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IALA GUIDELINE

G1113
DESIGN AND IMPLEMENTATION PRINCIPLES FOR HARMONIZED SYSTEM ARCHITECTURES OF SHORE-BASED INFRASTRUCTURE

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1. INTRODUCTION AND OVERVIEW

This Guideline establishes relevant principles for the design and implementation of harmonized shore-based technical system architectures, as follows.

Firstly, this Guideline identifies consequences stemming from the international context for the design and implementation of any harmonized shore-based technical system architecture.

Secondly, this Guideline identifies the principles governing the seamless and traceable derivation of system engineering requirements for any such system architecture from user needs and user requirements, and the resulting stack of functional layers is introduced.

Thirdly, this Guideline introduces the Common Shore-based System Architecture (CSSA) as a harmonized shore-based technical system architecture showing its most fundamental design principles.

This Guideline supports the IALA Recommendation *R0140 (e-NAV 140) The Architecture for the Shore-based Infrastructure "fit for e-Navigation".*

2. THE CONTEXT OF A HARMONIZED SHORE-BASED SYSTEM ARCHITECTURE "FIT FOR E-NAVIGATION" AND ITS CONSEQUENCES

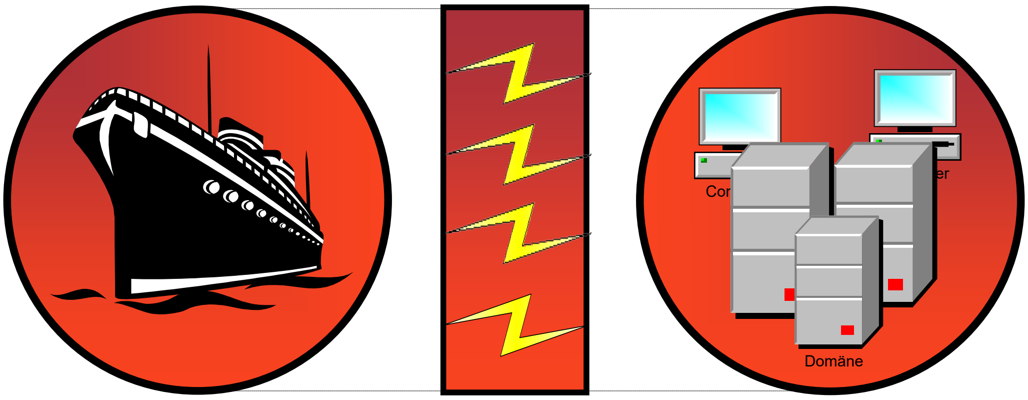
When designing and implementing a shore-based system and its architecture, the international context for doing so should be considered in several aspects that are described in this chapter.

2.1. THE HOLISTIC NATURE OF THE E-NAVIGATION ARCHITECTURE

IMO adopted a "Strategy for the development and implementation of e-Navigation" (*MSC85/26*, Annexes 20 and 21). Therein, IMO adopted the following definition of e-Navigation:

> *e-Navigation is the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment.*

The highest level representation of an architecture derived from this definition is represented in Figure 1 (IMO *MSC85/26*, Add. 1, Annex 20, section 4, refers).



'harmonised collection, integration, exchange, presentation and analysis of maritime information *onboard*'

'harmonised collection, integration, exchange, presentation and analysis of maritime information *ashore*'

Figure 1 Highest level representation of e-Navigation architecture

Three parts of the e-Navigation architecture that interact with each other should be recognized:

1 Shipboard systems of information/data processing devices.

2 Application-to-application data exchange via physical links, ship to shore and shore to ship

3 Shore-based systems that integrate a variety of shore-based technologies and data processing devices.

This implies that all parts should be considered in the context of their respective role or roles when designing and implementing a shore-based system, i.e., they should be considered holistically, while there may be a certain degree of independence for the parts (e.g., the detailed layout of technical systems on-board and ashore) that cannot be separated without missing the goals of IMO's e-Navigation strategy and vision.

2.2. THE OVERARCHING ARCHITECTURE FOR E-NAVIGATION AND ITS CONSEQUENCES

The overarching architecture for e-Navigation (Figure 2), that IMO has adopted and that is a more elaborate representation of Figure 1, should be considered.

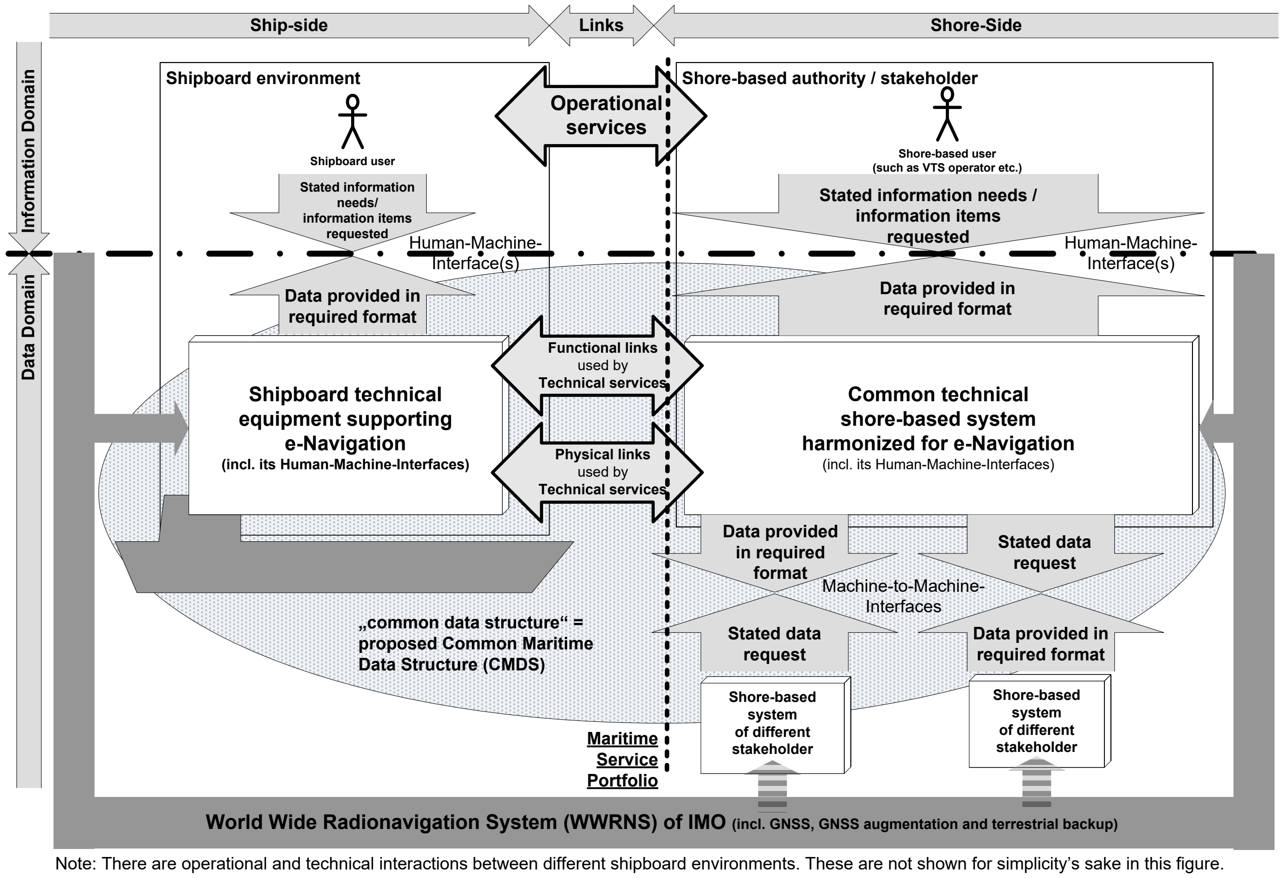


Figure 2 The overarching architecture as adopted by IMO for e-Navigation (compare NCSR1/28, Annex 7, Figure 1, as adopted by MSC94)

Figure 2 shows the most important features and elements such as the:

1 Distinction between the shipboard and the shore side;

2 Information and the data domains;

3 Notion of request/fulfilment relationships throughout;

4 Technical Human Machine Interfaces (HMIs)[1];

5 Notion of operational and technical services provided to shipping as embedded in Maritime Service Portfolio(s) (MSPs);

6 “Shipboard technical equipment supporting e-Navigation”;

7 “Common shore-based technical system harmonized for e-Navigation”;

8 Overarching role of the Common Maritime Data Structure (CDMS) within the data domain;

9 Shore-to-shore data exchange facilities and the required Machine-to-Machine (M2M) interfaces;

10 Dependency on the World-Wide Radio Navigation System (WWRNS).

It should be recognized that Figure 2 implies the following consequences that should be considered when designing and implementing a shore-based technical system:

- *Encapsulation*

  The details of both the shipboard and shore-based system architectures are not shown, i.e., their respective technologies and functions are encapsulated. They are encapsulated because neither the physical links nor the individual technical services or systems matter to the CSS users as long as they are available and reliable. It is the functional links between the shore-based applications and the shipboard applications that matter to the users on both sides. A similar setup of interactions applies for ship-to-ship and shore-to-shore applications. The encapsulation principle hides the technology’s sophistication of the shore-based system as a whole and thus reduces complexity. Amongst other benefits, it allows for parallel work by the appropriate experts in the particular fields.

