Introduction to the Maritime ICT Reference Architecture

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Intelligent Ship Transport System

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Executive Summary

This report gives an overview of the background for the ISTS project. This includes the role of digitalization in reaching the UN sustainable development goals as well as a discussion of the benefits of digitalization and standardization (section 2 and 3). A main point is that digitalization is essential in reaching the sustainable development goals, but that the maritime sector is small compared to others, and that standards and international cooperation are required to accelerate digitalization in the sector.

Section four goes on to give an overview of a suggested maritime reference ICT architecture (MIRA) that can be used to facilitate harmonized standardization in the sector, without losing the opportunity to develop the different components separately.

Terminology and abbreviations

AIS	Automatic Identification System
API	Application Program Interface
CG	Correspondence Group
CMDS	Common Maritime Data Structure
EGDH	Expert Group on Data Harmonization (sub-group of IMO FAL Committee)
FAL	Facilitation Committee in IMO
GNSS	Global Navigation Satellite System
GT	Gross Tonnage (for ships)
HF	High Frequency (Short wave radio)
HTTP	Internet hypertext transfer protocol, secure version as HTTPS
IALA	International Association for Aids to Navigation and Lighthouse Authorities
ICT	Information and Communication Technology
IEC	Standards organization International Electrotechnical Commission
IHO	International Hydrographic Office
IMO	International Maritime Organization
IP	Internet Protocol
IRDM	IMO Reference Data Model
ISO	International Organization for Standardization
ITPCO	International Taskforce Port Call Optimization
ITS	Intelligent Transport System
JSON	JavaScript Object Notation
kbps	Kilo-bits per second
MF	Medium frequency (medium wave radio)
MIRA	Maritime ICT Reference Architecture
MSC	Maritime Safety Committee in IMO
MSW	Maritime Single Window
MQTT	A publish-and-subscribe messaging protocol maintained by OASIS
NAVTEX	"Navigational Telex", mainly on MF or HF frequency bands. Low bandwidth messaging service.
OASIS	The Organization for the Advancement of Structured Information Standards, https://www.oasis-open.org/.
OPC UA	Open Process Control Unified Architecture

OT	Operations Technology
PCS	Port Community System
PKI	Public Key Infrastructure
S-100	The new hydrographic system for description of electronic chart s and overlays
SIP	Strategic Implementation Plan (of e-navigation [12])
SOLAS	IMO Convention on Safety of Life at Sea
REST	Representational State Transfer (architectural style for HTTP and similar systems)
UNECE	UN Economic Commission for Europe (Responsible for UN/EDIFACT maintenance)
UN/EDIFACT	Messaging standard developed and maintained by UNECE.
VDE	VHF Data Exchange (2-300 kbps sub-channel of VDES)
VDES	VHF Data Exchange System (Not yet fully standardized). Will include the existing AIS.
VHF	Very High Frequency – for ships this is approximately 156 MHz to 174 MHz. Mostly voice communication, but AIS and VDES uses digital channels in this band.
VTS	Vessel Traffic Services
WCO	World Customs Organization
XML	Extensible Markup Language

1 Introduction

This document will discuss the benefits of digitalization, the need for an ICT reference architecture, and the need for standards. It will also identify other ISTS deliverables that will describe the main standards and specifications that can be the basis for the maritime ICT reference architecture.

1.1 ICT versus ITS

In the following, the terms ICT (Information and Communication technology) and ITS (Intelligent Transport Systems) will be used in the same meaning as we in both cases are referring to maritime transport. ITS is not a generally accepted term in the maritime domain, so in external communication it is more useful to refer to maritime transport ICT rather than ITS.

1.2 Reference architecture versus architecture

In the application for the ISTS project, the term used was MIA (Maritime ITS Architecture). As will be discussed in section 4, a more appropriate term is a reference architecture, as we aim to develop a more general requirements specification (the reference architecture). More specific standards and specifications will partly define a more concrete physical ICT architecture. However, as standards change over time, the physical architecture may change while the reference architecture remains basically constant. In the following the maritime ICT (or ITS) reference architecture will also be referred to as MIRA (Maritime ITS/ICT Reference Architecture).

1.3 Digitalization

As will be discussed in section 3, digitalization is a combination of digitization and digitalization. In addition, one will also often refer to the digital transformation as a higher level than both. In this document, we will refer to digitalization as any or all these concepts. In the cases where a specific part of the digitalization process is meant, this will be made clear in the text. See also section 3 for a more detailed discussion of these issues.

1.4 A system of systems

The maritime ITS infrastructure consists of several sub-systems or domains as illustrated in Figure 5. This report will provide a background for the ITS architectures as well as a description of the general topology interconnecting the different systems. Other reports in the R3 series will go into details on each system and one report in the R2 series will also detail the protocols and data models related to the whole system.

1.5 The purpose of maritime ITS architectures

Sections 2 and 3 discuss the general benefits of digitalization and section 3.4 discusses the specific need for standards in the area. The ISTS project and reports will attempt to realize these benefits on different levels:

1. Simplify integration within one specific maritime ICT system by proving a more standardized infrastructure and standard integration protocols. This is not the main goal of the work but may be a side effect.
2. Enable easier integration of new and innovative functions into a system by providing standardized data models and mechanisms for transfer of data between existing equipment and the new functions.

3. Simplify communication between systems, and particularly between the ship and land-based systems, by providing higher level standardized data models and mechanisms for data transfer.

These goals require mechanisms on different abstraction levels, from relatively detailed and equipment specific specifications on level 1 to higher level and function-oriented specifications on level 3.

1.6 Structure of this report

This report will describe the concept of the reference architecture and the physical architecture. It will also discuss the benefits and need for standardization in the maritime sector. In addition, it will also go through existing standardization initiatives that are relevant in this context The sections are organized as follows:

1. This is the introduction and general overview of this document.
2. A link between digitalization and sustainable development goals
3. A discussion on what digitalization is and what technical benefits it has.
4. An introduction to the concept of a reference architecture.

The last unnumbered section contains references. The corresponding reference in the text is the number in square brackets, e.g. [1].

Annex A gives an overview of the e-navigation framework and architecture.

Note that the content of sections 2 and 3 to a large extent is copied from a report that was written by the author for IMO.

