must be examined carefully with other government stakeholders to assess whether the domestic marine laws are sufficient to enable, maintain and sustain the MSDI capacity building.

The IGIF-H is providing comprehensive guidance on the Strategic Pathway SP2 Policy and Legal components that are relevant to an MSDI. The four key elements required to develop and sustain the enabling environment are:

- Legislation;
- Policies, Norms and Guides;
- Governance and Accountability;
- Data Protection, Licensing and Sharing.


***Figure 4-4 – IGIF Strategic Pathway 2: Policy and Legal***

For marine spatial data governance, the actions given in the IGIF SP2 document to achieve this Policy and legal IGIF Strategic Pathway SP 2 can be defined and interpreted as:

i) **Providing Leadership** to establish a national or regional Marine Policy Review Group to define Common Legal Terms to use to better standardise, make interoperable and unify Marine Legislation and facilitate Marine Spatial Data Governance. This review group must include legal practitioners and professionals understanding MSDI, Marine Cadastre and MSP along with the geospatial information-related policies and legal matters facing marine stakeholders. Establishing a community of practice on marine spatial data governance can help with this action and several of the other actions described below;

ii) **Assessing the marine Legislative and Policy Needs** through a review of Legislative and Administrative Gaps and Opportunities;

iii) **Addressing the Opportunities** through the adaptation of existing policy and legislation with marine impact and the design and development of new policy and legislation (fill the gaps) considering Data Sharing and dissemination as well as Licensing of Marine Geospatial information;

iv) **Future-Proofing** the legislation by forecasting the country's evolution in MSDI maturity and allowing accommodation of new and emerging technology with associated ethical issues. This allows for change management allowances in policies, laws and regulations affecting marine spatial data and its governance;

v) **Addressing Coherence** by adapting or establishing policy and legal instruments to protect Intellectual Property Rights on Marine Data, by ensuring consistent Privacy and Data Protection, by addressing Liability Concerns and issues with Sensitive Information;

vi) **Delivering Compliance** through an Impact Assessment and the development of a Compliance Strategy.

The MSDI being part of an ecosystem of interdependent systems and processes, the legislation and policies that enable marine spatial data governance through an MSDI must also consider strengthening both the Marine Cadastre and Marine Spatial Planning as interoperable complementary components.

Effective MSP requires policies and regulations allowing the well-informed development and enforcement of the Marine Spatial Plans. One of the policy components that is required to make the system work is the mandatory provision by their data owners of critical and foundational data layers with participation in the planning. Other legislation that allows enforcement of MSP is also required to give teeth to MSP. MSP depends on the data, services and arrangements provided by the MSDI as well as on the marine cadastre information to overlay regulatory and administrative geospatial data with a standardized content on rights, restrictions and responsibilities over environment protection and scientific information on climate change.

Several examples of national hydrographic legislation were compiled in the IHOs Publication C-16 National Hydrographic Legislation[43]. These concentrate on hydrographic data and services to fulfil the charting responsibilities of HOs. These legislations may not be applicable to the wider Marine Spatial Data Governance applying to non-navigational data. Legislations focussing on MSDI and MSP offer a better and more adapted support to these non-navigational data uses.

The following are examples of national legislations in support of MSP or MSDI or both.

- United States of America legislation example:
  - Geospatial Data Act 2018[44]

    Although not specifically focussed on marine spatial data governance aspects, this Act clearly establishes a national geospatial data governance structure applying to its National Spatial Data Infrastructure.
- European legislation example:

  The following European Union marine directives all come with a time table and requirements[45] for its member States.
  - Water Framework Directive (2000);
  - The INSPIRE Directive (2007/2/EC);
  - Marine Strategy Framework Directive (2008/06);
  - Marine Spatial Planning Directive (2014/89/EU).
- Republic of Korea legislation example:
  - "Marine Spatial Planning and Management Act (2018)";
  - "Act on Marine Research and the use of Marine Information (2020)";
  - These Acts enable MSP and scientific data contributions to the MSDI by allowing enforcement.

Among these policies, "Open Data Policies" are perceived as greatly beneficial if not necessary to support and promote wider user engagement and participation in a MSDI. This is supported by the G8Open Data policy presented in Chapter 2, Clause 2.3.3 which gives the advantages of an open data policy. In this context the value of a Marine Spatial Open Data Infrastructure can be explored (Contarinis et al. 2020)[46]. These policies are adopted by a large number of countries as shown in the Open Data Barometer Global Report[47]. They facilitate the promotion of both transparency and accountability of governments where data collected and processed with public funds is made accessible to the wider public.

Domestic legislation will enact international treaties and designate the custodians of relevant foundational data. In the IGIF-H, the three main international treaties and conventions given which will affect HOs are the International Convention for the Safety of Life at Sea (SOLAS), the United Nations Convention on the Law of The Sea (UNCLOS) and the International Convention for the Prevention of Pollution from Ships (MARPOL). The legislation that enacts UNCLOS defines the maritime limits and boundaries which are represented on HOs charts. These MLBs form a foundational layer necessary to define the extent of several areas of marine regulations. Geographic coordinates defining jurisdictional boundaries and administrative areas will be embedded in the legal text of georegulations and licenses. Data governance policies are mentioned in Clause 4.2.1.1. The marine data governance policies will have to reflect the common aspects of the data governance policies developed for the National SDI.

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[43] https://iho.int/uploads/user/pubs/cb/c-16/C16upd1208small.pdf

[44] https://www.fgdc.gov/gda/online

[45] Sandalinas, Jordi.- Recent researches in the Marine Strategy Framework Directive, Marine Spatial Planning and IHO Standards; Marine Domain Working Group, OGC Technical Committee meetings, June 17, 2021.