- Applications should be described using the *data flow concept* developed in IT:[2]
  - *Original sources of data* should be identified together with the data objects stemming from those sources, i.e., the *source data*;
  - Likewise, *ultimate sinks for data* should be identified, together with the data objects required by a particular sink in the information flow, i.e., *recipient data*;
  - When there is *intermediate processing of data objects involved*, the appropriate algorithms should be stated; and
  - *All data objects* should be described by their relevant *attributes or properties*, including their constraints (such as permissible minimum/maximum values).

- *Co-operation* in ship-to-ship, ship-to-shore, shore-to-ship, and shore-to-shore data exchange is at the core of the overarching e-Navigation architecture.

  It is this co-operative nature that prompts the need for harmonization in the definition of e-Navigation.[3]

- The *distribution of responsibilities* among operational stakeholders and engineers as implied by the overarching architecture should be taken into account:
  - *Users and/or operational stakeholders* should state their information needs and the required presentation format at the user interfaces;

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1 A *HMI* can be any kind of appropriate combination of displays, keyboards, voice interfaces (microphone / loudspeaker), and other human interaction devices. The suite of those devices at one operational working position may be called the *Operational Presentation Surface (OPS)* in a summary fashion.

2 The imagery of a ‘flow’ is borrowed from the flow of water; hence, by analogy, the terms ‘information/data source’ and ‘information/data sink’ can be used with a similar meaning: They designate the originator and the ultimate destination, respectively.

3 By the same token, some technical services are called co-operative. There are also so-called *non-co-operative technical services,* which do not require a specific shipboard device for the ship-shore/shore-ship data flow. Examples of non-co-operative technical services are e.g., radar detection in the data flow direction ship-to-shore or visual Aids-to-Navigation in the data flow direction shore-to-ship. These non-co-operative technical services should also be considered an integral part of the shore-based technical system architecture ‘fit for e-Navigation.’

They should continuously involve themselves in the design and implementation process to ensure that their information needs and format requirements are met;

- Engineers should analyse the information needs and take into account the management goals of their organization when designing and implementing the shore-based technical systems, in particular considering the life-cycle-management aspects of any system or component;

  The result of their analysis should be *an engineering-like representation*;

- This engineering-like representation should constitute the service performance specification or even the core of a Service Level Agreement (SLA) between the operational stakeholders and the engineers, i.e., a statement/promise regarding a service level that a technical service delivers;

- *Engineers* should eventually provide the appropriate technical HMI(s), that fulfil(s) the stated information needs and the stated format requirements; and

- The distribution of responsibilities is reflected in an appropriate *documentation framework;*

  This *engineering-like representation* is contained in several documents which are arranged to reflect the e-Navigation paradigm (compare chapter below).

- *Achieving and exploiting commonalities.*

  The e-Navigation strategy is envisioned over a ship's complete voyage from berth-to-berth. Therefore, a high degree of commonality of the data objects and their encoding formats exchanged between the shore-based technical systems interacting with the electronic environments of transiting vessels is required. Minimum common service levels for the shore-provided services are implied by the global nature of the e-Navigation strategy.[4] These aspects are brought together in the IMO defined MSPs concept and are intended to fulfil the IMO stated e-Navigation core objective to demonstrate defined service levels (*MSC85/26*, Add. 1, Annex 20, 5.1.6 refers). Also, a high degree of commonality would result in a smooth transition for the shipboard electronic environment when passing through adjacent areas of provision of the same technical service provided by different shore-based systems, and is therefore required. These requirements are not entirely new, as the shore-based systems of IALA National Members are built to serve similar purposes and to perform similar tasks in particular in the realms of Marine Aids to Navigation and VTS already today. However, by standardising the shore-based systems' architecture further benefits can be gained. This is implied by IMO, amongst other things, when using the description "common shore-based technical system harmonized for e-Navigation" as in Figure 2. Hence, this Guideline eventually culminates in setting up the requirement base for the Common Shore-based System Architecture (CSSA) – common in the above sense.[5]

2.3. THE USER NEEDS AND USER REQUIREMENTS REGARDING INFORMATION/DATA

IMO stated that e-Navigation should be user needs driven. That means that user requirements or operational requirements must be derived from user needs, while taking into account the requirements of the maritime transportation processes they contribute to. User requirements should be analysed and their impact on any shore-based system architecture should be assessed, thereby fulfilling the demand for a user requirement driven system architecture. Conversely, internationally analysed and consolidated operational requirements should be represented in a way that relates to the individual parts of the shore-based system architecture. These two tasks should be continually performed as part of the life-cycle management of the shore-based system architecture.

4 To gain the maximum benefit, the shipboard side needs to eventually also carry standardized minimum capabilities for the functions that are planned to be implemented for e-Navigation.

5 By 'common' it is not implied to say 'shared' which is the other major meaning of the word.

Users should describe their requirements in terms of their respective information needs to perform their tasks. The required information items are to be delivered at the HMIs of the applications as fulfilment of the user requirements using the human-centred design principles. These information items are transmitted, stored, and processed as data objects by the technical systems involved (compare Table 1). They are exchanged using the *functional links* between applications, both shipboard and ashore.

• User needs	(**user/information domain**)
• Identified information needs	(**user/information domain**)
• Functions and services	(**user/information domain**)
------- **Human-machine-interface (Operational presentation surface)** --------	
• Maritime data items	(**data domain**)
• Maritime data encoding for data exchange	**(data domain)**

Table 1 Relationship between User/Information domain and Data domain (IMO NAV56/8, paragraph 26)

Hence, a thorough understanding of the information flows between users and the associated data flow between applications is fundamentally required for e-Navigation. When there is an information flow between users, there is always a parallel data flow between applications associated with it, also implying the storage of data over periods of time together with the retrieval of that data.

User requirements or operational requirements and their associated information needs should be represented in terms of appropriate information structures together with abstract descriptions of the processes and of the functions (including interactions) which are required to properly process the data to arrive at meaningful information for the users.

Since information items can and should be structured in an orderly and meaningful manner, the same should be required for data. Data can and should be structured in an orderly and meaningful manner. By applying certain stated principles of structuring, such a structure is called a model, hence data modelling or data model.

The different dimensions of information/data flow should be considered when analysing the user requirements as follows:

- the large *variety of the nature and amount of information/data to be exchanged* between users/applications resulting in a large variety of appropriate technologies to be considered;
- *widely distributed location of the participating users and/or applications:* on board ships, onboard aircraft interacting with the maritime community and on shore, on floating AtoN, etc.;

  This dimension highlights the requirement for a high connectivity;
- *distributed responsibilities* of stakeholders, e.g., different authorities ashore operating in the same area, but with different tasks;
- *Quality (Quality of Service; QoS), including safety;*

  The usability, accuracy, integrity, reliability or availability, continuity, timeliness, latency, maintainability etc. should be defined, bearing in mind that they are also dependent on software quality; and
- *security:* security, confidentiality etc. should be defined (ISO 27001 refers).

2.4. THE POINTS OF SERVICE DELIVERY OF TECHNICAL SERVICES

For the shore-based technical system under consideration ("own system"), i.e., the "common shore-based technical system harmonized for e-Navigation" in the overarching architecture (Figure 2), *three categories of points of service delivery* should be recognized, namely the technical service(s):

- provided from ashore to shipping as embedded in the MSPs;
- that provide(s) the HMI directly to the shore-based user, e.g., at a VTS centre; and
- that provide(s) data to other shore-based systems via M2M interfaces.

Figure 3 provides a graphical depiction of the overarching architecture which is focussed on the shore-based technical system in a "cut-free" mode, i.e., showing the above points of delivery in their context by using the following graphical symbols:[6]

- *Interfaces* between entities involved are symbolized by a little circle and a line leading to the system which provides and owns the interface;

  There are two main categories of interfaces, namely HMIs and M2Ms. The shore-based system is required to simultaneously support a variety of both interfaces.
- *Technical systems* are symbolized by rectangles, that express the encapsulation principle explained above (black boxes).
- The arrows with the dotted lines indicate *requirements*, which are put forward by the entity at which the dotted line starts.

  Requirement arrow(s) always point to interfaces because the interface(s) fulfil the requirement(s) and are thus the points of service delivery proper.

2.5. THE RELATIONSHIP BETWEEN FUNCTIONAL AND PHYSICAL LINKS AND RELEVANT PHYSICAL LINK TECHNOLOGIES

The relationship between functional and physical links and relevant physical link technologies should be considered as follows. The bold arrow in Figure 2 as well as the several arrows in Figure 3 are graphical representations of the functional connections for data exchange between the shore-based system and the shipboard equipment, and vice versa. In IT terms the originating entity of data in a functional link is called a source, while the receiving or destination entity of that data in the same functional link is called a sink. The physical path of the data exchange uses the physical links and the various physical interfaces between the shore-based technical system and the shipboard equipment, as indicated by the small arrows. *The functional connection* is the abstract statement in regard to requirement analysis for the data exchange of the application. *The physical path* may take a completely different and more sophisticated route. Thus, the analysis is simplified by looking at the functional links, rather than the transmission, network, and/or channel routes.