2 Digitalization and the sustainable development goals

Digitalization is often thought of as a means to do more with less effort, i.e. mostly related to efficiency and economic benefits. This is certainly not the only benefit of digitalization. As will be discussed in section 3, digitization and digitalization have other benefits, and they are a prerequisite for a digital transformation of the maritime sector. In this section we will also briefly explain why digitalization is an important factor in reaching the sustainable development goals for international shipping.

2.1 SDG-5: Gender equality

Shipping and particularly ship crews have a low share of female workers. The BIMCO/ICS 2021 Seafarers report states that only about 1.2% of the seafarers are women. The reasons for the imbalance are varied, but many of the barriers are associated with a masculine working environment and real or perceived difficulties for women to fit in [1]. Digitalization and automation are also generally considered greater problems for women than men regarding the future job market. The jobs that are expected to benefit most from digitalization are, among others, in management, STEM occupations (Science, Technology, Engineering, Mathematics) and entrepreneurship where women are still under-represented in most countries [2].

However, digitalization and automation can also help to improve the gender balance in shipping. One can expect more jobs on shore which is important for having a good family life. It may also ease up the strong hierarchical structure onboard which may reduce the masculine dominated culture on many ships.

This will require that more emphasis is put on the training of the future female workforce with more focus on digital literacy and technical expertise.

2.2 SDG-8: Decent work and economic growth

Various reports investigate the general status of the seafarer workforce [3] and the general satisfaction of the people working onboard [4]. Digitalization and automation can play different roles, both negative and positive in relationship to the seafarers' work conditions, and it is important to make sure that developments also consider what effects they have on the seafarer profession.

One of the positive effects of digitalization is that it has the potential to remove many routine and dull jobs and transfer the ship into a working place for advanced and technically challenging jobs. This will likely increase the demand for officers and highly skilled technical specialists, which is already a noticeable trend [3]. It is also likely that the number of crew now has reached the lower limit and that more automation can help to give the crew more time off and more time to socialize which has been reported as a problem today [4], rather than to further decrease the workforce onboard conventional ships.

However, as for gender equality, digitalization in the maritime sector must be followed up with better and more relevant training to make seafarers more capable to reap the benefits of digitalization and automation.

2.3 SDG-9: Industry, innovation and infrastructure

The maritime sector has changed dramatically over the last 150 years, going from sail, to steam and then to diesel, and within the last 40 years seeing a dramatic increase in computer technology onboard the ships. However, it can be argued that the sector is still using business models that are as old as 150 years or more. This includes such relationships as between charter and ship owner, ship and port, and also related to many of the regulatory prescriptions. These relationships hinder some of the changes that may be necessary to implement the SDG. One example is just in time arrivals, where the economic risk related to late arrival lies solely on the ship owner while the benefit of reduced fuel consumption lies solely on the charterer.

Digitalization and the new innovations that it enables has the potential to change the underlying business models of shipping, with more emphasis on transparency, collaboration, and more effective risk and profit sharing. This can create a new and more effective sea transport system that can much better support the future transport needs.

2.4 SDG-12: Responsible consumption and production

It has been argued that a digital transformation is a necessary component in the shipping industry and to integrate it deeper into the global supply chains [5]. This is a similar argument as for SDG-9 but directed at creating a shipping sector that is much more in line with a future circular economy on an international scale.

There are also digitalization issues related to ship recycling which is expected to grow significantly in the coming years [6]. Many ships will have to be phased out due to stricter emission rules and new ship types may be more complicated to recycle. Appropriate digital information about ship construction, retrofits, repairs, and materials ("digital twin") will be necessary to do effective recycling.

2.5 SDG-13: Climate action

Zero-carbon fuels will be a major challenge for international shipping. Biofuels are not likely to be available in sufficient quantities so ships must probably use new carbon free energy carriers. Energy carriers like hydrogen or ammonia are very expensive and voluminous compared to traditional heavy fuel oil. They are also expensive to produce in terms of the energy needed and require more complex storage facilities. Natural propulsion assistance from, e.g. wind and currents will help to some degree, but operational energy savings will be necessary to keep costs and complexity at a reasonable level. This is closely connected to digitalization to make ship operations at sea and in port more efficient.

2.6 SDG-14: Life below water

Digitalization will also play a major role in making shipping safer and by that reduce accidental spills or lost cargo. This can involve better ship routing, more rapid response when accidents happen, and better monitoring of how the ships impact the environment. Improved control systems on the bridge and in the ship at large can also significantly improve safety and reduce the ship's impact on life below water.

2.7 SDG-16: Peace, justice and strong institutions

Digital communication between ships and authorities can also help to develop a more transparent enforcement of legislation related to ships and shipping. It can be easier to determine when something illegal happens and there will be more detailed and accurate information about how some event occurred. This is particularly important when more complex legislation may be needed to monitor the environmental and safety performance of future ships.

3 Why maritime digital standardization?

Digitalization is a somewhat ambiguous concept as will be discussed in the following. A useful way to illustrate it is as a three-layered pyramid, as shown in Figure 1. The left diagram shows the digitalization pyramid and the right diagram the corresponding role of standards.

In this document, we will use the term digitalization to mean the two lowest layers, although it is more or less implicit that the third and top-most layer follows from the two lower.

