A domain-specific architecture framework for the maritime domain

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Abstract: The maritime domain has the goal to harmonize heterogeneous systems and integrate new approaches into existing structures. In this paper we discuss the need for architectural methodology to overcome the challenge to coordinate the development of new systems considering technology issues, governance aspects and users between existing architectures in the maritime domain. We introduce already approved domain-specific architecture frameworks and present our approach for a suitable architecture framework which takes into account the appropriate structure of maritime domain.

Keywords: Maritime domain, system architecture, enterprise architecture framework, MAF, e-navigation

1 Introduction

Vessels and shore-based facilities are equipped with a variety of maritime systems to improve save navigation and traffic management. These heterogeneous systems such as automated broadcasting of vessel information (AIS), Electronic Chart and Data Information Systems (ECDIS) or shore-based vessel traffic management differ in a high degree.

Stakeholders in the maritime domain face the challenge to harmonize existing systems and integrate new approaches and technologies into existing technical and organizational structures for sustainable, reliable and safe maritime transportation. This affects technical components, organizational structures and human users as well as the common interaction as elements of socio-technical systems [Se13].

Hence, the International Maritime Organization (IMO) – the organization for global maritime matters as part of the United Nations - established the e-Navigation strategy. This is initiated as "the harmonized collection, integration, exchange, presentation and analysis of marine information on-board 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" [MS09], [NC14].

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This strategy is for the maritime domain. It defines a set of goals for the evolution of the maritime domain. E-Navigation focuses on the users needs shipside and ashore and aims to reduce the risk of accidents on sea and improve safety and efficiency in the maritime processes. This strategy bases mainly on interoperable information exchange between services and systems [NC14].

Thus, it is a vision in which direction the further development of the maritime domain shall go. However, the contribution wherein the strategy is defined, lacks on tools and methodologies to accomplish the goals defined in the strategy [MS14], [MS09].

Therefore, the maritime stakeholders face the challenge to operationalize the e-Navigation strategy successfully. This includes the use of a domain-wide suitable methodology considering relevant characteristics of the maritime domain to enable a structured and consistent view on maritime systems from different perspectives. This methodology needs to support a common development process for upcoming e-Navigation systems.

Thus, this paper introduces the Maritime Architecture Framework (MAF) as a domain specific architectural methodology to overcome the challenge to coordinate the development of new systems between technology issues, governance aspects and users between existing architectures.

In the following sections, we discuss first the need for a maritime domain specific architecture framework. Second, we present existing approaches for a domain-wide architecture model before we introduce the MAF as maritime domain specific architectural methodology including its relationship to the structure of the maritime domain. Finally, this paper is concluded in section 5.

2 Challenge for a domain-specific architecture framework

The existing systems in the maritime domain are stand-alone solutions for each use case. These systems are barely integrated and combined with each other. Currently applied solutions also do not support a domain-wide information exchange. In addition, they do not follow the e-Navigation strategy and thus they are less future-oriented but well embedded in the maritime domain infrastructure [DN15].

The IMO aims with its e-Navigation strategy for a harmonized collection and integration of maritime information and systems. Upcoming solutions such as new maritime systems, for instance communication between ship and shore, should consider the high number of already existing heterogeneous systems [NC14]. This results in a high integration and coordination effort for managing the interactions with these various systems [MS09].

Therefore, it happens that existing socio-technical systems are based on different architectural designs and are embedded in various organizational and governance structures in international, regional and national matters. Following IMO's e-Navigation vision for seamless integration between existing and upcoming systems, existing systems have to be analyzed in a structured way on their system architectures including the specific context and organizational structures in which a system is embedded to enable views from different operational or technical perspectives on the examined systems. This will enhance the understanding of the relationship between the maritime world and the examined systems and to consider this during the development of new e-Navigation systems (see figure 1).

Fig. 1: Challenge for a domain-specific high-level framework

The answer to this challenge should consider the overarching e-Navigation strategy and IMO's reflection of the maritime domain. Consequently, it shall provide a consistent methodology to structure the engineering process of socio-technical system concepts and to align technical systems. Hence, such a framework needs to frame the maritime domain including its stakeholders, the existing and upcoming technical system (architectures), related business processes and organizational structures including governance and regulation aspects to enable a complete view on the maritime infrastructure.

Summarized, there are challenges within the maritime domain, which could be solved by an integrated maritime framework. The requirements for such a maritime framework are:

- Support the development of maritime system architectures by offering a structured methodology, which enables to identify possible interoperability issues to ensure a communication and cooperation across the systems or to identify overlaps and gaps within their system architectures.
- Support the analysis of maritime systems regarding their technical architectures and organizational structures.
- Ensure a domain-wide consistent terminology for a common understanding using

this framework.