[46] Contarinis, S.; Pallikaris, A.; Nakos, B. The Value of Marine Spatial Open Data Infrastructures — Potentials of IHO S-100 Standard to Become the Universal Marine Data Model. J. Mar. Sci. Eng. 2020, 8, 564.
https://doi.org/10.3390/jmse8080564
https://www.mdpi.com/2077-1312/8/8/564

[47] https://opendatabarometer.org/doc/3rdEdition/ODB-3rdEdition-GlobalReport.pdf

| Authoritative Management system for nautical information **- Italy** |
|---|
| The nautical information exchange is a key step for MSDI. A web platform open to public-private stakeholders and authorities can guide the flow of information into the MSDI.<br>The web interface, created in 2022 under a European Union funded project, is designed to speed up and simplify the official exchange of nautical information between public and private entities and the Italian Hydrographic Institute. This method of exchange will expedite the updating process of the official nautical documentation, maintaining the necessary legal constrains. Furthermore, the platform allows releasing standard web services in order to facilitate the availability and accessibility of marine geospatial information.<br>This kind of management system creates many positive outcomes, not exclusively related to the updating process of the official nautical documentation and the visualization of the nautical products and services. In fact it is also a prototype of a legally binding method of information exchange between public administrations; since the web platform completed with all relevant information, attributes and metadata, designed for technical and non-technical users, can be uploaded through the web interface by synthetic and constrained structured fields.<br>In addition, it represents an example of reusable information exchange tool for different uses for a broader audience. Information can be shared and extended to other nations or organizations; using a technological and procedural application of standards focused on improvement of working practices and procedures.<br>Through the quick collection and exchange of information, its centralized and massive storage, the punctual and certified updating of the nautical cartography and its almost immediate availability, the web portal will provide better and faster marine information to decision makers, organizations and people responsible for the marine resources and the blue sustainable development.<br>In fact, this kind of MSDI promotes the knowledge of the marine domain and increases the engagement of stakeholders in planning, managing, protecting and controlling marine areas..<br>Furthermore, it could represent the basis for the development of an interface that can collect different open marine datasets that are often complete and updated but not connected one to each other.<br>Access to the website will be allowed, permanently or temporarily, through the release of credentials to those interested party who request it. The account will be nominative and the authorizations levels will be defined based on the specific needs of the user.<br>Coast Guard offices, public authorities (ministerial offices, research institutions, local authorities), private companies, concessionaires, private citizens with specific interests in marine and maritime activities would enter and use the portal by specific accounts and different level of authorizations and interactions.<br>All stakeholders will be able to transfer authoritative nautical information quickly and in a simpler way. They will be equipped with an efficient and effective system graphic tool useful for planning and management of their zone of jurisdiction and presenting initiatives of regulated marine areas to be submitted for the technical-cartographic check by the hydrographic office. On the other hand, the hydrographic office will be able to automate the process of entering/updating features on the products and to streamline the interactions with the Coast guard and local maritime authorities.<br>Pictures and/or Sources: https://geo.istitutoidrografico.it |

***Figure 4-5 – Italy's Authoritative Management system for nautical information***

### 4.1.4 Financial

The IGIF-H[48] provides guidance on:

[48] UN-GGIM IGIF-H Part Two; https://ggim.un.org/meetings/GGIM-committee/13th-Session/documents/

- Business model;
- Opportunities;
- Investments;
- Benefit realization.

The implementation guidance provided within IGIF-H are intended to highlight and address considerations specifically focused on marine geospatial information. There is substantial flexibility within the IGIF-H guidance which considers that each individual country's governance, plans, policies, and value outlooks can and likely will lead to different implementations.

#### 4.1.4.1 Operational sustainability of a MSDI

The development cost of setting up and establishing a MSDI can be significant and the benefits and return on investment of a MSDI would be expected. Benefits from a MSDI can be direct and/or indirect, quantitative and/or qualitative and it is advised that the value produced should not be confused with revenue generated. HOs typically collect and hold a lot of data that is not used in the production of nautical charts and services (for example backscatter data, salinity, temperature, etc.). MSDI provides a way to distribute and make this data available to a variety of end-users, who may derive significant value from the data for a variety of purposes. There is potential for MSDIs to generate revenue and MSDIs could consider the various cost structure models (for example Open-access, Extract and Deliver, Subsidised, Cost recovery, Freemium or Full commercial) outlined under the IGIF Strategic Pathway 3 Financial, Appendix 3.4 Business Model Canvas[49] in determining the possibility of a revenue stream.

However, in many cases and depending on the business model chosen, the return on investment may be indirect and difficult to discern. In many cases, access to MSDI data may yield better scientific insights or be used by private sector entities to develop for-profit services, thereby providing indirect benefit to governments through tax revenue. It is therefore recommended that cost-benefit and/or cost-effectiveness analyses be conducted to monitor the benefits generated and to inform its strategic directions. Lastly, in considering the sustainability of a MSDI, in addition to significant costs associated with initial set up, there can be large, harder to predict costs associated with maintenance and enhancements of data storage and archiving.

| General Bathymetric Chart of the Oceans (GEBCO) Case Study - Financial |
|---|
| The provision of open marine spatial data could require concerted funding effort. GEBCO has a voluntary participation basis where each participant's organisation funds their attendance. GEBCO's ocean mapping progress would be limited without a major financial enabler: the Nippon Foundation – GEBCO Seabed 2030 project. This project, with oversight by GEBCO and direct contribution to its mission, is presently the effective driving force behind GEBCO ocean mapping. It brings forth financial support and resources distributed worldwide stimulating the development of Partnerships, Innovation, Governance, Success indicators (number of partners, percentage of world oceans mapped to modern standards), Outreach, Communications and sustains a global community of practice. |

***Figure 4-6 – GEBCO Case Study - Financial***

## 4.2 Technology

### 4.2.1 Data

Data is said to be the "new oil" of the hydrospace and with the advancements in technology, data acquisition has promoted the increase in Big Data. HOs, acting as data custodians, must consider elements which promote consistent and reliable access to authoritative marine spatial data. Data is at the core of MSDI and

[49] UN-GGIM IGIF Strategic Pathway 3 Financial, Appendix 3.4: https://ggim.un.org/IGIF/documents/SP3-Appendices-19Jun2020-GLOBAL-CONSULTATION.pdf

there are various Sections in this Publication which touch on it: Clause 1.5.1 suggests a definition for data; Clauses 1.5.2 and 1.5.3 outline the data principles to account for; Section 2.4 recommends third party data incorporation methods; Section 4.1 sets the institutional context of marine data governance; and Clauses 2.2.2 and 4.1.2 underscore what it means to provide "authoritative" data. This Section elaborates on the data governance policies and expounds on common data challenges and solutions in data curation, privacy, security, integrity, and themes that HOs could consider.