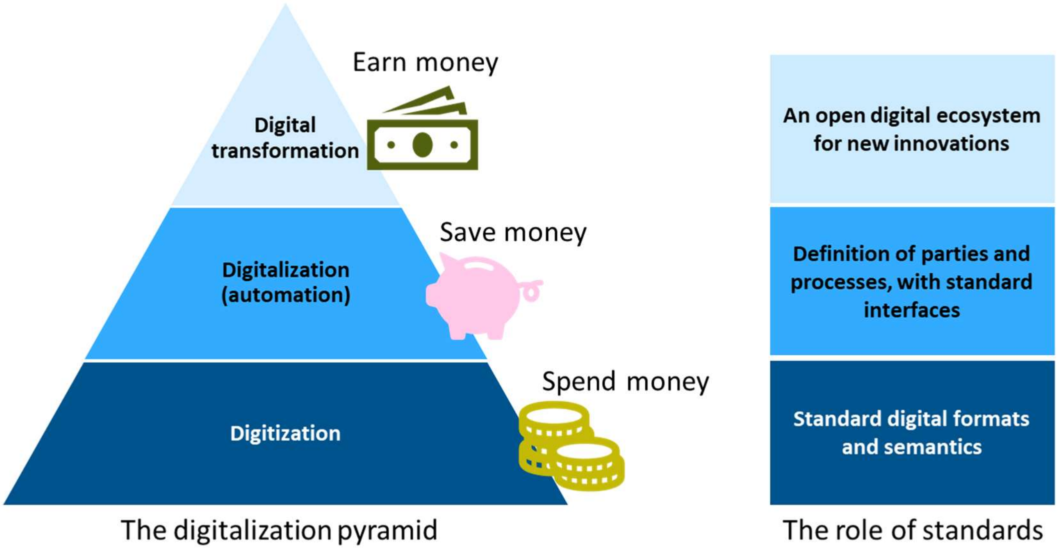

Figure 1 – Digitalization pyramid

The following sub-sections will give a more specific definition of each of these three layers and what role standards play in each.

3.1 Digitization

The lowest layer is **digitization**, which transfers information that was previously in analogue form, e.g. voice or paper into the corresponding digital representation [7]. There are different interpretations of this term, e.g. that an electronically scanned document is a digitized version of the original, but in this report, we will assume that digitization converts the material into a machine readable and understandable format that differentiates between numeric, text and other forms of information. Digitization is a time consuming and expensive activity that does not necessarily return much on the investments. The main benefits of digitization are generally related to the possibility of storing information electronically, e.g.:

1. Save space and money as electronic storage of information normally is cheaper than of the corresponding analogue form.
2. Easier and faster to search in the information, particularly over many files.
3. Better protection of information, e.g. from natural disasters, fires or other accidents as it is easy to establish physically redundant storage spaces with duplicates of the information.

One should note that digitization also requires digital connectivity, i.e. the ability to collect information electronically and transfer it to storage. Digitization will also require some changes in how work is done, e.g. starting to use some form of electronic tool for information management, but the underlying work processes will mostly remain the same.

While the digitization process by necessity is resource consuming, standards may be very helpful if they can provide data models that reduce the need to systemize the data elements and develop own data models. The use of internationally accepted standards may also increase availability of third-party software tools to support the process.

3.2 Digitalization

Digitization will not reduce the workload in the processes affected. Digitization may actually increase workload if, e.g. web forms have to be filled in instead of just writing the information directly on paper forms. To reduce work related to data entry and verification, **digitalization** is necessary to automate the work processes and allow direct machine to machine communication. However, digitalization cannot be done without digitization.

Digitalization is changing business processes to use digital information. This also normally include a high degree of automation of more trivial tasks such as data entry or verification. This enables, e.g. the use of fully automated reporting to coast state authorities through a maritime single window. This can mean significant savings, although the digitalization process as digitization can be resource demanding and expensive. Some important benefits that are expected from digitalization are:

1. Automate trivial and repetitive tasks like data entry and verification. This increases productivity and improves working conditions.
2. Increase speed of processes, e.g. ship clearance, by automating many tasks that do not need human interaction.
3. Provide better information to the decision makers in the processes. This is in reality an effect of digitization, but digitalization allows easier and more relevant automatic retrieval of background information.
4. Better information quality as some human data entry errors can be avoided by transferring the information electronically.
5. Reduce possibilities for fraud through automated and better check of information. This is closely related to electronic authentication and protection of the information.

Standards will be even more important for digitalization than for digitization, as even simple process reengineering can be much more complex than digitization. Also, standards can provide general specifications for interaction with organisations outside one's own when that is necessary. Standards for digitalization, however, is completely dependent on standards for digitization.

3.3 Digital transformation

Having generally accepted standards for digitalization can also contribute to the creation of a "digital ecosystem" where many parties use the same information models and exchanges. This makes it much easier to create new and innovative applications to further increase automation and efficiency, i.e. support a **digital transformation.** This is where the renewal of the maritime industry can take place and where new business methods and tools can be developed.

However, digital transformation also has its challenges. As it normally creates a larger eco-system where the involved parties' roles will change or will have to be developed from scratch, the number of and complexity of the interdependencies between parties are likely to increase. The functioning of the eco-system will directly depend on how well these interdependencies are resolved.

This creates a danger in that some parties are unwilling to participate on equal terms in the new ecosystem and that the transformation fails, and any investments are lost. Thus, in addition to having the physical prerequisites for the eco-system, i.e. the digitization and digitalization in place, one need also to build trust among the parties. In a large eco-system like for smartphones, this is normally less of a problem as interdependencies are weakened by the sheer size of the eco-system. In the maritime environment, this may be a larger challenge.

3.4 The need for standards

The previous sub-sections discussed the size of any new digital eco-system in the maritime sector and compared it to the smartphone market. As illustrated in Figure 2, the smartphone market consists of more than 7.5 billion smartphones where there are essentially only two different software platforms, Android and iOS [8]. In comparison, there are about 96 000 ships larger than 100 GT in international trade, [9]. In addition, virtually all these ships have different ICT infrastructures and equipment. On the land side, Lloyd's Maritime Atlas [10] lists around 8000 ports around the world. Again, most of these ports are different and use different software for their management functions.

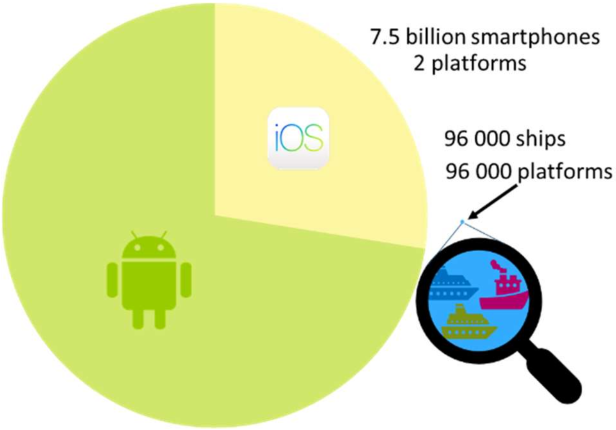

Figure 2 – Relative sizes of markets for smartphones and ships

The mobile phone market is more than large enough to support an organic evolution of the platform technology. This cannot be expected in the maritime sector where international cooperation must be established to develop the necessary standards to ensure a more homogenous maritime ICT architecture and by that a suitable platform for more extensive innovations in digitalization and automation.