- Allow the design of organizational and technical harmonized and optimized architectures.

3 The Maritime Architecture Framework

To overcome the challenges and requirements described in the upper section, the authors have negotiated to develop the Maritime Architecture Framework (MAF) in a broad community process. MAF is derived from the successfully established architecture model in the energy domain named Smart Grid Architecture Model (SGAM). SGAM is shortly explained in section 3.1, where after the specific development of the MAF is discussed (section 3.2). Section 3.3. introduces the concept before a well suitable visualization and modelling approach for the MAF is shown in section 3.4. The methodology to close the gap between the generic e-Navigation strategy and the current architectural world in the maritime domain is presented in section 3.5. Next to this introduction of the MAF, the following chapter will discuss the application and evaluation.

3.1 SGAM - A domain specific framework from the energy domain

Smart Grid Architecture Model (SGAM) is a successfully established implementation of an Enterprise Architecture Framework to address domain specific issues in the electric utilities domain. SGAM was developed to handle the complexity of the Smart Grid system-of-systems approach with focus on interoperability and standardization aspects for business and governance as well as for technical issues [CE12].

SGAM structures the electric domain to ensure a consistent basis for discussions in heterogeneous groups. It takes established domain-independent frameworks (e.g., TOGAF [TO16]) as well as domain-specific models into account. SGAM is used to describe technical use cases as well as business cases [UE15].

SGAM structures the aspects of the domain into three dimensions. It covers an interoperability dimension with five layers of specification aspects ranging from business objectives down to physical components. Furthermore, it includes a hierarchical dimension (named *zones*), which structures the power system management as well as a domain related dimension (therefore named *domain*) to represent the energy production and consumption chain. Besides the multidimensional model, SGAM's methodology supports the specification of use cases including stakeholders, actors and technical aspects and allows the mapping to its model [UE15].

The SGAM approach is successfully applied in the energy domain and already adapted in other domains. The industry 4.0 initiative in the industry domain uses the design principles of SGAM in the Reference Architectural Model Industry 4.0 (RAMI 4.0) to enable different user perspectives to achieve a common understanding of the industrial value chain including their components, standards and use cases [HR15].

3.2 Development

The MAF is adopted from the SGAM Model by a community process. The authors derived an initial version directly from SGAM using existing maritime architectures and reference architectures. This includes the Common Shore Based System Architecture [IA15a], [IA15b] and IMO's e-Navigation architecture as well as the maritime service portfolio, a collection of maritime services done by the IMO [NC14].

In a second step the MAF proposal was discussed with numerous stakeholders from industry (provider for navigation systems and communication technology, system integrators, ship-owners, pilots and others) as well as engineers working for governmental maritime agencies (e.g. Germany, Denmark, Sweden, Korea) and researchers (in Norway, Australia, Austria, Korea). This lead to an updated version as introduced by this paper.

At present, the MAF is under discussion by the working group of the eNAV committee of the IALA, the International Agency for Aids to Navigation and Lighthouse Authorities. Additionally, there are the test cases for using the MAF to structure a base architecture for e-Navigation named the Maritime Cloud, the development of data exchange to portable pilot units (PPU) and synchronization of port services within the project CPSE-Labs (see chapter 4).

3.3 Concept

The MAF needs to establish clear relationships between technical systems, users and related governance aspects. This includes:

- existing business objectives, that explain the benefits of the systems,
- regulation and governance aspects, which regulates the maritime domain,
- technical functions, that are required to realize the business objectives,
- information exchange between those technical functions including the related information types and / or data models,
- communication protocols to allow the aspired information exchange and
- components, which are required to implement the technical hardware in the system.

It needs to cover the domain as stated by the IMO [MS09]. To enable the representation of relationships between technical issues with organizational aspects such as business objectives or governance issues, the framework needs to include different interoperability views. Therefore, the MAF derives the interoperability layer used in the SGAM approach [CE12].

Similar to the user-needs driven e-Navigation strategy, the MAF focuses on a user-oriented analysis of specific use-cases with respect to the examined architectures. It adapts the Maritime Service Portfolios (MSP) as improved provision of services to vessels and users [MS09] to define the scope of the MAF and as a basis for user and use case specifications of examined architectures.

Referring to established approaches, the framework is divided into two parts:

- The multidimensional cube for a graphical representation of the underlying maritime domain and the examined system architecture,
- A methodology to structure the examined system including the system requirements and (possible) use cases in a consistent way.

3.4 The multidimensional cube

The multidimensional cube (MAF-Cube) offers a consistent view on architectures on different levels. As shown in figure 2, the requirements which were defined in section 3.2 are used to display (1) interoperability-, (2) hierarchical- and (3) topological aspects of the maritime domain. From now on, we use the terminology *axis* for the name of the dimension and *layer* for the surface with all aspects, which belong to a *category*. All aspects on a layer can be sub-structured by the categories of other dimensions.