#### 4.2.1.1 Data curation

One of the fundamental functions of any spatial data infrastructure is the curation of authoritative data assets meant for broader community use. The Organization doing the curating could be a designated administrative group – such as the GIS team – or a committee of distributed domain experts. The key goals are to help accelerate use of spatial data and information products by providing a trusted brand to a catalogue of content that signals quality. Authoritative data must be supported by a minimum standard of quality that comes with a trusted methodology for content review and approval. It's often the expert curation of 'pre-certified' datasets that solve 80% of the data use discovery cases within certain communities of practice. A selected group of Data curators must be appointed for this task, their function is to ensure the best maps and layers are made available through the system. Curation rules enforce minimum requirements for an item to be accepted. But it is the curator who leads the user through discussions on how to get the most out of each item. The overall curation process ensures that a qualitative review can occur, so all parties know what is expected, what the benefits are to users, etc.

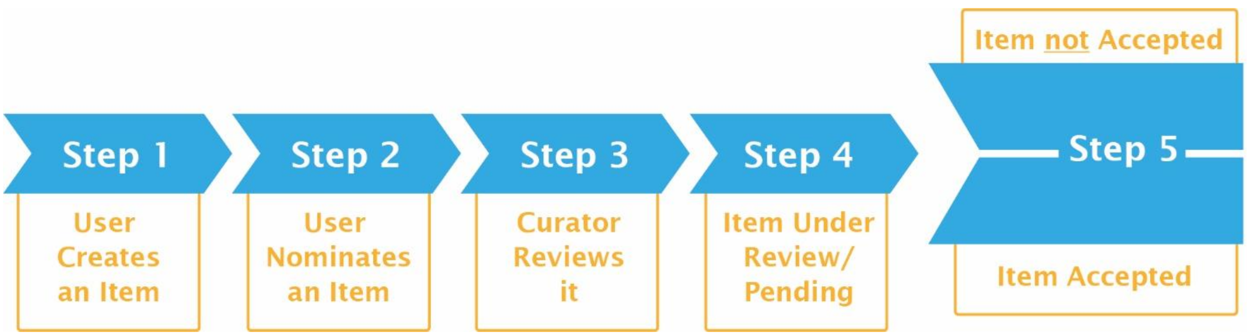


***Figure 4-7 – Curation workflow***

#### 4.2.1.2 Data privacy

Sometimes referred as information privacy, it is an area of data protection that concerns the proper handling of sensitive data (personal data, confidential data, intellectual property or financial data among others). For MSDI geospatial data, an Organization should consider the development of regulatory requirements to define how data should be kept protected. There are typically three broad categories: traditional data protection (backup and restore copies); data security (encryption, access control, authentication, threat monitoring); and data privacy (legislation, policies, best practice for data governance). The latter can be considered an outcome of best practice in data protection. The term "data privacy" contains what the European Union (EU) refers to as "data protection". An important aspect to consider, mainly when collaborating beyond national borders, is the "data sovereignty", which refers to digital data that is subject to laws of the country in which it's located. The increased adoption of cloud data services and a perceived lack of security has led many countries to introduce new legislation that requires data to be kept within the country in which the customer resides. Some countries are trying to prevent data from being stored outside their national boundaries. In most countries, privacy is a legal term and not a technology one; and so it's the term "data protection" that deals with the technical framework of keeping the data secure and available.

#### 4.2.1.3 Data security

Data privacy is not data security. Data security protects data from compromise by external attackers and malicious insiders, whereas data privacy governs how data is collected, shared and used. Due to the sensitive nature of that data, HOs often work closely with the Navies of their respective nations and their information technology experts.

#### 4.2.1.4 Data integrity

*Refer to MSDIWG10 discussion on Data Integrity available at IHO MSDIWG10: https://iho.int/en/msdiwg10-2019*

#### 4.2.1.5 Data themes

*Refer to IHO-OGC Concept Development Study recommended themes and any others available at IHO MSDIWG Body of Knowledge: https://iho.int/en/body-of-knowledge*

### 4.2.2 Innovation

Innovation from a MSDI perspective is twofold. As new trends and technologies emerge, MSDIs must be enabled to support new innovations and innovation programs to fulfil the quantitative and qualitative benefits of providing open marine spatial data. Likewise, platforms and opportunities for innovation are important in advancing MSDIs.

#### 4.2.2.1 Supporting innovation programs

Fundamentally, MSDIs are a single window and authoritative source for marine spatial data, web services and APIs required for innovation projects and/or programs. Identifying MSDI related innovation programs being developed and potential gaps in areas of interest are the first steps for supporting MSDI innovation. For example, the OGC Federated MSDI Case Study is a good source of information to determine how useful federated MSDI and open hydrographic data can be beyond its traditional use for safety of navigation.

#### 4.2.2.2 Innovating and enhancing MSDIs

##### 4.2.2.2.1 The "one map" concept approach

Many Organizations are building their geospatial infrastructures around the "one map" concept. This can be understood as a strategic resource providing a collection of authoritative products and web services in one place (a single window or one-stop-shop) for all geospatial information needs, organizing partners, involving different levels of government, private sector and academia among others. The idea is to enable access to any information required by the user (who doesn't have to be a technical expert) in the least number of clicks possible. Providing applications, analysis tools, and APIs to build apps, data can be browsed by themes, used online or downloaded for local consumption.

##### 4.2.2.2.2 MSDI patterns in practice

In practice there are different patterns to develop an MSDI, which in general is part of a National SDI. These patterns are understood as ways in which organizations approach the coordination and relationships with stakeholders. Some of the most common patterns of practice are:

- Regional planning initiatives;
- Foundational data initiatives;
- Thematic initiatives;
- "Whole-of-Government" (WoG) collaboration;
- Emerging Hub networks;
- Sustainable development thematic initiatives.

##### 4.2.2.2.3 OGC APIs – building blocks for location

Leveraging on OGC web service standards (WMS, WFS, WCS, WPS etc), OGC APIs are an ongoing work led by the OGC "designed to make it easy for ANYONE to provide and use geospatial data on the web, and to integrate this data with ANY other type of information". Refer to latest information at https://ogcapi.ogc.org/

##### 4.2.2.2.4 Data at the "speed of trust"

Collaboration is foundational to the success of any MSDI. Trust is the bonding among those that form the Community of Practice. It is commonly said that when the trust goes up, speed goes up with it and associated costs (economical, time or resources) go down. Many books and articles have been written about this, they refer usually to enterprises, relationships, business, leadership. All important, but how to translate this concept to data? Trust can be understood as credibility and with that, there are four key elements: integrity, intent, capabilities and results. Data in a MSDI must be authoritative, quality controlled and its metadata clearly established to understand its capabilities and possible results in use it.