Eventually the data exchange and the processes and functions using that data need to be manifested in physical links, e.g., a physical communication link, and physical entities and devices. Hence, the requirements and limitations stemming from that physical world need to be considered also. Physical links between (fixed) shore and (mobile) shipboard equipment each employ one or more appropriate mediums such as radio waves or light. Figure 4 shows a variety of physical link technologies which are relevant for the e-Navigation architecture.[7]

6 This usage is informed by the Universal Modelling Language (UML).

7 It also shows that well-known non-cooperative technologies (compare Footnote 3) such as VTS radar can be modelled as a physical link: the data exchanged is the ship's radar echo signature. Figure 4 shows that visual or traditional AtoN can also be modelled in the same way. In fact, visual AtoN may employ a variety of state-of-the-art physical link technologies simultaneously, not just light.

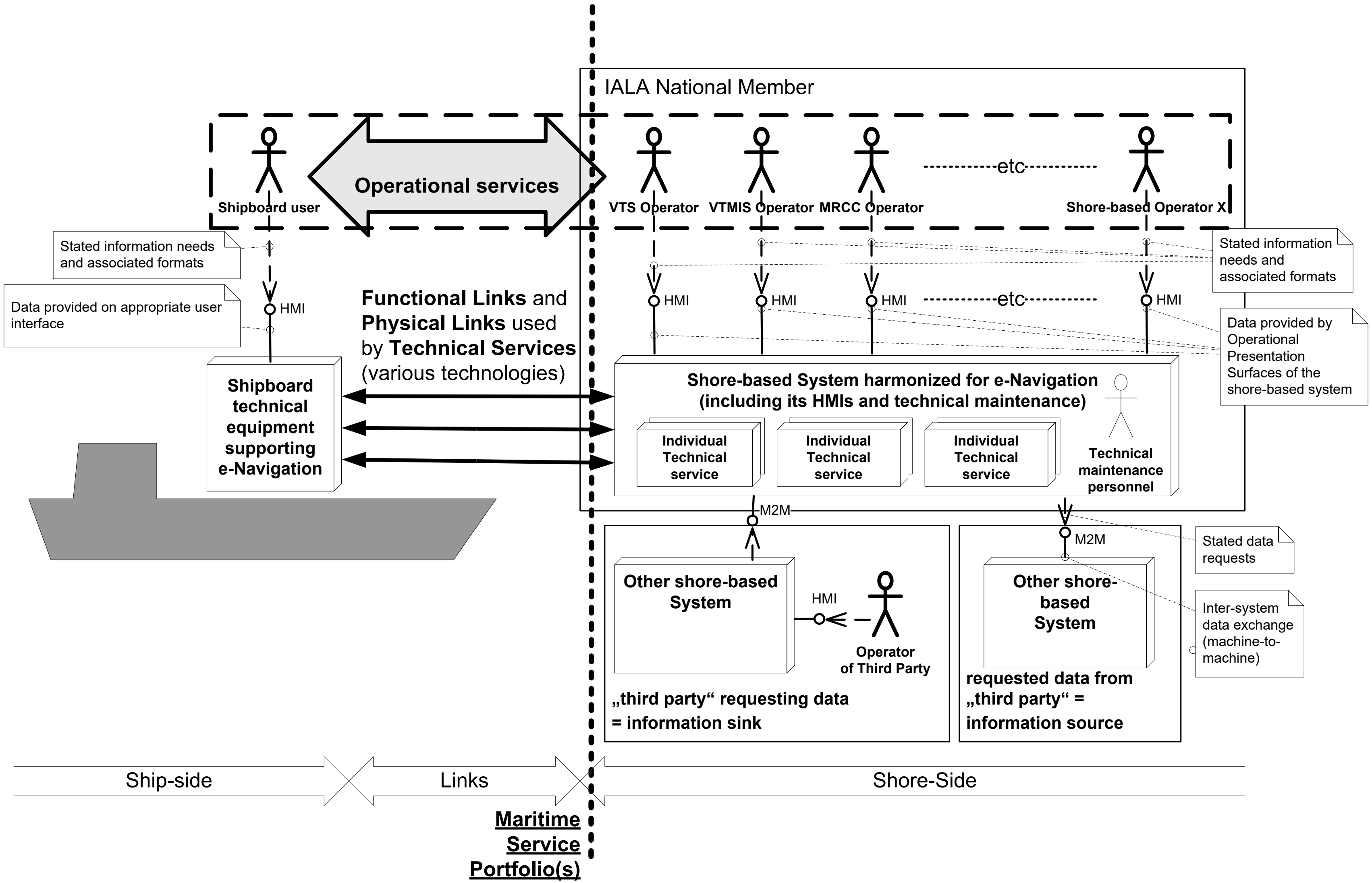

Figure 3 The overarching architecture with focus on the shore-side (simplified representation; i.e., without CMDS and WWRNS)

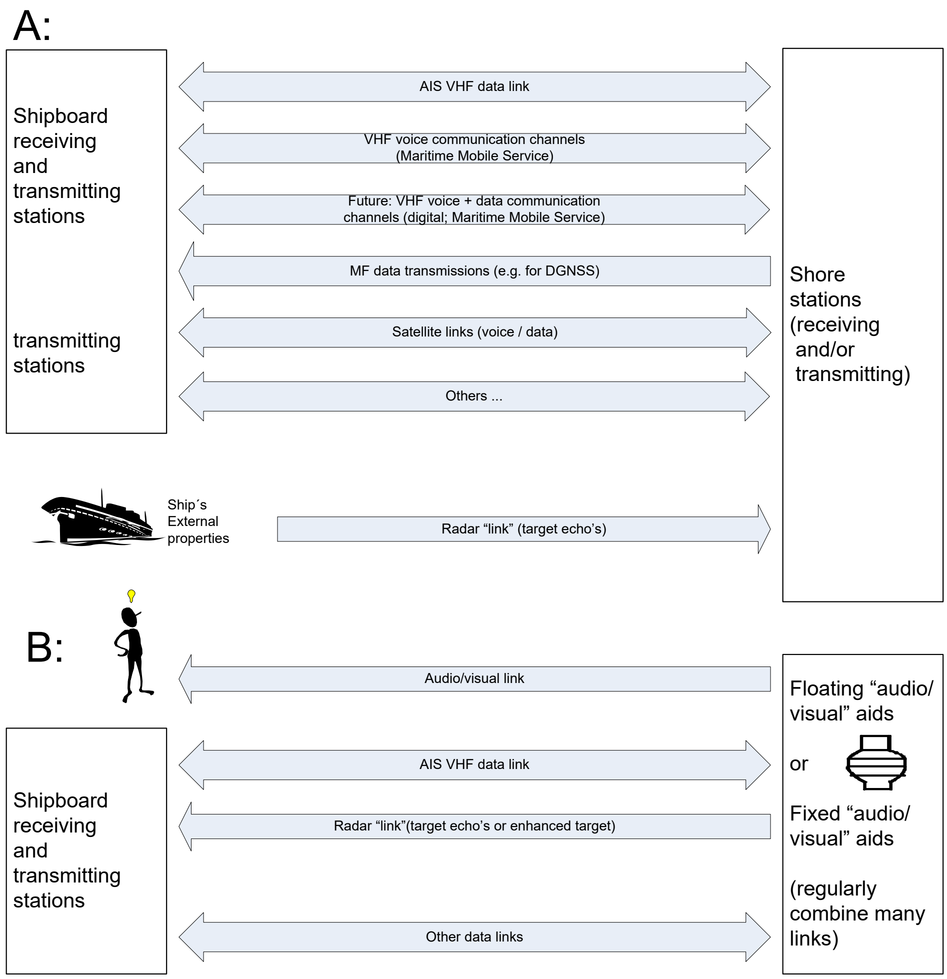

Figure 4 A variety of physical link technologies relevant for the shore-based system architecture

The requirement to address the complexities of both domains, i.e., the functional and physical links, prompted the need for an overarching technical concept to achieve the required connectivity between participants (i.e., their functional links) by the optimum selection of available telecommunications technologies (i.e., physical links or networks).[8] The shore-based system architecture therefore should be capable of supporting such an overarching technical concept.

Arising from the general requirement for appropriate standardization, the technical interfaces of the entities involved as well as their protocols and encoding techniques used throughout the data flow chain should be standardized.

2.6. THE INTERACTIONS OF SHORE-BASED TECHNICAL SYSTEMS AMONGST EACH OTHER

Design and implementation of a shore-based technical system on a local, national, regional or global scale should be considered:

- *Local systems;*

  Local systems provide services to users in geographically confined areas of waterways. Their main goal is to serve the mariner in that confined area.

8 The notion of the 'Maritime Cloud' under discussion is expected to eventually result in such an overarching technical concept. In this context, it should be noted that the 'Maritime Cloud' should not be confused with 'cloud computing' otherwise used in IT.