As has been pointed out in the sections above, standards are critical for efficient digitalization of the maritime sector. However, the shipping sector is small and cannot rely on organic evolution of the necessary ICT standards. This means that the sector needs a more structured and cooperation-oriented approach to development of standards. Also, the establishment of a common eco-system for new innovative digital solutions requires that we cooperatively work with standards to get a common agreement on how relationships in this new eco-system should work.

4 The Maritime ICT Infrastructure and the Reference Architecture

4.1 An outline physical architecture

The digital interactions in the wider shipping community are quite complex as illustrated in Figure 3. A wide range of different parties need to communicate with the ship in addition to ship internal integration. The figure numbers four main classes of communication as follows:

1. **Onboard system integration** represents onboard data networks, protocols and infrastructure that makes data from the ship system available.
2. **Local nautical operations** are communication implemented on mandatory channels such as AIS and VHF radio (red label) and which is used to communicate with other ships or entities in the fairways. This is the main component of e-navigation.
3. **VSAT/MSS/5G (IP)** is communication that is done via satellite. This can be via satellite systems requiring a directional dish antenna (Very Small Aperture Terminal – VSAT) or via systems that can operate with more general non-directional antennas (Mobile Satellite Systems – MSS), or land digital infrastructure, e.g. 5G mobile data. This includes business to authority (red lines) as well as business to business (black). This type of communication is normally via various Internet Protocols (IP) and can be both mandatory exchanges with authorities (red) or more commercial and operational exchanges (black).
4. **Local port operations** are communication related to infrastructure in port, such as tugs, pilots, mooring systems, land supplied electric power (cold-ironing) or cargo handling. Currently this is mostly voice over VHF, but it is expected that many of these systems may be automated in the future, e.g. with the development of the new VHF Data Exchange System (VDES). This also includes parts of the terminal operations that are directly linked to ship operations, e.g. cargo tracking and tracing.

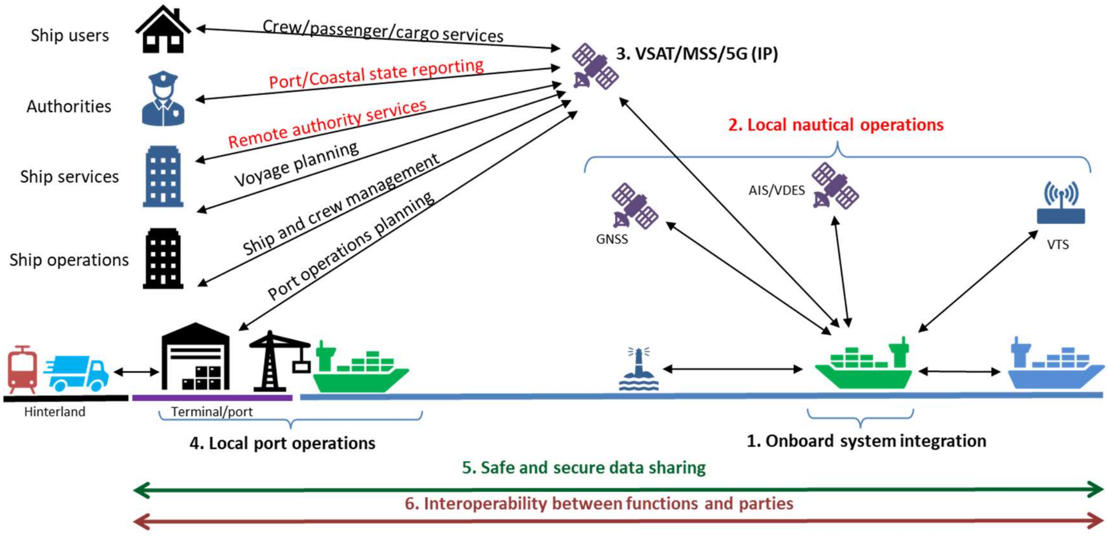

Figure 3 – The ship's digital context

In addition to the actual communication facilities, there are also two other dimensions of electronic communication that needs to be considered:

5. **Safe and secure data sharing** to ensure that communication is not tampered with or overheard when it is of a confidential nature.

6. **Interoperability** between functions and parties to make it easier to share information between parties, independently of in what context the information was acquired.

The maritime ICT architecture is intended to define a framework for all the different communication links as well as the more general interoperability and safety/security perspective. The focus is more on a case-by-case physical inter-connection between stakeholders than on a systematic principle for construction of the relevant protocols.

4.2 The purpose of a maritime ICT reference architecture

As can be seen from Figure 3, the maritime ICT context is complex with a high number of different information exchange and network standards. These are unfortunately still being developed in their own "silos" with little coordination with other standards for adjacent applications or areas. This is unfortunate as increasing digitalization requires increasing communication between physical entities and different business and organizational domains.

To address this problem, one might want to develop one holistic, all-integrating standard, but this is not possible for several reasons. One problem is the different communication channels utilized in the area and very different physical properties for each. This makes it impossible to use, e.g. general IP type protocols on all exchanges. Another problem is that the complexity of such a specification would be prohibitive for effective development and maintenance. Also, the different business and organizational domains are also overlapping with other domains even further from the ship-land interface that would also need to be taken into consideration.