### 4.2.3 Standards

From the development of the data store or database, to the formats in which the datasets are stored and shared over a possible web-based data catalogue or geoportal, Standards play a vital role in MSDIs. Internationally-recognised open Standards are especially important to enable marine spatial data, services and systems to be interoperable and open for users and use-cases which are often broad, cross-boundary and interdisciplinary. HOs are encouraged to refer to international Standards set by standards developing Organisations: International Hydrographic Organization (IHO) (https://iho.int/en/standards-and-specifications), Open Geospatial Consortium (OGC) (https://www.ogc.org/standards/) and International Organization for Standardisation (ISO) (https://www.iso.org/popular-standards.html).

The S-100 Universal Hydrographic Data Model and Product Specifications led by the IHO is working with various international and inter-Governmental Organisations towards international standardisation of marine datasets across the marine domains (for example IHO – International Association of Marine Aids to Navigation and Lighthouse (IALA) S-2xx and IHO – World Meteorological Organization (WMO) S-4xx). As demand for these products are expected to grow beyond the traditional navigation users, at the point of this Publication it is an ongoing discussion at the IHO MSDIWG on how HOs should consider MSDIs role in the provision of these data.

## 4.3 People

Community of Practice is formed of three groups: Data Providers (or custodians), Data Consumers, and a Coordinating Body; hence the diverse people, roles and expertise involved in a MSDI are typically associated with each of these groups. This Section provides guidance on people involved in provider / custodian teams. For further information on building a MSDI team, refer to Clause 4.3.3 – Capacity and education; and users in Section 2.3 – MSDI development – demanding aspects.

### 4.3.1 Data Providers: roles and expertise

A MSDI that forms a contribution to a NSDI (or similar) may likely require two or more agencies to collaborate in its operational delivery, beyond transactional data exchange or arms-length cooperation. This requires not only data interoperability, but interoperability of institutions and their decision-making processes for an integrated MSDI that supports onward applications like Digital Twins. This institutional interoperability requires a common understanding of Data Governance roles and of terms used in Data Management.

Different institutions can have markedly different responsibilities for the same role titles, such as "Head of Data" that may be managerial in large organisations with reduced expectations of technical expertise, which is held by lower-level subject matter experts (SMEs). At the other end of the spectrum in smaller organisations, such a role may conversely be highly technical, yet requiring higher-level approvals for making decisions and committing to action.

This can inhibit agile decision-making and responsiveness for urgent issues within a multi-agency MSDI implementation, as managerial-dominant roles must take time to confer with their SMEs, whilst technical-dominant roles must delay until leadership approval is given. These layers of delay and communication increase the risks of decisions being made too late, which even for routine tasks will eventually accumulate into far longer delays overall. It is also a similar situation for definitions used across different institutions and incorrectly assumed to be understood by each organisation in the same way, but now with the risk of wrong decisions being made. For example, Data Quality may mean statistical conformance to one organisation, whilst meaning cleansed data subject to a strict Standard by another.

One recommended solution is to use common Data Governance role titles alongside regular job titles from a host agency's hierarchy, such as Senior Risk Owner, Information Asset Owner, Data Custodian, Data Steward, and/or Data Practitioner. These are only recommended examples and can be changed according to institutional culture, it is far more important that these roles are commonly and clearly understood by **all** stakeholders, regardless of the actual terms used. A similar solution of mutually agreed upon common Data Management terms will also empower communications amongst MSDI agencies.

As an example of an issue relating to pipeline instability due to seabed movement, it may be far quicker for the Information Asset Owner (Pipelines) in Agency X to directly request a crucial meeting with the Information Asset Owner (Bathymetry) in Agency Y, than a more traditional method of trying to navigate a 3rd party hierarchy, where conventional job titles may have markedly different practical responsibilities to similar ones within their own institution.

**Certification** of hydrographers and land surveyors for surveys in the marine environment:

**New skills:**

- Data science;
- MSDI literacy.

**Bridging the training gap:**

- Traditional Hydrography: Safety of navigation, surveying, nautical charts and products;
- MSDI: whole of government approach for data centric marine data management;
- How to bridge HOs' expertise and Non-navigational Marine Science sector expertise to make data FAIR: Findable Accessible, Interoperable, Reusable;
- People to assemble and implement knowledge transfer from other marine sectors:
  - Data owners and managers;
  - Infrastructure providers and managers and maintenance service providers;
  - Technology and standards integrators;
  - Testers and implementers;
  - Applications developers;
  - Facilitators bridging IT and MSDI;
- Distribution of roles and expertise for a Federated MSDI.

#### 4.3.2 Partnerships

Where appropriately chosen, the use of common Data Governance role titles can also facilitate partnerships between different national sectors, such as Government, Academia, and Industry; whilst also serving a role across national boundaries for federated initiatives (such as the OGC's FMSDI initiative). The possibility of "diagonal partnerships" across national borders may also offer unique benefits where the need and opportunity arise, outside of traditional Government to Government (G2G) or Government to Business (G2B) within the same country.

Whether national or international, partnerships are crucial for maximising strengths and capabilities, as an effective MSDI will need the participation of Government, Academia, and Industry, perhaps alongside international bodies in some instances. The governance of such **multiparty** partnerships will likely require robust implementation via a number of consensus groups that empower fair and inclusive decision-making. A three-level example may begin with a top-level MSDI Governance Board for strategy and vision, a mid-level MSDI Steering Group for operational planning, followed by an MSDI Working Group for implementation.

A key trait of effective governance enabling real-world progress is that each group adopts collaborative goal-setting, not just passive cooperation, but a "One Fail, All Fail" approach to prevent minimalist and/or individualist contributions and encourage true joint working. This may require a political and cross-domain level of understanding that lies outside the scope of this document, but is worth the time and effort in realising.

To ensure inclusive participation and decision-making, independent Chairs are an ideal solution where possible for each group, supplemented by common MSDI (or Data) Governance titles to break down perceived hierarchies, which can cause relatively smaller participants to feel side-lined or dominated by larger peers, leading to disengagement or withdrawal. The use of common MSDI Governance titles should also be supplemented by a robust diplomatic-style approach by the Chair(s), where each participant is taken as an "sovereign ambassador" representing their organisation, regardless of perceived status due to regular job titles, or the heritage, size, budget, or influence of their home institution. An effective MSDI requires close operational interoperability of institutions, to deliver unique outcomes that no one, two, or sometimes even three parties could deliver alone. This goes far beyond contractual and transactional data exchanges, where even one "broken link" could have outsized deleterious impacts on the collective outcome.