- *National systems;*

  National systems provide services to users of appropriate waterways in their respective countries.

- *Regional systems;*

  Regional systems provide services to users in a specific region of the world. For instance, the St-Lawrence-Seaway, the whole Baltic area, the Malacca Strait, as a region.

- *Global systems.*

  Global systems provide services on a world-wide scale.[9]

Figure 5 illustrates how the above shore-based technical systems communicate with each other and with the shipboard equipment of vessels passing by. The lines show a substantial sample of the possible relations between shore-based technical systems and shipboard equipment.

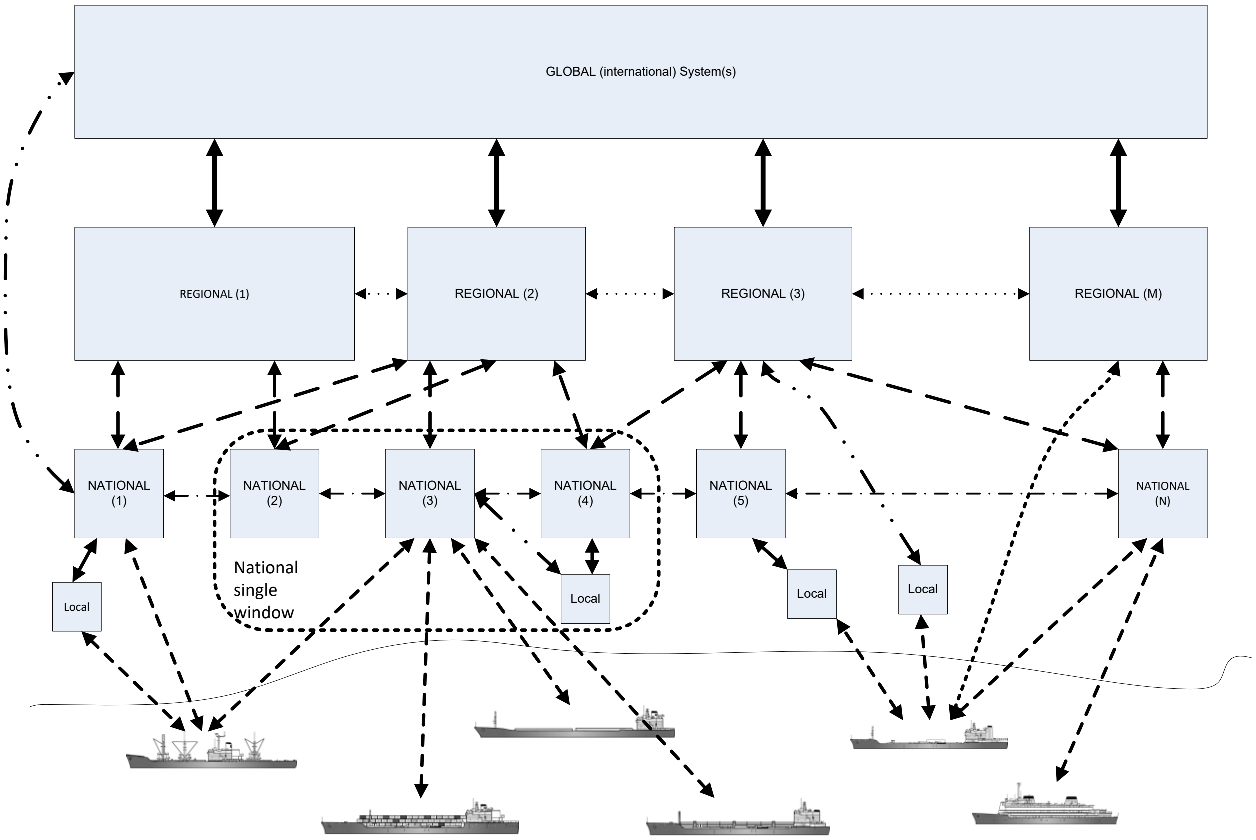

Figure 5 Example of a topology of interactions of different classes of shore-based systems

An IALA National Member generally operates and maintains one of the national systems. Hence, an IALA National Member should take into account the required connectivity to the other shore-based systems operated and maintained by other stakeholders (compare e.g., Annex 2 to Annex 20 of IMO *MSC85/26*, Add. 1, for a list).[10]

In addition, one "core objective" of the e-Navigation strategy is that it should "provide opportunities for improving the efficiency of transport and logistics" (*MSC85/26*, Add. 1, Annex 20, section 5.1.4). The *"Sustainable Maritime Transportation System"* aims to improve, harmonize and optimize the international/global maritime transportation

9 The more general term 'transnational' covers 'regional' and 'global' and will therefore be used as a summary term.

10 Figure 5 provides an example of vessels interacting with shore-based authorities using a 'single window' (indicated by the dotted rectangle) provided by the national system No. 3. National system No. 3 would be responsible for disseminating the data required by the other shore-based systems, i.e., national systems No. 2 and 4 and local system collocated with national system No. 4.

processes. This even *transcends the berth-to-berth scope of the e-Navigation strategy.* The overarching architecture for e-Navigation is able to support the required exchange of data about cargo, passengers, crews, stores, inspections, vessels, vessel traffic etc., so that it may eventually provide a platform for data exchange that connects all the different stakeholders of the global maritime transport processes, including the whole logistics chain (compare Figure 6).

Due to this, efficient, i.e., increasingly automated and standardized, data exchange would be required between the shore-based technical systems of shore-based stakeholders like ports, shippers, consignees as well as with those of different competent authorities and administrations. This would require both interoperability of the shore-based technical systems of different shore-based stakeholders as well as a high degree of connectivity.

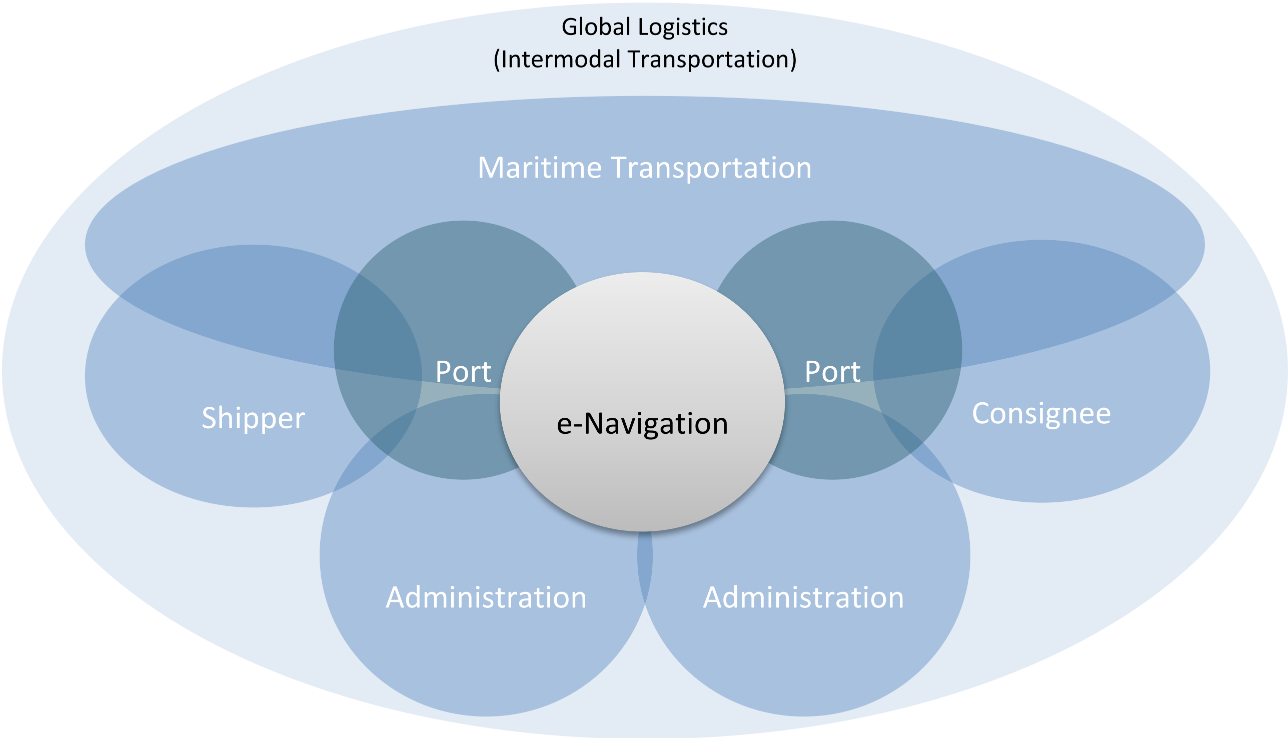

Figure 6 The context of IMO's e-Navigation initiative within the global framework of maritime transportation processes, including the logistics chains

To satisfy both requirements, a degree of international standardization for operational requirements, system architecture considerations, and human-machine as well as machine-to-machine interfacing is required. Standardization of data exchange between the shore-based technical systems should have the goal of achieving a more consistent and reliable system interaction, but also to minimize the burden on the mariner for reporting to the shore-based authorities and to ensure more reliable and more complete information about shipping.