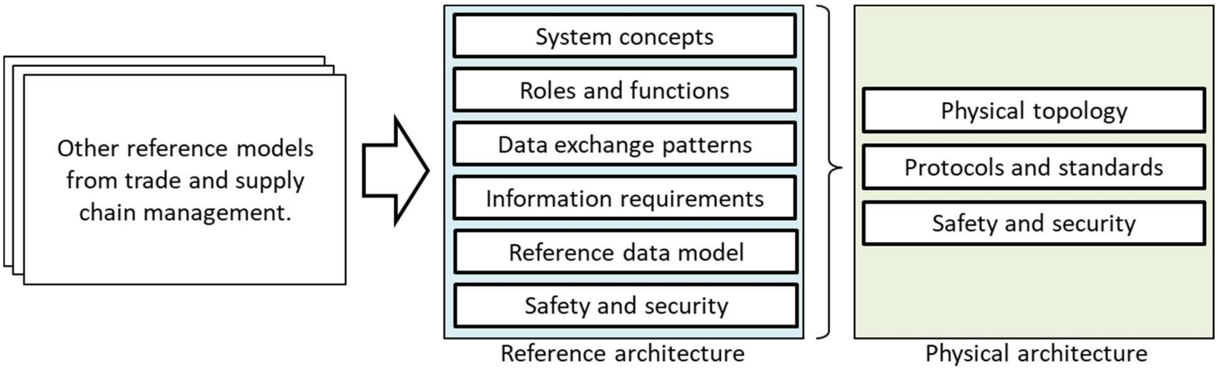

Figure 4 – Outline of an ICT reference architecture

A more viable solution may be to develop a reference architecture that can act as a pattern for the development of the individual standards. A reference standard can be seen as a requirements specification that the actual physical architecture can be built on. Specific protocols and standards will be part of the physical architecture as well as the specification of the actual topology and any necessary infrastructure services.

The reference architecture may also use building blocks from other reference architectures. In Norway, the ARKTRANS model [13] has been proposed, but with limited uptake. However, some components may still be useful. The ITS community has also proposed some architectures that may be considered, e.g. the US National ITS Architecture [14] or the EU FRAME Architecture [15].

By defining these general elements in the ICT reference architecture, one should be able to define the individual components of the physical architecture independently, but still retain a good level of interoperability in the system. The next sub-section will give a brief overview of the components.

The physical architecture will consist of three main components:

1. **Physical topology:** A description of how parties are interconnected. This is most likely an evolving specification with some differences between different regions.
2. **Protocols and standards:** These are the actual protocols used in communication between parties, implementing the physical topology. If linked to a reference architecture, these elements will be a realization of the information requirements, reference data model, and data exchange patterns from the reference architecture.
3. **Safety and security:** These are the same elements as in the reference architecture, but with specific implementation related to the physical topology and the real protocols.

Thus, a physical architecture will be one possible realization of the reference architecture.

4.3 Content of the maritime reference ICT architecture

Some of the components of the maritime ICT reference architecture are at least partly available. However, there is a need to systemize and standardize the components. The furthest developed is the reference data model in the form of the IMO Reference Data Model (IRDM).

The following subsections will provide a brief description of the main components.

4.3.1 System concepts

This is high level view of the maritime transport system with a definition of the main entities and the system's surroundings. A simplified example was shown in Figure 3.

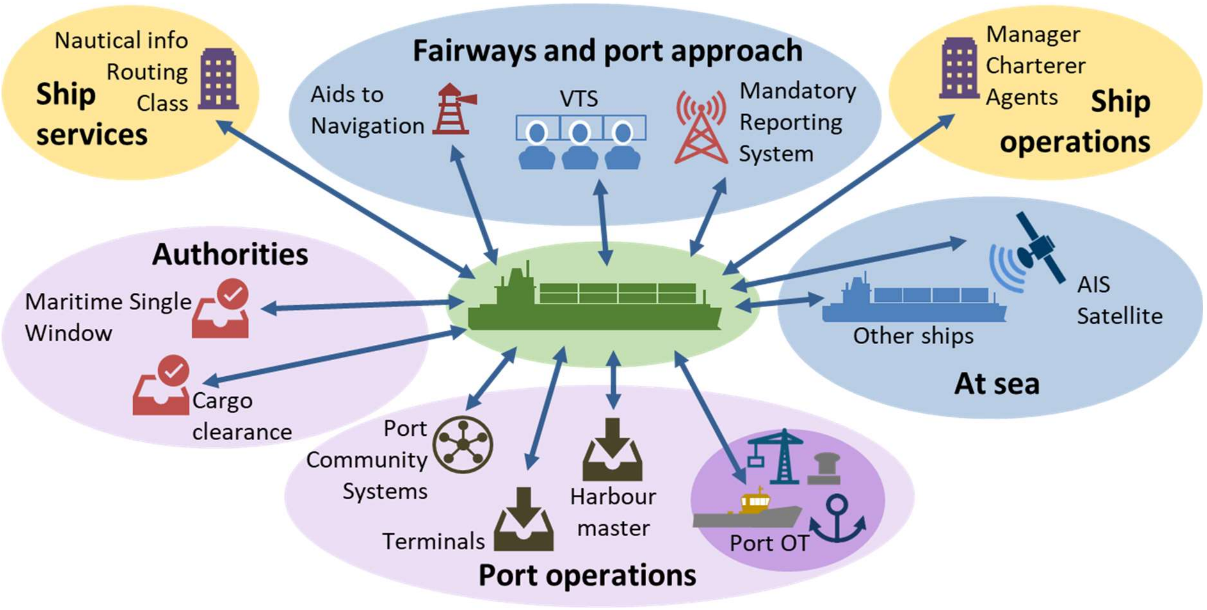

Figure 5 – A more detailed overview of domains

Figure 3 is further refined in Figure 5 where "local nautical operations" have been split into "fairways and port approach" and "at sea". "Port operations" include port and terminal elements. More details have been added to the different domains except the ship itself.

4.3.2 Roles and functions

This is a general description of the most common parties to the different information exchanges and for what purpose they communicate. As the physical organization vary between ports, ships and authorities, this type of description should focus on higher level "roles" and "functions" rather than the physical institutions and the specific local work processes. It is also important to focus on the interactions between roles to perform a given function rather than the internal process that each role uses to implement the function. The main purpose is to describe interfaces.

This component has so far been implicit in some of the IMO instruments as well as some of the documents that have been the basis for the IRDM. Some relevant examples are:

- FAL Guidelines for setting up a Maritime Single Window [16]. This document defines certain types of computer systems and single windows used by the port and the port state.
- The e-navigation strategy implementation plan [11] defines some types of roles and connections related to the work on e-navigation.
- The ITPCO has published a process model with roles and functions for the port call process[18]. This is related to the just in time arrival guide [17].