#### 4.3.3 Capacity and education

Building the Team to deliver MSDI:

Identify the appropriate skills and knowledge in your workforce to enable the development of SDI within the HO to progress. These skills considering specifically MSDI could include:

- Understanding what constitutes an MSDI and how it might be developed and delivered;
- Understanding the data (for example its constituents, capture, aggregation);
- Understanding the variety of potential users of the MSDI and their specific needs can better inform decision making regarding content, accessibility and metadata;
- A knowledge of data management (standards, metadata, architecture, modelling, best practice);
- A knowledge of ICT such as web services and delivery, interoperability, data sharing and exchange, geo-portal development;
- The ability to communicate (for example with users to determine requirements and describe data; with management to gain support, acceptance and funding to provide the best service);
- A knowledge of software solutions across the geospatial information industry (for example platforms for delivery, database design and operation); and
- Experience in team working to ensure delivery of common MSDI goals.

More elements of a Hydrographer of the Future can be found in an International Hydrographic Review, volume 28 paper: "The Hydrographer of the Future – Reflections on an international virtual workshop" (Foroutan, Bhatia and Béchard, November 2022)[50].

#### 4.3.4 Communication and engagements

In an area of increasing societal concern around misinformation and disinformation, it is important to not only make authoritative and assured data openly available, but to ensure that decision-makers are cognizant of the need for trusted data and metadata. Succinct messaging and infographics to capture the attention of end-user communities are needed amidst increasing amounts of parallel, alternative, and competing communications. It is equally crucial for motivating decision-makers (for example Ministers, treasury officials) to contribute or support a MSDI implementation.

Whatever the chosen channel, medium, and approaches taken, communication is important internally within the Government and externally with its other stakeholders. Coordination with national peer-agencies or higher-level Executive bodies (where applicable) through a recognised governance structure could help avoid unnecessary duplication (unless deliberately desired) and even conflicting messaging. Feedback from developing country HOs have indicated communication tools like infographics are necessary to compete for political bandwidth against more headline-friendly topics like crypto-blockchains and AI, to convince officials that the heavy-lifting of a MSDI is needed to make trendy concepts like Digital Twins and Metaverse a reality.

Having a unified whole-of-Government approach can leverage each participating party's strengths and resources, enabling a wider synergy greater than the sum of its parts. A concurrent campaign of intra-Government communication and engagement may be needed alongside external campaigns to users, customers, or consumers. The intensity and breadth of such a campaign will depend on many factors such as the diversity of marine or maritime agencies, and the presence of competing or alternative narratives.

[50] https://ihr.iho.int/articles/the-hydrographer-of-the-future-reflections-on-an-international-virtual-workshop/ [accessed: 15 April 2023]

# 5 Emerging Trends in MSDI

HOs are advised to consider emerging trends related to MSDIs at its implementation phase when the latest technologies and solutions could be factored into technical Specifications or its mature phase(s) when enhancements to the system could be made. This chapter summarises emerging trends in MSDI and in doing so envision a “Future MSDI”.

## 5.1 Transformation of the Hydrographic Office

As detailed in Chapters 2 and 3, the role of the HOs has or can be transformed with MSDIs and with the advent of new technologies, this role will extend to provide not just a single dataset or product, but combinations of data and services for a wide variety of products, such as weather simulations and predictions, real-time data that changes with respect to time. This is an interdisciplinary effort involving multiple agencies and organizations across the data life cycle:

- Data collection;
- Raw data processing;
- Providing easy access to data;
- Applications and Commercialisation of the data.

HOs can and should play a central role in all these activities.

## 5.2 Emerging trends

### 5.2.1 Digital Twins

A Digital Twin is a representation of a physical asset, created by using data collected by various means. Such data can be surface data (for example bathymetry, lidar, photogrammetry), pressure, temperature, wind velocity, direction, or any other parameters. Metaverse is a term often used to describe a set of technologies and its end-product which allows you to see visualization of a physical asset or any real-world object in such detail that the visualization begins to look exactly like the real world.

Digital Twins in the past were a numerical representation of a physical asset. For example, if your asset was a wind turbine, the Digital Twin of the wind turbine would be all the data generated from it. Each wind turbine over a period would generate data that will show its wear and tear and ageing. The representation of such data in charts and tables was the only way to see that data as data visualization techniques were limited by the compute capabilities available.

Today, compute capabilities have improved, therefore we can now visualize 3D Digital Twins which models an asset (a wind turbine for example), along with its data. We can apply the data to the 3D model. For example, if your data is revolutions per minute, you can show the 3D model of the wind turbine blades and gears rotate accordingly.

#### 5.2.1.1 Features of a 3D Digital Twin

Features of a 3D Digital Twin that are common across multiple domains are:

- Raw 3D data collection and its processing mechanism;
- Internet of Things (IoT) data collection and its processing (in real time.);
- Storage of data on cloud.
- Wireless connectivity.
- Applications such as hazard communication, emergency response, maintenance, operations.
- Knowing the state and location of expensive mobile assets (such as aircrafts, helicopters, ships) and stationary assets (such as oil terminals, gas terminals, airports, oil refineries, oil wells, oil platforms).

#### 5.2.1.2 Technology stack involved in a 3D Digital Twin

3D Digital Twins could involve the following technologies:

- LIDAR, photogrammetry, satellite imagery, bathymetry;
- Artificial intelligence (AI), Machine Learning (ML);
- Cloud computing, edge computing;
- 4G, 5G telecommunication technologies;
- Very Small Aperture Terminal (VSAT), Broadband Global Area Network (BGAN);
- High performance computing;
- Virtual Reality (VR), Augmented Reality (AR);
- Wearable devices, headsets, mobile devices;
- Game engines;
- High performance computing;
- Methods for collecting and storing IoT data in real-time;
- Simulations.

#### 5.2.1.3 Relevance of a 3D Digital Twin to the maritime sector

In the maritime domain, common assets are the infrastructure associated with ports and natural features such as shorelines. A large port can have several manmade structures such as locks, bridges, pipelines. For example, Berendrecht lock is the world's second largest lock located in the port of Antwerp. A 3D Digital Twin in this case would be the 3D model of the lock plus the lock's positional data which can change with respect to time.