2.7. THE COMMON MARITIME DATA STRUCTURE (CMDS)

Standardized data exchange requires both a standardized data model and standardized data exchange formats. A *standardized data model* describes the data exchanged by using data property definitions. Each and every data object as well as each and every property needs to be identified by an appropriate universal identifier. There are *several data encoding options to* exchange the same data item by using different data exchange formats, each of which is tailored to a specific need. In addition, there are several *data transmission technology options* available to transmit the encoded data. Each shore-based service provider should state, in an appropriate data format, the combinations used by their system.

IMO has identified a common data structure at the core of the overarching architecture for e-Navigation (see Figure 2). The scope of this common data structure is confined to the maritime domain, hence *Common Maritime Data Structure (CMDS).* The CMDS is an abstract data representation of those parts of the maritime domain defined in it at any given time. Specifically, it represents the entities and relationships among the entities that exist in the maritime domain as *meta-level* data descriptions but does not represent processes. The CMDS will contain some degree of data modelling and is intended to serve as a common reference for all implementers and thereby accommodates for harmonization. Therefore, when designing and implementing any shore-based technical system architecture the CMDS should be employed and used as far as available at planning time.

2.8. THE GEO-SPATIAL REGISTRY (GI REGISTRY) BASED ON S-100/S-99

IMO has determined that the IHO standard S-100 should be the baseline for the CMDS. This standard describes the IHO GI Registry which is structured using several "registers" to store meta-level formalized descriptions of "portrayal" and "feature concepts." The IHO standard S-100 also introduces the notion of "products." The IHO standard S-99 describes how organizations external to IHO may interact with the IHO GI Registry by performing roles like "Submitting Organization" or "Domain Owner." Hence, when creating data models and/or "products" for any harmonized system architecture of shore-based infrastructure it is required that they are designed and implemented in accordance with the framework created by the IHO's GI Registry based on IHO standards S-100/S-99.

2.9. THE INTERACTION BETWEEN HARMONIZED SHORE-BASED SYSTEMS AND SHIPBOARD EQUIPMENT ALONG WITH THEIR ANTICIPATED MIGRATION TO E-NAVIGATION

In Figure 2 the term "harmonized shipboard electronic environment supporting shipboard applications" implies that will be a well-defined set of functions and/or components. It is recognized that the presently available modular concepts of the *Integrated Navigation System (INS)* and of the *Bridge Equipment System (BES)* may form a basis for defining the future "shipboard technical architecture harmonized for e-Navigation" (refer to several relevant tasks of the IMO SIP). Similarly, to the shipboard side, the term "harmonized shore-based technical services (…) supporting applications implies that present technologies and system architectures may not be fully supportive of the demands of e-Navigation. Along the maritime and inland waterways there are and will be different shore-based systems operating providing technical services, namely "e-Navigation compliant" systems and legacy systems. These distinct shore-based systems will need to interact with the systems on board ships and other shore-based systems at all times during the migration. Therefore, migration strategies will be required, both for the shipboard and for the shore side individually and jointly. Ease of migration should be considered when designing and implementing a shore-based system and its architecture.

2.10. ADDITIONAL DRIVING FORCES

The following additional drivers should be considered when designing and implementing a shore-based system and its architecture:

- *Increased demand for improved data processing in maritime services;*

  It should be considered that more data is collected and stored in order to facilitate data comparison, data exchange and statistical evaluation.

- *Increased degree of automation;*

  An increased degree of automation is needed to process the increased amount of data and is required to assist shore-based operators and maintenance personnel and to reduce the administrative burden placed upon them.

- *Request for simplification of information sharing between information users and information providers;*

- *Increased demand for communication capabilities and capacity;*

  The maritime community requires user friendly and efficient communication systems that ensure confidentiality where required, integrity and availability of information being transmitted and received ship to ship, ship to shore, shore to ship, and shore to shore. Also, there is an increased demand for communication capabilities with Search-and-Rescue and law enforcement aircraft;

- *Advent of digital information technologies;*

  Most information is now available in digital format both on-board ships and within shore-based systems;

- *Extended area coverage, up to global coverage;*

  There is a requirement for extended area coverage which can be fulfilled more readily by technologies presently under development.

- *Reduction in staffing level;*

  A steady reduction in staffing level is demanded by national governments. Administrations require:

  - An optimum of enhanced technical services to support in terms of both investment and maintenance;
  - An efficient life cycle management system for technical services.

- *Demand for improved cost/benefit ratios;*

  Nationals administrations face a requirement to improve the cost/benefit ratio of their shore-based systems, both in terms of operating and in maintaining them.

- *International standardization;*

  International standardization has been recognized as a state-of-the-art description for technology. Hence, there is an increased need for information and documentation for a common, international and public understanding of system functions.

  Open architecture;

  Modular and open system design principles should be applied striving for “plug-and-play” capabilities. Open system architectures are more scalable and more maintainable. When individual technical components need to be replaced as part of life-cycle management, their functions need to continue to be available even during the component replacement process.

- *Increased demand for formal quality assurance,* applied in particular to the development of systems and products, it will help to foster reliability and simplify the certification process.

3. SEAMLESS AND TRACEABLE DERIVATION OF SYSTEM ENGINEERING REQUIREMENTS FROM USER REQUIREMENTS

3.1. INTRODUCTION AND SCOPE

This chapter addresses the seamless and traceable derivation of system engineering requirements from stated user requirements, which are derived from user needs, from the MSPs which constitute, once fully developed, a requirement base regarding the services provided from ashore to the mariners and shipboard equipment as well as from the other requirement domains listed above. This derivation is necessary because IMO requires a user needs driven design of the e-Navigation architecture:

"The architecture should include the hardware, data, information, communications technology and software needed to meet the user needs. The system architecture should be based on a modular and scalable concept. The system hardware and software should be based on open architectures to allow scalability of functions according to the needs of different users and to cater to continued development and enhancement." (*MSC85/26*, Add. 1, Annex 21, paragraph 5).

Traceability achieved by the seamless derivation is a highly desirable goal in system engineering: Traceability allows to link user or management requirements with system engineering requirements.

3.2. LAYERING AS A STRUCTURING PRINCIPLE

Layering is a structuring methodology which permits the relevant aspects of the desired information/data, services, and systems to be viewed as logically composed of a hierarchy of layers, each wrapping the lower layers and separating them from the higher layers.[11] The "wrapping" and the "separation" incur certain benefits, namely in particular reduction of complexity, relative independency of work on different layers concurrently, encapsulation, and the appropriate design of interfaces.

The basic concept of layering is that each layer adds further value to results provided by the set of lower layers in such a way that the highest layer is offered the fullest set of desired results. Layering thus divides the total problem into smaller pieces.

Another basic principle of layering is to ensure relative independence of each layer by defining the requirements for the results to be achieved by a lower layer under consideration, *independent of how these results are achieved in detail.* This allows also for different methodologies and structures for different layers, which in turn allows for applying the best methodology and structure to the problems to be solved by the layer under consideration, layer by layer. Layering also permits changes to be made in the way a layer or a set of layers operate, provided they still offer the same results to the next higher layer(s).

Figure 7 shows the application of the layering principle to the shore side of the overarching architecture for e-Navigation (compare Figure 2) and as discussed in preceding sections. Figure 7 presents a generic architecture of seamless and traceable system requirement derivation from user and other requirements.

All objects within a layer or at the boundary between adjacent layers need to be uniquely identifiable.

11 This concept of layering should not be confused with the ISO/OSI concept of communication stack layers.

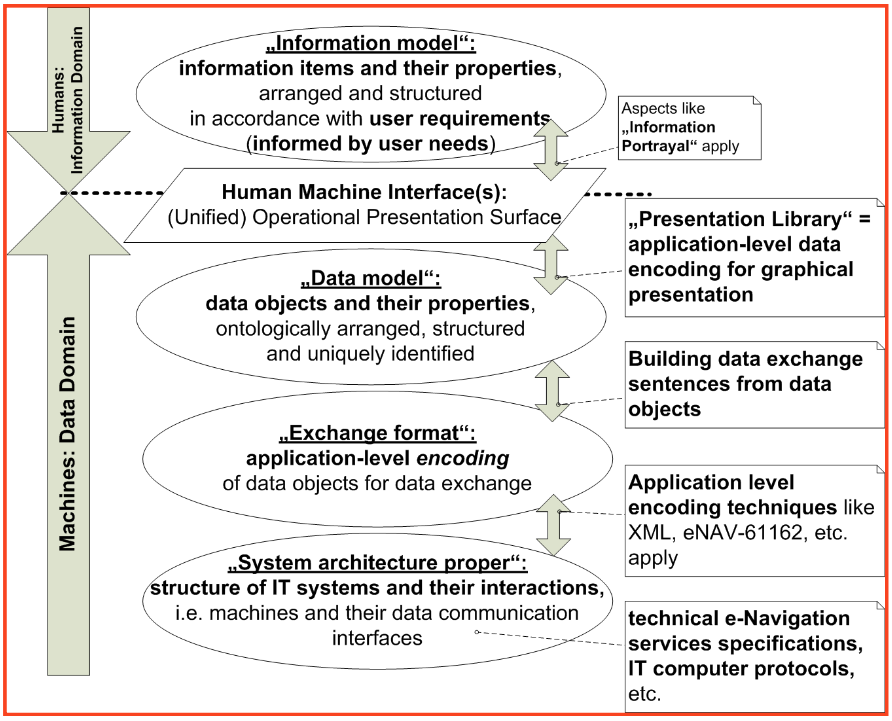

FIGURE 7 Complete overview of a generic architecture of seamless and traceable system requirement derivation from user and other requirements

3.3. THE NEED TO EMPLOY A SYSTEM ENGINEERING MODEL

Due to the rather complex nature of the architecture and the many technologies involved, it is required to apply a state-of-the-art system engineering model that governs the interactions between different layers of the above stack. Also, the system engineering model provides a life cycle management concept for the stack.