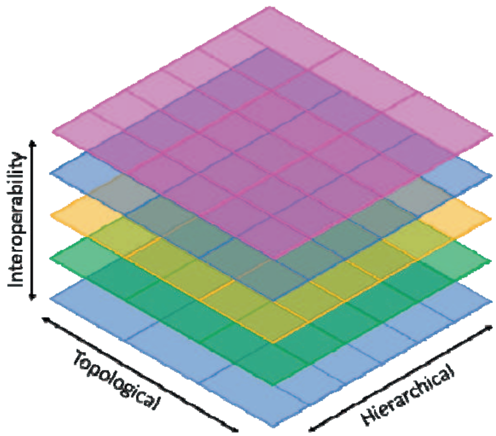

Fig. 2: The MAF-Cube

The topological axis represents the logical location where a technology component is located. The interoperability axis addresses communication, data and information, usage and context of a maritime system. The hierarchical axis substructures management and control systems of the maritime domain, for example for maritime transportation systems from the traffic management of a coastal area down to the radar echo of a vessel.

3.4.1 Topological axis

The layers are derived from IMO's breakdown of the maritime domain [NC14] and cover the structure of the maritime domain in a logical location. The axis contains the layers:

- Ships and other maritime traffic objects: Representing entities in the maritime domain (e.g., vessels). It covers the ship-side entities of the e-Navigation architecture.
- Link: Representing entities dedicated to physically interact between maritime traffic objects and shore, such as telecommunication methods and protocols. Represents the three levels of *Operational links*, *Functional links* and *Physical Links* between shipside and shore-side.
- Shore: Representing entities of the shore side infrastructure, activities and systems on shore including interfaces to logistical movements in/out of maritime domain.

3.4.2 Interoperability axis

The interoperability layers cover organizational, informational and technical aspects and include the different levels of interaction (*operational*, *functional*, *technical* and *physical*) as stated in IMO's e-Navigation vision [MS09] and are derived from SGAM [CE12].

- Regulation & Governance: Role and legal basis of international, regional or national (shipping) authorities.
- Function: Functions and (elemental) services including their relationships.
- Information: Data and information that is being used and exchanged between functions, services and components. It describes data and information objects including its semantic and data models.
- Communication: Protocols and mechanisms for the interoperable exchange of data between components.
- Component: Required components in engineering terms. This includes, amongst others: systems, actors, applications, services, network infrastructure.

3.4.3 Hierarchical axis

This axis covers economic, technical and physical issues of a maritime system. It starts with the classification of the examined system into its field of activity and continues with system-specific operations before the system will break down into technical services and their components as well as interfaced physical components.

- Fields of activity: Systems, which support or manage different markets or eco systems along the maritime domain.
- Operations: Global, regional, national and local operational perspectives used by companies or authorities (e.g. a traffic flow management).
- Systems: Technical systems, which integrate or use technical services for gaining a virtual representation and control of the transport processes.
- Technical Services: Single technical and logical services.
- Sensors & Actuators: Local infrastructure for detecting objects with physical means and receiving / processing the results with physical systems and hardware.
- Transport Objects: Entities of maritime transport processes such as vessels, floating objects and aircrafts operating in the maritime domain.

3.5 Methodology

The methodology is composed of three main steps leading to enable an easy mapping of system architectures to the MAF-Cube. The scope of this process is to structure the system engineering phases starting from planning over the identification of requirements to the use case development in a harmonized and formal way. This allows the user to map the results, to visualize in the MAF-Cube to explore interoperability issues and to identify spots which need to be standardized.

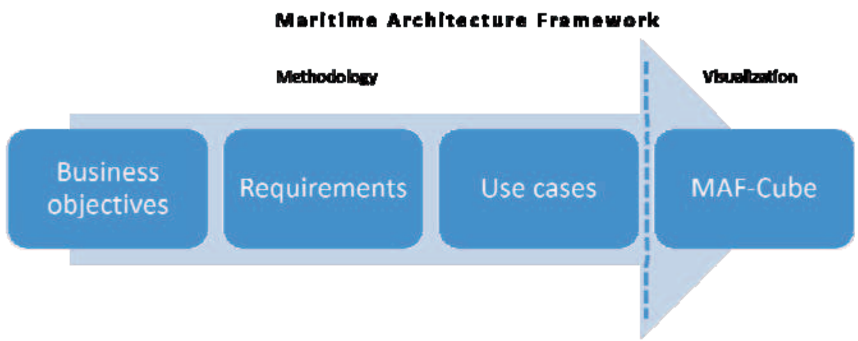

Fig. 3: The Maritime Architecture Framework

As shown in figure 3, the methodological steps are built upon each other. During this process, the MAF orients towards at least three different user-groups:

(1) Business: Sorts all high-level decision makers governing the business objectives and the ambient business structures.