#### 5.2.1.4 MSDI and Digital Twins of the Ocean

One of the ten challenges of the UN Decade of Ocean Science for Sustainable Development is to create a digital representation of the ocean. MSDIs are enablers of Digital Twins of the Ocean, without which the standardised data, services and partnerships required to be integrated for the Digital Twins would not be possible. Its fundamental service is to provide Digital Twin "readable" data and/or APIs, which could go beyond standardised 2D hydrographic data and include 3D and (near) real-time data from various domains. At the point of this Publication, the IHO MSDIWG[51] is exploring the role of MSDI with Digital Twins of the future and the latest discussions can be found on the Group's webpage.

Two notable initiatives aligned with the UN Decade of Ocean Science for Sustainable Development that could also guide the role of MSDIs are: (1) The Digital Twins of the Ocean (DITTO)[52]; and (2) The UN-GGIM Working Group on Marine Geospatial Information - led IGIF-Hydro[53], an operational framework for integrated marine geospatial information.

### 5.2.2 Visualization of spatial data – VR, AR, MR

There are many options of spatial data visualization that MSDIs can consider providing or enabling through the provision of data. From animated movies to Computer Aided Design (CAD), surface model of seafloor, visualization of weather simulation, Computational Fluid Dynamics (CFD) simulation. Earlier, all this 3D data was seen on flat screens. Today, in addition to screens, there is the option of wearable headsets which MSDIs could consider. Virtual Reality (VR) as a visualization technique where the display is mounted on the user's head and replaces the user's visual input of the real world with a 360 virtual screen. Alternate Reality (AR) is when the user sees the real world with small amounts of 3D data and non 3D data is overlaid on top of the real-world visual inputs. Mixed Reality (MR) is when the user sees highly realistic and detailed 3D visualizations mixed with the real world. The goal here is to make the virtual 3D data indistinguishable from the real world.

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[51] https://iho.int/msdiwg [accessed: 15 April 2023]
[52] https://ditto-oceandecade.org/ [accessed: 15 April 2023]
[53] https://ggim.un.org/UNGGIM-wg8/ [accessed: 15 April 2023]

AR or MR use-cases from HOs, ports, ship owners could involve inserting or overlaying information regarding navigation, AIS data, situational awareness (with nearby ships, land) on top of the live imagery. Ideally the base layer of the live imagery should have 360° coverage coming from cameras with views unobstructed from the ship's own surfaces. The information displayed on the head mounted display could use 4 modes of display:

1) User Interface (UI) pinned to the head of the user for certain critical information for information that is not 3 dimensional in nature;
2) UI pinned to a wall on a bridge or anchored to a point in 3D space within the bridge;
3) A holographic display which multiple people can see simultaneously;
4) See through mode where you could see the surface below or beyond ship surfaces (for example ocean floor below the keel for Under Keel Clearance – UKC).

### 5.2.3 Handling of big data

As MSDIs grow in capability and capacity, enhancements to data storage and optimisation would be required, whether it is stored on-premise or in clouds. Especially with increased demand for 3D data and (near) real-time data, there will be an increase in the footprint of data by several magnitudes compared to 2D data.

#### 5.2.3.1 Optimization of 3D data

3D data collected and processed could come from various sources such as satellite-based sensors, UAVs, LIDAR, photogrammetry, bathymetry, sounding and radar. 3D data in its raw format can be very large (up to petabyte size), hence MSDIs should be prepared to cater for appropriate data infrastructure that can handle big 3D data. To display and process 3D data over the web-based portals or headsets – which are thin clients and have limited memory, storage, and processing power – MSDIs or its end-user would have to consider the abstraction, optimization, or conversion of 3D data. And where remote connections are required for wearable devices, it would also require the help of high-performance computing, 3G, 4G, satellite broadband connections (BGAN, VSAT) (See Annex B for more information).

In the case of 3D data, HDF5 is one of the possible optimised data formats that MSDIs can consider. It has been in use for scientific visualization of 3D data and is part of the S-100 Framework encoding. Original 3D data stored in HDF5 format can create an abstraction of it for display.

### 5.2.4 Other emerging trends

There are many other emerging technological trends MSDIs could be expected to provide and/or support. For example edge computing, high performance computing, artificial intelligence/machine learning, micro services etc. HOs and MSDIs are encouraged to discern their role amongst these trends, and data-centric and user-centric approaches could help guide this discernment.

# 6 Conclusion

So where will HOs, as part of the global geospatial community, be in the next 10 years?

There is no doubt that there has never been a more urgent need for a paradigm shift in how we inhabit our planet. In this decade of ocean science and towards the 2030 Agenda, and in line with the IHO Strategic Plan 2021 – 2026, it is an exciting time for MSDIs which can expect increasing variety of aspects seeking it (see Section 2.3).

There is no escaping that technology now dominates our lives, with a large part of the world's economy and society now relying on smart phones, IT and the internet. At the heart of today's world is the data that this technology generates. Yet, in these existing and/or emerging trends of big data, open data, the Internet of Things, sensors, VR/AR/MR and almost instantaneous sharing of information on social media, there is a mismatch between the rate of change of technology and the ability for our world's leaders and policy makers to keep up and understand the implications of this change. The ongoing challenge is that the time taken to deliver such policy and standards is extraordinarily long, whilst technology is moving forward much more quickly. Hence, MSDIs must consider all four MSDI pillars while bridging to the wider geospatial ecosystem, the UN-GGIM IGIF 9 Pathways and the wider data community through international Open Standards (see Section 3.3).

Spatial information has a critical part to play here as "everything happens somewhere!". Providing a sense of place is extremely powerful and knowing "where" can help us further investigate the "what", "how" and "why". This is now more important as our world increasingly operates online, remotely, and becomes more intangible.

Many of the key skillsets geospatial specialists had previously taken for granted as exclusively ours are now shared by other professionals, users and even hobbyists such as gamers, geo-cachers, travellers and ramblers. What this gives the geospatial industry is the opportunity to evolve into a new role in this information rich world. Transformative HOs and their MSDIs today have to also consider a much wider range of "people" – roles and expertise – beyond traditional HOs (see Section 4.3).