These are only a few examples that can be used as a starting point for defining roles. Functions are somewhat more complicated to systemize, but the functional descriptions are available in the same type of references as above. In addition to the list of roles, the architecture should also maintain a list of general function descriptions. Both will have to be living documents, developing as more functions are included in the architecture.

4.3.3 Data exchange patterns

This is a general definition of the necessary interactions between functions in the previous layer should be performed.

Figure 6 shows an example of a message sequence diagram for the port call process where the captain of a ship negotiates arrival times with the berth operator.

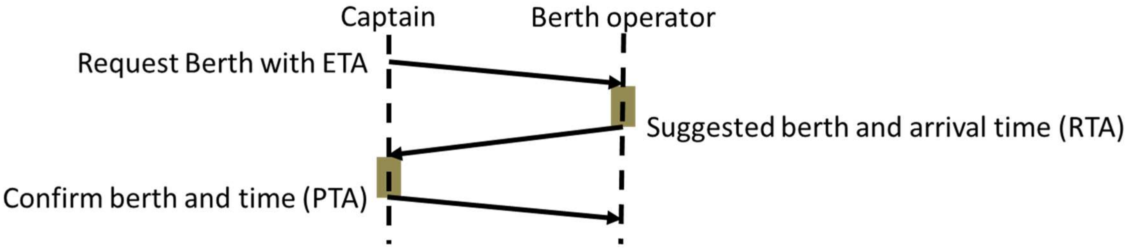

Figure 6 – Example of message sequence diagram

This type of diagram is used to describe the work process interactions necessary to realize the functions from the previous sub-section. The roles will label each of the vertical lines, representing the order in which information is exchanged.

4.3.4 Information requirements

This specifies the general information requirements for each role to perform its side of a specific function. This defines the information that must be available and possibly transmitted between the roles.

On each of the arrows in the sequence diagram there will be a minimum information requirement. Going back to the just in time arrival guide [17], and looking at the departure passage planning function for the voyage to the next port of call, one can see that the captain needs the following information:

1. Berth information for next port of call.
2. Port information for next port of call
3. Applicable Nautical charts and publications.

As some of this information may not be publicly available, it may be necessary for the captain to explicitly request the missing information from the other party. The information request may be a separate more general function, or it may be embedded in one of the triggering messages in the underlying function description. The specific message exchanges will normally be described in the specific technical protocol describing the implementation of the function and will not be part of the architecture.

However, the general information requirements, as far as they are known, should be described together with the function.

4.3.5 Reference data model

This layer should give semantic unambiguous definitions of information elements that are used to implement the functions. This would allow the implementation of different protocol standards for the different functions but ensure that the same meaning and representation is given to each common information element. This is already being developed within the IMO framework for some of the information requirements [11].

The IMO Compendium and the IRDM should be the starting point for the reference data model. This work is already progressing with good speed, but as complexity of the model increases, it may be necessary to look at a better modularization. One should also note that the model covers different types of information as shown in Figure 7. The definitions of each of these information types are maintained by different organizations. The grey cloud illustrates that the IRDM should be a sub-set of the relevant information sets and provide harmonized definitions for data elements that exist in the intersections between sets.

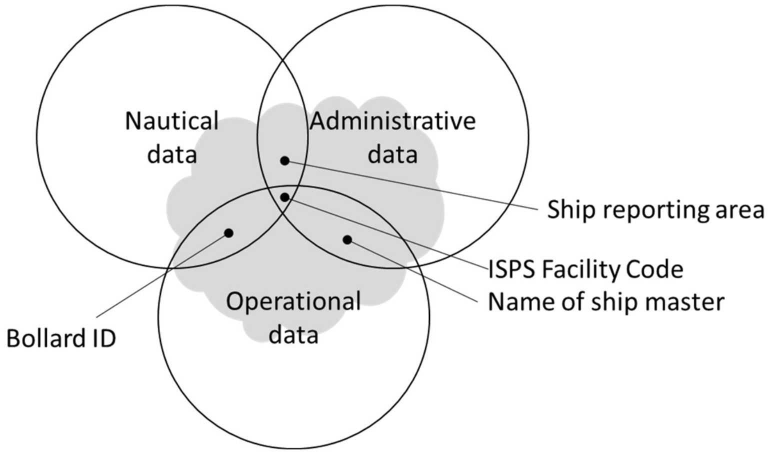

Figure 7 – Different types of data in IRDM

The different types of data that are illustrated are:

- **Administrative data** is data that is exchanged between businesses and administrations, e.g. as in most maritime single windows. The ISPS facility code, name of ship master and a ship reporting area are examples of objects in this group. These data elements are defined in international conventions, e.g. the FAL Convention, MARPOL or SOLAS.
- **Nautical data** is geographic information system (GIS) type data and is normally managed by IHO and will typically go into S-100 type specifications to identify and describe geographic objects, such as an ISPS facility, a bollard or a ship reporting area.
- **Operational data** is information that is exchanged between businesses, e.g. berth operator and captain to facilitate efficient operations. Information about bollards to be used for mooring and the ISPS code may be useful data objects in this group as is also the name of the ship master. These data elements must be defined by the industry.

As different actors are involved in the maintenance of the data sets, it is very important also to establish a good cooperation between these actors so that the organizations' definitions of the individual data items always are in line with the IRDM definitions.

4.3.6 Safety and security

Safety and security mechanisms need to be defined to ensure that critical data cannot be tampered with, and that confidential data cannot be listened into. This may also include information backup procedures, fall-back solutions in case of critical component failures etc.

The need for integrity checks, authentication of sender, confidentiality of content and non-repudiation of sent messages will be central in a more digital and automated environment. As these issues must be catered for also in digital information exchanges, it should also be covered by the ICT architecture. See also the IMO guidelines on this subject [19].

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Annex A – E-navigation architecture

The e-navigation strategic implementation plan (SIP) [12] also defines an "ICT architecture" as illustrated in Figure 8. According to the SIP, two central elements are:

- The Common Maritime Data Structure (CMDS) that spans the whole of the horizontal axis. This corresponds to parts of the reference data model in MIRA.
- The World Wide Radio Navigation System (WWRNS). This is not an element in MIRA as that has a higher-level operational scope than e-navigation.