An internationally agreed and recognized system engineering model which may be employed for the above stack in accordance with ISO/IEC *15288* standards series is described. It facilitates both a seamless top-down derivation of technical functionality from stated user requirements as well as a bottom-up feedback chain taking into account the impact of technology on human-machine interaction. In both directions traceability and consistency of the respective requirements is maintained, as well as the integrity of the process at large.

3.4. THE COMPLETE PICTURE OF THE SYSTEM ENGINEERING PROCESS – SUMMARY AND CONCLUSIONS

The generic stack as introduced in Figure 7 is shown in a more formalized fashion (but still generic) in Table 2 overleaf in top-down order of appearance and with the complete requirement context included on one hand and with national/regional bodies and/or industry on the other hand.

The "Shore-based technical system" and its architecture in system engineering terms, the Common Shore-Based System (Architecture) (CSS / CSSA), is at the core of the scope of this Guideline and will be further discussed in the following section.

Note to Figure 7: The "sentence" at the layer addressing encoding (in the encoding-free sublayer) should not be construed as an interface sentence (such as e.g., IEC *61162* sentences), but is an encoding-free and orderly arrangement S-100 defined data objects taking into account semantic considerations. Any "sentence" can be encoded for transmission in various ways, eventually. Examples of this internationally harmonized encoding are collected in the appropriate sublayer.

Table 2 Complete representation of the resulting generic layered structure or "stack" together with the system engineering process operative

Topic of layer and name of layer (if defined)	Sub-divisions ("sub-layers," if any)	Administered item of layer	System engineering process
Processes of the (Sustainable) Maritime Transportation System ((S)MTS)	To be determined in due course	Identified logistic processes of the (S)MTS	Informs user requirements
IMO User Needs	Shipboard, shore-based, SAR	Identified user needs	
Maritime Service Portfolios (MSPs) definitions	Operational services	Individual MSP, services delivered to shipping from ashore, their request/fulfilment dependencies, service parameters and their quality level definitions; "product" descriptions for service	Informs user requirements
	Technical services		Informs system engineering requirements
Normative Collection of harmonized user requirements for shore-based technical system(s) of stakeholders assembled at IALA (possibly collected in a register to exploit the maximum of commonality between user requirements)	User requirements common to some or all stakeholders;	User requirements	
	User requirements specific to stakeholder	User requirements	
Normative collection of unified or at least harmonized information portrayal features of the Operational Presentation Surfaces (HMIs) to shore-based users (to be stored in the Portrayal Register of IHO GI Registry within "IALA Domain")	To be determined in due course	Presentation library entries, portrayal descriptions, and/or presentation requirements	Top-Down Path
Normative collection of harmonized or even unified data objects and their properties within "IALA Domain" within the IHO's GI Registry	Feature Concept Dictionary Register	Features' = data objects which in turn are meta-level abstractions of real world entities	Bottom-Up-Path
	Meta-data Register	Meta-level description of above features, such as parameter quality tags and measures	
Normative collection(s) of harmonized or even unified application level encoding prescriptions ("exchange formats")	Generic sentence definition layer	Encoding-free "sentences" (syntax and semantics for data exchange without giving encoding constraints)	
	Technology-specific sublayer(s)	Internationally harmonized technology-specific encoded "sentences" (e.g., in IEC 61162, AIS VDL message, or XML)	
Shore-based technical system and its architecture in system engineering terms: Common Shore-Based System (Architecture) (CSS / CSSA)	Generic part: generic service model	Entities of the CSSA, in particular technical services and their descriptions.	
	Technology-specific part of CSSA: individual specific services		
Procurement documentation with National / regional adaptations by IALA members			
Implementation architectures of manufacturers of shore-based equipment			

4. THE COMMON SHORE-BASED SYSTEM ARCHITECTURE (CSSA)

This chapter focuses on the principles for designing and implementing a shore-based technical system and its architecture, as introduced in Figure 2 and explained in the previous chapters. This shore-based technical system and its architecture are henceforth called Common Shore-Based System (CSS) and its Architecture (CSSA), employing the above requirements:

- "Common": already defined by IMO in their overarching architecture for e-Navigation; for meaning of "common" in this regards see section 2.2;
- "Shore-based": self-evident by the location of the technical system ashore (within the shore-based infrastructure relevant for the scope of e-Navigation);
- "System": self-evident by the topic at hand; and
- "Architecture": self-evident because each technical system has an architecture (whether expressively stated, which is the topic of this Guideline, or implicitly used).

It should be noted, that CSS and CSSA are thus generic names. Each IALA member needs to find a name for their own system appropriate and tailored, like the system itself, to their domestic requirements.

Since the e-Navigation concept mainly is about information/data flow, the CSSA under consideration in this section uses IT concepts and terms extensively.

4.1. THE ENGINEERING APPROACH TO THE COMMON SHORE-BASED SYSTEM

The information requirements as described above can be analysed using an appropriate engineering methodology to provide comprehensive documentation of the data objects and their inter-relationships, technical services functions and their interactions, and component specifications.

The shore-based technical services supporting the information requirements of the shore-based users in turn require certain physical links (signal-in-air) and certain shipboard devices in most cases. Similarly, a requirement chain exists for the shipboard user. (Note: These statements address the requirement chains as opposed to information flow chain.)

During this process management goals such as life-cycle management requirements, need to be taken into account.

There are state-of-the-art engineering methodologies available to facilitate that work, such as the Object-oriented Engineering Process (OEP) and the Use Case methodology.

The most important part of the paradigm of the CSS is the OEP (see Figure 9 below). It describes the methodology applied to the engineering task at hand in the following step-by-step process.

1 List and specify all information requirements and their associated information items for the CSS as a whole.

2 List and specify the internal requirements for the CSS as a whole from a management and technical point of view, taking into account life-cycle management and resource usage requirements.

3 Use engineering methodologies to do an engineering analysis of requirements for the CSS:

The well attested Use Case approach provides such an engineering methodology. It is a point in case that IMO defines e-Navigation in accordance with the Use Case concept: e-Navigation is the harmonized *collection, integration, exchange, presentation* and *analysis* of maritime information *onboard* and *ashore* (…):

a The *five keywords highlighted* above describe what tasks are to be performed with maritime information and are indeed Use Case designations.

b It should further be noted, that IMO's definition explicitly discerns the Use Cases for the shipboard side and the shore side (also *highlighted* above).

c Hence, it can be concluded that IMO's definition of e-Navigation is fully compatible with many state-of-the-art engineering methodologies for requirement analysis, and vice versa.

4 Derive the essential system requirements [12] by exploiting the similarities between stated information requirements of different users and of internal information requirements.

5 Design a CSS layout using the concept of a technical service as building blocks.

6 For each and every essential system requirement identify the interactions of the relevant individual technical services needed to fulfil that specific essential system requirement.

7 Draft a precise functional description of an individual technology as a technical service in accordance with a generic service model.

8 Derive all component requirements for components of an individual technical service.

9 Capture all the above descriptions in a documentation methodology and prepare for the submission to quality management audits.