We must take charge of technology by raising our profile to view the wider geospatial picture. There is far more to "location intelligence" than maps and charts. It is all about the data, what you do with it and what outcomes you can provide that counts. Data is now considered a 'modus operandi' and the role of MSDIs are more important than ever in providing internationally standardized marine spatial data to achieve national, regional, and global agendas.

# 7 Glossary (including Abbreviations and Acronyms)

| | |
|---|---|
| AI | Artificial Intelligence |
| AIS | Automatic Identification System |
| AR | Augmented Reality |
| API | Application Programming Interface |
| APM | Association of Project Management |
| ARHC | Arctic Hydrographic Commission |
| ARMSDIWG | Arctic Marine Spatial Data Infrastructures Working Group |
| BGAN | Broadband Global Area Network |
| BoK | Body of Knowledge |
| CAD | Computer Aided Design |
| CFD | Computational Fluid Dynamics |
| CSDI | Corporate Spatial Data Infrastructure |
| DIKW | Data Information Knowledge Wisdom |
| DITTO | Digital Twin of The Ocean |
| ECDIS | Electronic Chart Display Information System |
| ENC | Electronic Navigational Chart |
| ER | Extended Reality |
| EU | European Union |
| FAIR-TLC | Findable Accessible Interoperable Reusable Traceable Licensable Connected |
| FAO | Food and Agriculture Organization |
| FMSDI | Federated Marine Spatial Data Infrastructure |
| GEBCO | General Bathymetric Chart of the Oceans |
| GIS | Geographic Information System |
| GNSS | Global Navigation Satellite System |
| GSDI | Global Spatial Data Infrastructure |
| G2B | Government to Business |
| G2G | Government to Government |
| HO | Hydrographic Office |
| ICT | Information and Communication Technology |
| ICZM | Integrated Coastal Zone Management |
| IGIF | Integrated Geospatial Information Framework |
| IGIF-H | IGIF Hydro - Operational Framework for Integrated Marine Geospatial Information Management |
| IHO | International Hydrographic Organization |
| IMO | International Maritime Organization |
| IMU | Inertial Measurement Unit |
| IoT | Internet of Things |
| ISO | International Organization for Standardization |
| KPI | Key Performance Indicator |
| LIDAR | Light Detection and Ranging |
| LSDI | Local Spatial Data Infrastructure |
| MARPOL | International Convention for the Prevention of Pollution from Ships |
| ML | Machine Learning |

| | |
|---|---|
| MLB | Maritime Limits and Boundaries |
| MR | Mixed Reality |
| MSDI | Marine Spatial Data Infrastructure |
| MSDIWG | Marine Spatial Data Infrastructures Working Group |
| MSP | Marine Spatial Planning |
| NSDI | National Spatial Data Infrastructure |
| OGC | Open Geospatial Consortium |
| QMP | Quality Management Principle |
| RDF | Resource Description Framework |
| RHC | Regional Hydrographic Commission |
| RSDI | Regional Spatial Data Infrastructure |
| SDI | Spatial Data Infrastructure |
| SDRA | Source Data Receipt and Assessment |
| SIP | Strategy Implementation Plan |
| SLAM | Simultaneous Location and Mapping |
| SOLAS | International Convention for the Safety of Life at Sea |
| SP | Strategic Pathway |
| SSDI | State Spatial Data Infrastructure |
| UKC | Under Keel Clearance |
| UN | United Nations |
| UN-GGIM | United Nations Committee of Experts on Global Geospatial Information Management |
| UNCED | United Nations Conference on Environment and Development |
| UNCLOS | United Nations Convention on the Law of the Sea |
| VR | Virtual Reality |
| VSAT | Very Small Aperture Terminal |
| WCS | Web Coverage Service |
| WEND | Worldwide ENC Database |
| WFS | Web Feature Service |
| WMO | World Meteorological Organization |
| WMS | Web Map Service |
| WMTS | Web Map Tile Service |
| WoG | Whole of Government |
| WPS | Web Processing Service |

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# ANNEX A: VR, AR, MR Wearable Headsets

## A-1 What are the basic building blocks of VR, AR, MR headsets or devices?

- Headset or display device;
- Gyroscopes;
- Sourcing of 3D data;
- Optimization of 3D data;
- Positioning data, GPS, GNSS, IMU;
- Simultaneous Location And Mappng (SLAM);
- Anchors in 3D space;

To fit the above criteria, these devices will likely have processors that are used on mobile phones and hence are expected to have around 4-16 GB RAM. In other words, these are thin clients with limited memory and processing power.

### A-1.1 Headset or display device for industrial use

You can expect these wearable devices to be:

- Intrinsically safe;
- Ruggedized to withstand fall from 2m height on a hard surface;
- Low in weight, power consumption;
- Expected to withstand, dust, heat, sun water;
- Able to withstand humid, salty environments for maritime use;
- Minimum moving parts, no fan, passive cooling.

### A-1.2 Gyroscopes

These are used to sense the head orientation and movement of the user. Around 7 of these are present in new generation mobile phones.

## A-2 Positioning data, GPS, GNSS, IMU

These are inputs coming from larger systems that can be fed into the wearable devices. For example, the gyroscopes and IMUs of the wearable device will sense the head movement and orientation of the user but the location of the user or the ship on the face of earth would come from other systems such as GPS, GNSS in the form of positioning data.

## A-3 SLAM

SLAM stands for Simultaneous Location and Mapping. Such a system can process imagery data and extract positioning information out of it. SLAM is currently being used on autonomous cars. Anchors in 3D space is a software-based system which puts markers in 3D space.

## A-4 Current VR, AR, MR and maritime, industrial applications

### A-4.1 Virtual and Augmented Reality

There are several types of "realities" that sometimes can be confusing. The term "Virtual Reality" (VR) refers to a simulated world, where people can visit (or experience) different artificial scenarios using hardware (headsets) and software. As a virtual representation of the real world, it isolates the user from the real world. "Augmented Reality" (AR) on the other hand, is where parts of the user's physical world is enhanced with computer-generated feeds; this can be done in the form of sound, images, video, GPS and more types of overlays that respond in real time to changes (motion) of the user in the real world. Some digital elements appear over real-world views. The combination of VR and AR elements is called “Mixed Reality” (MR) and basically the designed elements are anchored to a real environment, where the digital and real elements can interact. There is an umbrella term used for technology that combines VR, AR and MR (and any new technology) to alter reality by adding virtual elements to the real world, the “Extended Reality” (ER).