(2) Engineer: Addresses the technical working group responsible for the realization of the objectives, given by the Business group.

(3) Consumer: Groups users, who are not participating in the system development but have interests in the future use of the systems.

The framework provides this methodology, tools and templates for an alignment of characteristics of different system architectures. This framework includes a derivation of the Requirement Abstraction Model [GW06] which originally ensure interoperability between product requirements. This approach is used in the MAF to concretize the business objectives and requirements to the same abstraction level as basis for the development process of a system architecture or for an alignment between system architectures.

Furthermore, the MAF methodology includes a use case template, which follows the international standard for use case methodology in [IE15] and is extended considering the domain-specific characteristics. The use case template comes with an actor list, which is derived from the maritime users as defined by [MS09] and is enriched by facilitating the descripted information to UML diagrams. Therefore, it is supposed to support a consistent understanding of functionality, actors and process across different projects and between different organizational structures in the maritime domain.

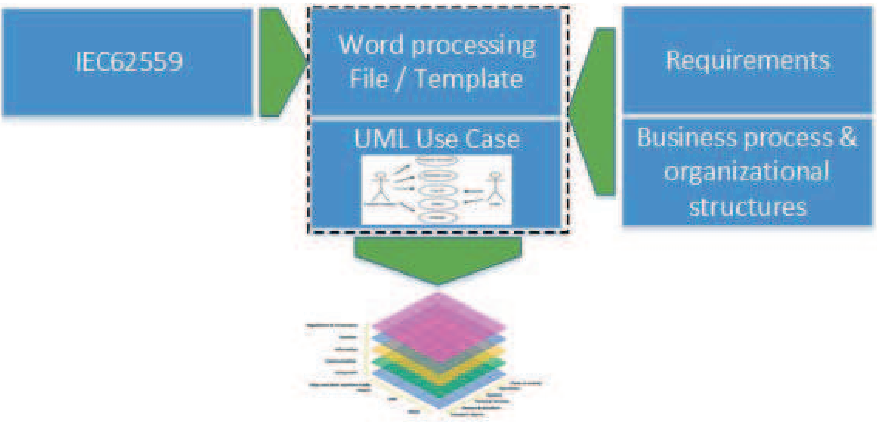

Fig. 4. The MAF process

Finally, the methodology includes a process to extract descripted information of a systems architecture from the use cases to ensure a successive mapping to the MAF-Cube. This step identifies physical components and business relatives of the examined architectures and includes standards, rules and regulations regarding to the interoperability layers. The cube allows to locate the system architecture and related components in the maritime domain (shipside, shore-side or as a link between them). Furthermore, the cube enables to structure the system construction including its field of activity in a hierarchical order (see figure 4).

4 Application & Evaluation

The Maritime Architecture Framework supports different functions. First, it ensures a common basis including consistent terminology to map existing architectural approaches and interfere between them.

Second, the framework can be used to support the development of an enterprise architecture by representing the technical aspects of systems and the interrelationships to organizational structures of the targeted field of application. This includes to follow a top-down approach, developing a business architecture and in relation to that, the belonging IT-environment. Otherwise, the framework is also proposed to follow a bottom-up approach to support the adaption of existing heterogeneous architecture into an e-Navigation compliant architecture to ensure interoperability with other systems.

First evaluations of the Maritime Architecture Framework are done as part of internal projects and interviews with experts of the maritime domain as well as experts for IT- and enterprise architectures. Regarding to this, the MAF is work in progress and has reached a stable maturity. Therefore, the framework is part of the 2nd round of experiments of the CPSE Labs Design Centre Germany North [CP16a]. The experiments focus on the development of different maritime systems in context of e-Navigation. The MAF will be used for evaluation on a larger scale by supporting the development of such Cyber-physical systems in the experiments [CP16b]. This includes the support for interoperability and integration for cooperation between the systems.

5 Conclusion

This paper addresses the need of a common methodology to align and integrate existing system architectures in the maritime domain. According to this, we present the Maritime Architecture Framework as a standardized methodology to assemble existing architectures in a meaningful and unique way to identify interoperability issues, interfaces and links to other (upcoming) systems. Thus, as an impact of the MAF, the gap between the visionary IMO strategy and the current problems of maritime players is handled to make the maritime domain more sustainable and future-ready. As first applications and evaluation steps show, the MAF is an effective, well suitable tool for that case. In subsequent stages of the MAF it is used in larger scenarios and further improved.

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