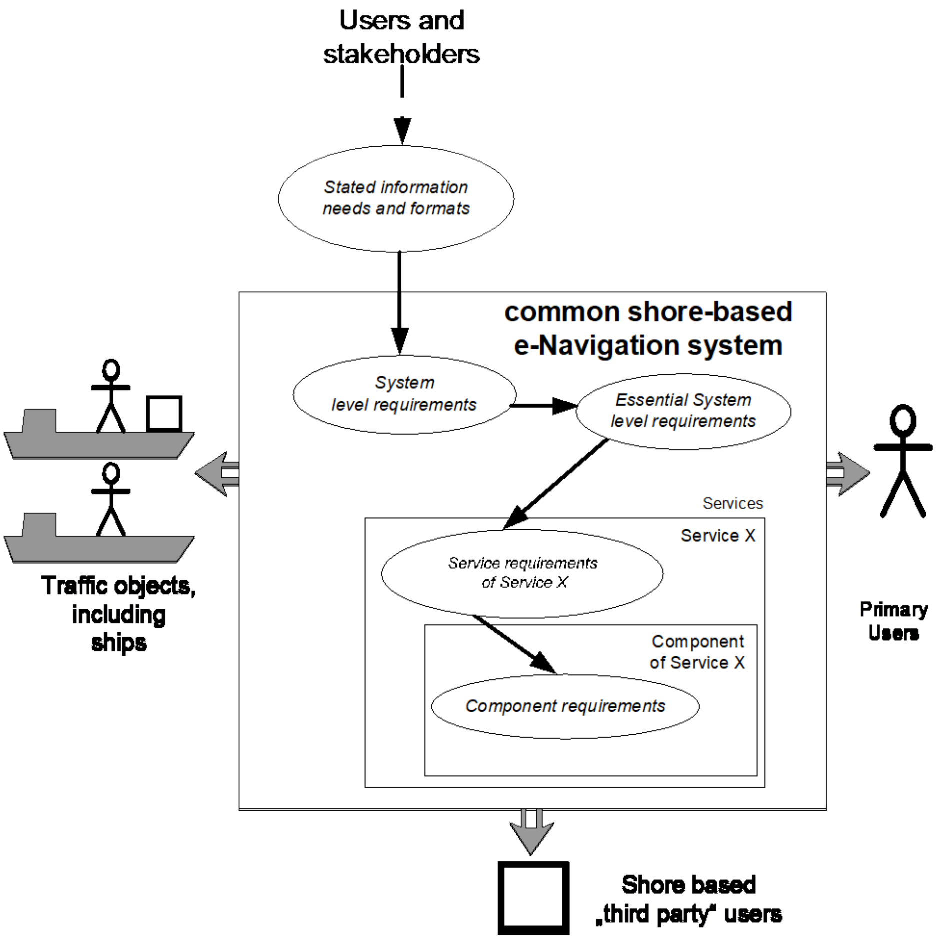

Figure 8 Engineering analysis of requirements for the Common Shore-based System

12 *Essential system requirements* are defined as being both a set of minimum requirements and as a means to exploit synergies due to commonalities or similarities detected. Thus the essence is established, hence essential system requirements.

4.2. GOALS FOR THE COMMON SHORE-BASED SYSTEM ARCHITECTURE

Implementing and adopting the CSSA will have the following benefits. Many of them have also been specifically identified in the IMO e-Navigation strategy.

4.2.1. QUALITY BENEFITS

- provision of user information, as stated and portrayed in a defined, human-centred way, including accuracy, integrity, reliability, continuity, and latency;
- demonstration of "e-Navigation compliancy"[13] to stakeholders by means of appropriate certification of service level achievements;
- application of objective criteria for each technical service provided;
- same level of service is achieved for users with similar requirements;
- extensive usage of applicable international technical standards;
- improved provision, in architectural terms, to incorporate new functions at planning phase, based on revised information and/or portrayal requirements;
- increased dynamic adaptability to incorporate new operational functions at run-time, based on new information and/or portrayal requirements;
- improved responsiveness to new or amended information and/or portrayal requirements; and
- promote Innovation, expand component offerings and improve their quality by creating an "eco-system" for technical services and their vendors.

4.2.2. COST RELATED BENEFITS

- full life-cycle cost evaluation facilitated by the early identification of cost items, both for investment and operating costs;
- reduced cost of design and development by using applicable international standards and re-use of engineering concepts;
- reduced cost of updating existing services and functions due to change of technology;
- reduce cost of implementing additional or changed services and/or functions;
- reduce capital investment:
  - reducing the per unit cost due to standardization; and
  - reducing the numbers of units needed due to better use of already available units (down side: a potential increase in single point failures, hence effective mitigation strategies will be needed).
- reducing operating costs over the full life-cycle, taking also into account cuts in staffing level:
  - remote access/control/maintenance as opposed to only-localized access/ control/ maintenance resulting in consequential savings of working time and travel;
  - automation; and
  - easier replacement of individual components; and

13 While there is presently no direct definition of 'e-Navigation compliancy' or of an 'e-Navigation compliant' operational or technical service or device provided by IMO, the working and therefore tentative definition can be inferred from the IMO e-Navigation strategy. 'e-Navigation compliant' would mean that an operational or technical service or device has been proven, tested, or checked by a competent body to be in conformity with relevant IMO performance standards, which were expressively created or revised as part of the implementation of IMO's e-Navigation strategy.

- avoidance of vendor-lock-in:

  IALA National Members would not be locked-into purchasing the majority of their CSS technical services from a single vendor. Instead it would allow them to assemble a CSS using “best-in-class” technical services. They would be able to mix-and-match technical services that best fit their requirements without facing inter-vendor compatibility issues. They would also be in a better stronger position to negotiate provision of technical service support and upgrades with their vendors.

4.2.3. ORGANIZATION AND STAFF RELATED BENEFITS

- maintaining and widening the level of expertise of technical personnel;
- achieving a common level of understanding between Authorities that interact with each other, if they both employ the CSSA;
- optimising the business processes and organizational procedures involved based on the use of the CSSA;
- potentially optimize the organizational structure; and
- improve training efficiency for technical personnel due to the transfer of knowledge from the general (i.e., the understanding of the generic model) to the specific technology under consideration (i.e., individual technical service).

4.2.4. PUBLIC RELATIONS AND SOCIETAL BENEFITS

- contribution to an improved public relations image of the administration by use of an internationally accepted, advanced system architecture;
- ease of public access to information by e.g., publicly accessible information portals provided by the administration, while the administration simultaneously has the benefit of a standardized method of presenting that information to the public; and
- success in achieving the IMO stated goals for improving the safety and efficiency of navigation, protection of the environment and security.

Most of the above benefits are critical to the success in achieving the IMO stated goals for the e-Navigation concept.

4.3. FUNDAMENTAL SYSTEM ARCHITECTURE DESIGN PRINCIPLES

To achieve the above goals the following fundamental principles for the CSSA should be used:

- user requirement-driven system design, including statements on human-centred design and/or quality levels of service, and a system engineering process;

  Only clearly and consistently stated user requirements result in a provided technical service or a function.
- use of information-orientation to design the system layout;

  All technical solutions should be based on data modelling.
- employment of the principles of modularity and encapsulation, while preserving a holistic view of the system’s intended functionality;
- application of a harmonized and ideally uniform model for all technical services provided by the system, regardless of technology, thus exploiting commonality; and
- use of specifications in international standards to the largest extent possible and procurement of technical solutions based on functional specifications as a rule;

- adherence to open system architecture and focus on open and standardized interfaces between components and services; strive to avoid proprietary interfaces;
- employment of remote access techniques where feasible in order to allow for minimal number of technical operation and maintenance centres;

  Components without remote access capabilities should be avoided (access capabilities should allow for open interfacing, too).
- implementation of life-cycle management in order to prevent quick-fix solutions with associated long-term costs;

  Full life-cycle impact of technical proposals should be considered before accepting them.
- documentation of each and every functional aspect in a uniform, comprehensive documentation system;

  This is a pre-requisite for any quality management system.
- provision of role-based access to the components of the system;

  In particular, roles and personnel for technical operation and maintenance tasks on one hand and roles and personnel for system development and optimization tasks on the other hand.
- take into account regulatory constraints when designing the system architecture, and consider consequential amendments to existing regulations based on the development of that system architecture; and
- support concepts such as certification in general, quality management system in accordance with ISO 9001 series, environmental management in accordance with ISO 14000 series, IT security certification in accordance with ISO 27000 series, and also the IMO Member State Audit Scheme (IMSAS).

4.4. DEPENDENCY ON EXTERNAL SYSTEMS AND INFRASTRUCTURE

4.4.1. DEPENDENCY ON GNSS, AUGMENTATION AND BACKUP SYSTEMS FOR POSITION AND TIME

As indicated in Figure 2, there is a dependency of the e-Navigation architecture on external systems such as Global Navigation Satellite Systems (GNSS) for position fixing and for timing. This may pose certain vulnerability for applications, since dynamic position information is involved in most and time information is required in each one. Hence, mitigation methods are necessary.

Thus, GNSS signals should be monitored by an appropriate technical service for radio navigation augmentation within the CCSA whose use is twofold. They improve the accuracy of GNSS positioning in accordance with the requirements for different phases of berth to berth navigation (ocean, coastal, harbour approach, canal/river, docking). But augmentation systems also inform the user by means of integrity information, if the system can be used for a specific application.[14]

In case of GNSS failure, the CSSA should provide for terrestrial backup radio navigation systems that are an independent source of positioning and timing with the required performance regarding e.g., accuracy, integrity, and continuity.

4.4.2. DEPENDENCY ON ON-SITE INFRASTRUCTURE

The on-site infrastructure provides resource building blocks needed to support the components of technical services on their sites of installation. Main topics include housing and other structures, traditional utility provision

14 An example for a shore-based augmentation system operated by IALA National members is the IALA radiobeacon DGNSS which can be considered as being composed of technical services within the CSSA.

such as power, water, sewer and roads, precise timing, local data networking (LAN), independent fault detection and alert management, HMIs for technicians. It should be noted, that:

- this aspect is usually the largest part of the cost for an IALA National member to support and maintain its shore-based system; and
- on-site infrastructure may have a strong impact on the quality of products / services offered by shore-based systems.