### A-4.2 Adding AR, VR to current ECDIS

It should be possible to project existing ECDIS information through a web browser which then gets projected onto the head mounted display. One of the devices used in these tests was an intrinsically safe head mounted display, called real wear HMT-1. Another was HoloLens 2. As of now there are multiple headsets available that are designed for industrial uses. No standards are set for such displays from a maritime perspective yet (this is where IHO could come in). As of now (and for the near future) head mounted displays may be used in "display only" mode. It is not envisioned to see inputs being fed back into the navigation systems from these devices (such as changing the course of the ship) supporting positioning and other information. As mentioned earlier, all the headsets and most higher-end mobile phones come with accelerometers and gyroscopes that can keep up with human head movements at 90-120 frames per second. In addition to accelerometers and gyroscopes many devices also use SLAM to extract positioning data from capturing images of the surrounding area. These provide the head position and orientation information within the local space of the bridge. However, as all gyroscopes and accelerometers accumulate errors over a period of time, some sort of correction will have to be applied at regular intervals (similar to an IMU). You might need a station for applying these corrections to the headset but otherwise, these headsets should be self-sufficient to position themselves within the local space of the bridge. It should be possible to connect the headset to the main ECDIS station through the 4G private wireless networks that are currently available. So, the headset should function anywhere on the ship as long as there is 4G available. The ships own position and orientation in world space is necessary. This could come from existing GPS, GNSS, IMU, etc. All this data is currently mashed inside the existing ECDIS which can be used on the head mounted display in AR, VR format.

## A-5 Limitations of current technology and future

Current technology and most of the developments are driven largely by commercial, consumer market demands. Hence, they do not necessarily cater for situations such as semi dark and dark conditions where SLAM becomes unreliable. Most of the headsets are designed to work within closed indoor environments so there is testing and R & D involved to see how it might work within maritime environments specially on a ship. The current displays do not have a wide field of view that comes close to natural human vision. However, some high-end devices have shown high fidelity and high resolution. The current combination of ECDIS data and displays were designed for flat 2D displays. In other words, they are a natural progression of a flat paper-based. chart. Hence the base layers are flat 2D images. To get the most out of 3D, VR, AR, we will need to add the third dimension to the data. We are already collecting the bathymetric and hydrological data with the understanding of 3D. We end up flattening it so that it can be displayed on a flat screen. Now that we have VR, AR displays that understand 3D space, such abstraction of 3D data in 2D space is not always necessary. Significantly, S-57 was designed in the days when electronic charts did not exist, and this is reflected by how the data is formatted. But S-100 should be able to adapt to new types of displays and accordingly have the data formatted or modelled appropriately. As for the processing and storing of data, you could say the on board ECDIS is an edge computing device. For smaller crafts that do not have ECDIS, the functions performed by ECDIS, especially the storage of base layer data, could happen at a shore-based cloud computing facility, connected to the thin client on board the ship via satellite broadband. In other words, the wearable device will be connected to an ECDIS-like system that sits on the shore, via a satellite broadband connection. Some computing will always have to happen on board the ship as the positioning data is being generated from ship-based sensors. Such a combination and split of ship-based, land-based computing would prevent data duplication, unnecessary data transmission, and provide for the ability to push more frequent updates. There will be certain latency issues involved here which are inherent with a satellite broadband connection, however, there are ways around it. Extending the idea of thin client and fat server, such a system would be connected to the thin client on board the ship via a satellite connection and can act as a backup for the on board ECDIS computing infrastructure or can provide

ECDIS like capabilities for smaller crafts which are too small or too inexpensive to have full-fledged ECDIS systems.

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# ANNEX B: Additional Emerging Trends

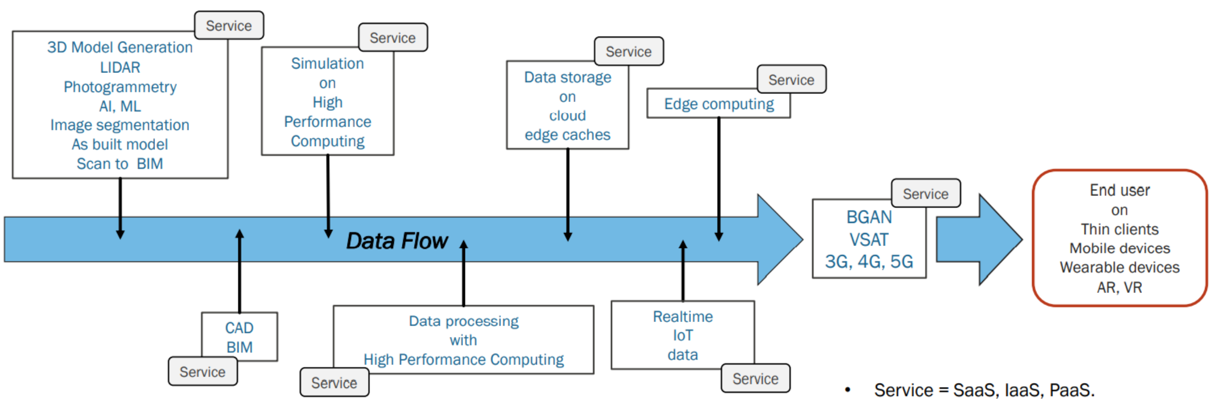
Wireless capabilities available (current and near future):

## Data vs Wireless Capabilities

- Size of 3D datasets originating from CAD, photogrammetry, LIDAR, bathymetry = Several 100 GB to 10 TB
- Typical memory (RAM) available on a high-end desktop is 128 GB. (1TB = 1000GB, 1GB = 1000MB)

| Wireless mode | Bandwidth (data/sec) | Data size | Time for transfer |
|---|---|---|---|
| VSAT | 4 Mbps | 128 GB | 32,000 seconds = 8.89 hours |
| BGAN | 500 Kbps | 1 GB | 2000 seconds = 33.33 minutes |
| 4G (smart phone in 2022) | 34 Mbps | 100 GB | 2,941 seconds = 49 minutes |
| 5G (smart phone in 2022) | 50 Mbps | 100 GB | 2,000 seconds = 33.33 minutes |

Data Flow from collection to wearable device end-user:




- Service = SaaS, IaaS, PaaS.
- Can also be run or installed on prem, on private infrastructure, private cloud.

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# ANNEX C: C-17 Edition 3.0.0 Drafting Team from the IHO MSDIWG

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