Otherwise, the architecture shows most of the principles for information flows in the e-navigation system and must be considered more of a physical architecture.

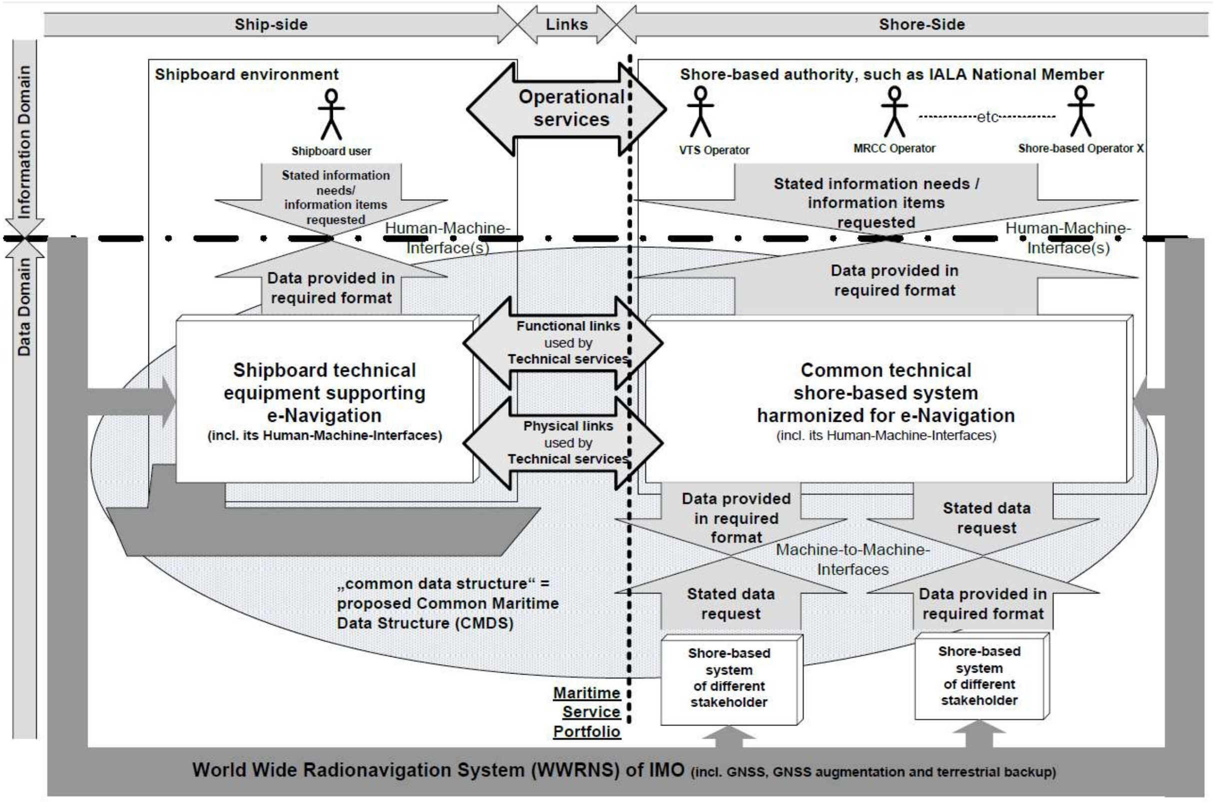

Figure 8 – Ship and shore e-navigation architecture [12]

While Figure 3 only outlined some relevant operational services, the SIP has identified five specific e-navigation solutions:

1. S1: improved, harmonized and user-friendly bridge design;
2. S2: means for standardized and automated reporting;
3. S3: improved reliability, resilience and integrity of bridge equipment and navigation information;
4. S4: integration and presentation of available information in graphical displays received via communication equipment; and
5. S5: improved communication of VTS Service Portfolio (not limited to VTS stations).

Each of the e-navigation solutions has been divided into several sub-solutions [12], but in this analysis only sub-solutions related to digitalization of communicated information have been looked at. These have a relevance code in the tables that refers to an annotation below the table. As annotations are only made once, many sub-solutions will refer back to previous annotations, e.g. relevance code 1.2 refers to item 2 in subsection A.1. Some of the solutions is relevant for ongoing work in the IMO facilitation committee (FAL). The latter is marked with the code "FAL" in the relevance column.

A.1 Improved, harmonized and user-friendly bridge design

Table 1 lists the identified sub-solutions. All sub-solutions are related to function group 1, onboard system integration.

Table 1 – Sub-solutions of e-navigation solution 1

Code	Description	Relevance
S1.1	Ergonomically improved and harmonized bridge and workstation layout.	1
S1.2	Extended use of standardized and unified symbology for relevant bridge equipment.	1
S1.3	Standardized manuals for operations and familiarization to be provided in electronic format for relevant equipment.	
S1.4	Standard default settings, save/recall settings, and S-mode functionalities on relevant equipment.	1
S1.5	All bridge equipment to follow IMO BAM (Bridge Alert Management) performance standard.	2
S1.6	Information accuracy/reliability indication functionality for relevant equipment.	2
S1.7	Integrated bridge display system for improved access to shipboard information.	1
S1.8	GMDSS equipment integration – one common interface.	1

The main relevance in solution 1 are summarized in the following annotations:

1. The work done in the OpenBridge project[1] also contains activities on integrated bridge system protocols, based on IEC 61162-450 to enable better integration of bridges as well as a harmonized style guides. The protocol work includes integration of several manufacturers' displays on a single screen, integrated dimming and palette selection and some related issues. This work will not be further elaborated on in this report.
2. There is work ongoing in IEC TC80/WG6 on the continuous development of IEC 61162-1 that is the recognized data transfer standard for ship bridges. This work will not be further elaborated on in this report.

A.2 Means for standardized and automated reporting

Table 2 lists the identified sub-solutions for standardized and automated reporting. As can be seen from the relevance column, many of these sub-solutions are relevant for work performed in FAL. This is also the sub-solution that probably requires the most coordination between the IMO committees FAL and MSC.

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[1] http://openbridge.no/

There are two distinct forms of ship reporting that is relevant in the context of this sub-section:

A. Ship reporting for call in port on international voyage as described in the FAL Convention. This is in principle within the domain of the FAL Committee and falls within function group 3, port state reporting.