Therefore, when setting up a shore-based system, the on-site infrastructure should be planned carefully to mitigate harmful consequences of that dependency.

4.5. MIGRATION CONSIDERATIONS

IMO has laid out an implementation path in and for their e-Navigation strategy (*MSC85/26*, Add. 1, Annex 20, paragraphs 9.6, 9.8ff) and has developed a more detailed Strategy Implementation Plan (SIP).

So far, IMO:

- has asserted overarching governance of e-Navigation (*MSC85/26*, Add.1, Annex 20, para 9.2 refers; see also for even more specific statements of IMO the Annex 1 to Annex 20 of *MSC85/26*, Add. 1);
- has considered several instruments to implement e-Navigation, namely "relevant international conventions, regulations and guidelines, national legislation and standards" (*MSC85/26*, Add. 1, Annex 20, para 9.1.3) as well as IMO Performance Standards (*MSC85/26*, Add. 1, Annex 20, para 9.1.7 and elsewhere);
- has specifically announced its intention to "set performance standards appropriate for e-Navigation" for the shore side (Annex 1, para 1.5, to *MSC85/26*, Add. 1, Annex 20), a specific example of which is the intended "Resolution on Maritime Service Portfolios" (Solution 9 and Task 17 of the SIP refer) which is even higher in standing than Performance Standards;

  In addition, IMO implicitly will set performance standards for shore-based equipment when deciding in the future upon new ship-shore/shore-ship radio communication systems under consideration presently (e.g., VDES and NAVDAT); and
- intends to set up a migration plan, culminating in a situation "with mandatory equipage and use of a full e-navigation solution in the longer term" (*MSC85/26*, Add. 1, Annex 20, paras 9.9.1, 9.9.3, 9.1.5).

IMO has stated that e-Navigation implementation will take place in phases. The first phase will be to integrate existing technology and systems. For IALA members this means that the current technical environment will still be relevant as IALA members should strive to move towards a "shore-based system architecture harmonized for e-Navigation". However, in the usual course of upgrading, recapitalization, changing user requirements and new regulations, the IALA member will eventually become "fit for e-Navigation".

4.6. DOCUMENTATION FRAMEWORK FOR CSSA

The CSSA is further detailed in appropriate IALA guidelines, which are considered to be generic technical specifications for the benefit of IALA members.

Figure 9 shows the hierarchy of IALA documents regarding CSSA and the relationship of IALA National members' procurement specification to those IALA documents:

- The left column shows the present IALA guideline as pointing to other IALA guidelines, some of which will be developed in the future;

  These documents are all generic in nature, i.e., in the OEP they are called "class descriptions".

- The middle column shows the existing as well as future IALA documents describing individual technical services, such as the shore-based AIS Service (IALA Recommendation *R0124(A-124) The AIS Service* refers);

  These technical service descriptions refer back to the generic architecture documents in the left hand column. They are specific to or instances of the generic service engineering model, while being generic themselves regarding implementation.

- IALA National members implement the services described generically in the middle column as indicated in the right column, in most cases by procurement.

  To create the appropriate procurement specifications, the IALA National member should refer back to the service descriptions in the middle column as much as possible. IALA National members may want to also refer back to generic descriptions in the left column.

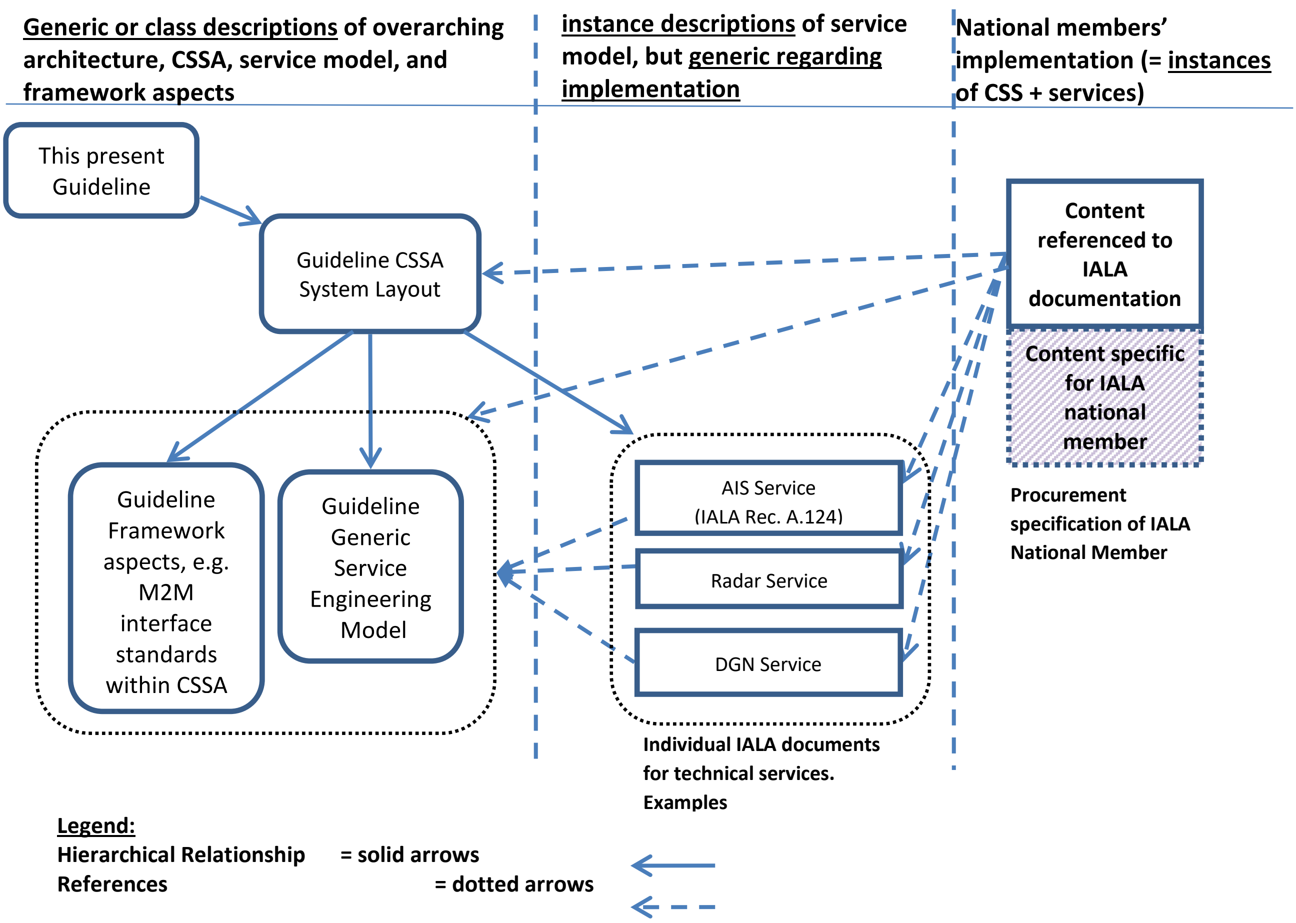

Figure 9 Hierarchy of IALA documents regarding CSSA and relationship of IALA National members' procurement specification to IALA documents

4.7. THE NOTION OF A CSSA "APPLICATION NOTE"

It is anticipated that the usage of the CSSA in various application fields will be explained in detail in appropriate IALA guidelines on "Application Notes of the CSSA."

5. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

6. ABBREVIATIONS

AIS	Automatic Identification System
AtoN	Marine Aid(s) to Navigation
BES	Bridge Equipment System
CMDS	Common Maritime Data Structure
CSS	Common Shore-based System
CSSA	Common Shore-based System Architecture
DGNSS	Differential Global Navigation Satellite System
GI Registry	Geo-Spatial Information Registry
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
IHO	International Hydrographic Organization
IMO	International Maritime Organization
IMSAS	IMO Member State Audit Scheme
INS	Integrated Navigation System
IT	Information Technology
ISO	International Organization for Standardization
LAN	Local Area Network
MF	Medium frequency (300 kHz to 3 MHz)
MSC	Maritime Safety Committee (IMO)
MSP	Maritime Service Portfolio
MTS	Maritime Transportation System
M2M	Machine-to-Machine
NAV	Sub-Committee on Safety of Navigation (IMO)
NCSR	National Centre for Sensor Research
OEP	Object-oriented Engineering Process
OPS	Operational Presentation Surface
QoS	Quality of Service
SIP	Strategy Implementation Plan (IMO)
SLA	Service Level Agreement
SMTS	Sustainable Maritime Transportation System
S-99	Operational Procedures for the Organization and Management of the S-100 Geospatial Information Registry
S-100	Geospatial Information Registry (IHO)
UML	Universal Modelling Language

VDES	VHF Data Exchange System
VDL	VHF Data Link
VHF	Very high frequency (30 MHz to 300 MHz)
WWRNS	World-Wide Radio Navigation System
XML	eXtensible Markup Language