B. Mandatory ship reporting systems as defined in resolution MSC.433(98) [20]. This is in principle in the domain of the MSC committee and will normally fall within function group 2, local nautical operations.

In the IMO Reference Data Model, both data sets are now included, but work in FAL has so far mostly been concerned with the reporting mandated by the FAL Convention.

Table 2 – Sub-solutions of e-navigation solution 2

Code	Description	Relevance
S2.1	Single-entry of reportable information in single window solution.	1, FAL
S2.2	Automated collection of internal ship data for reporting.	1.2
S2.3	Automated or semi-automated digital distribution/communication of required reportable information, including both "static" and "dynamic" information.	2, FAL
S2.4	All national reporting requirements to apply standardized digital reporting formats based on recognized internationally harmonized standards, such as IMO FAL Forms or SN.1/Circ.289.	2, FAL

The relevant issues for this report are:

1. This is currently being enabled by the IMO Reference Data Model and its implementation in standards from ISO and UNECE.
2. This can partly be achieved today by using the above-mentioned protocol implementations but will also require a standardized API and message exchange patterns as well as a standardized mechanism for authentication and integrity checks of reported data.

A.3 Improved reliability, resilience and integrity of bridge equipment and navigation information

Table 3 lists the identified sub-solutions. Relevance coded as 1.2 refers to item 2 in subsection A.1.

Table 3 – Sub-solutions of e-navigation solution 3

Code	Description	Relevance
S3.1	Standardized self-check/built-in integrity test (BIIT) with interface for relevant equipment (e.g. bridge equipment).	1.2
S3.2	Standard endurance, quality and integrity verification testing for relevant bridge equipment, including software.	1.2
S3.3	Perform information integrity tests based on integration of navigational equipment – application of INS integrity monitoring concept.	1.2
S3.4	Improved reliability and resilience of onboard PNT information and other critical navigation data by integration with, and backup of, external and internal systems.	1, 2

Mostly, this is relevant for protocols that may need to include more integrity information together with the information transmitted (ref. 1.2).

However, two other issues are also important:

1. Ship-shore communication links that carry safety related navigational data may need redundancy to ensure that information is not lost in case of a failure in communication equipment. This may also require mechanisms to switch between communication channels based on needed bandwidth, message priority etc.
2. It may be necessary to protect information from tampering by hostile parties. This may require, e.g. electronic signatures.

Note that item 1 above also will be referenced by later sections.

A.4 Integration and presentation of available information in graphical displays received via communication equipment

Table 4 lists the identified sub-solutions. Relevance coded as 1.1 refers to item 2 in subsection A.1 etc.

Table 4 – Sub-solutions of e-navigation solution 4

Code	Description	Relevance
S4.1	Integration and presentation of available information on graphical displays (including MSI, AIS, nautical charts, radar, etc.) received via communication equipment.	1.1, 1.2
S4.1.1.	Implement a Common Maritime Data Structure (CMDS) for Maritime Service Portfolios (MSP) and include parameters for priority, source and ownership of information.	1, FAL
S4.1.2	Standardized interfaces for data exchange should be developed to support transfer of information from communications equipment to navigational systems (INS).	1.2
S4.1.3	Provide mapping of specific services (information available) to specific regions (e.g. maritime service portfolios) with status and access requirements.	
S4.1.4	Provision of a system for automatic source and channel management on board for the selection of most appropriate communication means (equipment) according to criteria such as bandwidth, content, integrity and costs.	3.1
S4.1.5	Routeing and filtering of information on board (weather, intended route, etc.).	
S4.1.6	A quality assurance process to be followed to ensure that all data is reliable and based on a consistent common reference system (CCRS) or converted to such before integration and display.	
S4.1.7	Implement harmonized presentation concept of information exchanged via communications equipment including using standard symbology and text, taking into account human element and ergonomic design principles to ensure useful presentation and prevent information overload.	1.1
S4.1.8	Develop a holistic presentation library as required to support accurate representation across displays.	1.1
S4.1.9	Provide alert functionality of INS concepts to information received by communications equipment and integrated into INS.	1.2
S4.1.10	Harmonization of conventions and regulations for navigation and communication equipment.	

The main relevance identified here is the following:

1. The definition of the CMDS should be harmonized with the IMO Reference Data Model. This will require alignment with the S-100 system and

A.5 Improved communication of VTS Service Portfolio

Table 5 lists the identified sub-solutions.

Table 5 – Sub-solutions of e-navigation solution 5

Code	Description	Relevance
S5	Improved communication of VTS service portfolio (not limited to VTS stations)	1.2

A.6 Maritime services

As part of the improved provision of services to vessels through e-navigation, maritime services have been identified as the means of providing electronic information in a harmonized way, which in the SIP was linked to solution 5. The proposed list of Maritime Services is presented in Table 6.

A Maritime Service Portfolio (MSP) is a set of operational Maritime Services and associated technical services provided in digital format. The concepts of MSP and maritime services are not finalized, but the following section gives an overview of the current defined services.

Table 6 – Overview of maritime services

No	Name	Provider
1	VTS Information Service (INS)	VTS Authority
2	Navigational Assistance Service (NAS)	VTS Authority
3	Traffic Organization Service (TOS)	VTS Authority
4	Local Port Service (LPS)	Local port/harbour authority
5	Maritime Safety Information Service (MSI)	National competent authority
6	Pilotage service	Pilotage Authority/Pilot Organization
7	Tug service	Tug Authority
8	Vessel Shore Reporting	National Competent Authority and appointed service providers
9	Telemedical Assistance Service (TMAS)	National Health Organization/dedicated health organization
10	Maritime Assistance Service (MAS)	Coastal/Port Authority/Organization
11	Nautical Chart Service	National Hydrographic Authority/ Organization
12	Nautical Publications Service	National Hydrographic Authority/ Organization
13	Ice Navigation Service	National Competent Authority/Organization
14	Meteorological Information Service	National Meteorological Authority/Public Institutions
15	Real-time hydrographic and environmental information Service	National Hydrographic and Meteorological Authorities
16	Search and Rescue Service	SAR Authorities