DIWA Report

Sub-Activity 3.5: Technologies in other transport modes

Version: V1 (Final Version), October 2023
(Editorial deadline: March 2023)

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Co-financed by the European Union
Connecting Europe Facility

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1 Executive summary

The objective of the DIWA Sub-Activity 3.5 was to study digital technologies and associated technological developments in other modes of transport, namely in the road/Intelligent Transport System (ITS), rail, maritime, and – to a limited extend – aviation, with a view *to learn from them in whatever regard*. This meant to determine which digital technologies and associated technological developments could be adapted to the Inland Waterway Transport (IWT) fairway & navigation domain in the future, how this could be done in principle, and what this would require. This necessitated firstly the study of those developments that have left a sufficiently sizeable trace of engagement at the mode studied, and secondly the methodological assessment of their adaptability to the IWT fairway & navigation domain. The assessment task required an understanding and in some cases even a sketch of how a potential adaptation to the IWT fairway & navigation domain might look like.

This was done during roughly half a year of desktop research. The results are reflected in the present report in the shape of a *tri-partite inventory consisting of technology-oriented architectures, specific digital candidate technologies, and useful combinations of both*. The useful combinations allow achieving capabilities that are superior to those of the contributing architectures and technologies alone – thus rendering also potential solutions for 'smart' IWT shipping. At each inventory item, the relevant documentation was referenced for further consideration. The present report arrives at recommendations for further studies as well as for actions for potential implementation. They are valid in their own right and are also input to the roadmapping at the DIWA envisaged masterplan for digitalisation of the IWT fairway & navigation domain.

The findings out of this work indicate that *there is much on the move regarding digitalisation in other modes of transport*. Also for maritime as the most relevant other mode this holds true, even to the extent of imminent fundamental technological transitions. Hence, – even if no other recommendation would have been drawn – the following might be the one to sum everything up: *It is high time that the IWT fairway & navigation domain engages itself with the technology-oriented architectures, specific digital candidate technologies, and useful combinations as inspired by progress in other modes, together with their organisational and regulatory pre-requisites and fall-outs as indicated and recommended*.

The required assessment of the likely achievable digitalisation level of the IWT fairway & navigation domain as expressed in the pre-given DIWA Maturity Model, i.e. assessing the achievable IWT Digitalisation Level (IDL) per individual inventory item, together with other relevant criteria such as

- technological readiness of the inventory item in itself,
- its adaptability to the IWT fairway & navigation domain,
- the resources and time needed for any such adaptation, and
- the time horizon at which this inventory item might have been implemented – called 'Technology Radar' –

were further developed. The resulting generic methodology was described in a *'Manual on Inland Waterway Transport Digitalisation and Assessment Methodology'*, and the methodology was used throughout when assessing the inventory items. The five pre-given IDLs were: 'Reactive' (0-), 'Organised' (0+), 'Digital' (I), 'Connected' (II), and 'Intelligent' (III). The roman numerals were introduced for ease of reference. The manual provides definitions and examples for what these IDLs would mean in practical terms. Only the last three really constitute progress in digitalisation compared to today's situation.

The application of the assessment methodology finally resulted in a matrix showing the achievable IDL when implementing a certain inventory item vs. the resource and time demands required for this. This allows for final conclusions regarding the most desirable inventory items for the DIWA envisaged IDL increase. Since the inventory items assessed were recently or are even presently implemented or are to be implemented soon in other modes, the range of achievable IDLs for all inventory items started at IDL I as a minimum. This means that *all* inventory items covered would contribute to some DIWA envisaged increase of the IDL compared to present. Certain inventory items would allow for or be even a pre-requisite for progressing towards the highest IDL III.

In addition, with the advent of remotely operated and even autonomous vehicles in all modes, it was necessary to consider them, too. This resulted in the creation of the generic *'Guidelines on capturing Remotely Operated Vessels (ROV) and Autonomous Vessels (AV) for Inland Waterway Transport future planning'* as another stand-alone document.

It is impossible within the limitations of this summary to represent all relevant individual developments in other modes as applicable to the IWT fairway & navigation domain. Hence, the technology-oriented architectures that have been assessed as being *both most important and most powerful for achieving the DIWA desired increase of IDL* and that are also *pre-requisites to achieve IDLs II and III in general*, are all introduced, together with a brief introduction of 'useful combinations' building on them. For the specific digital candidate technologies only some major developments are indicated.

The following *technology-oriented architectures* were adapted to IWT fairway & navigation domain as informed by the other modes and then assessed; they are introduced here with the names proposed for their adaptation to the IWT fairway & navigation domain.

- The *Nautical Datalink Communications (NDLC)* architecture is the most fundamental and addresses any operational communication relationship via technical systems. Its defining point is, that it includes the full chain of the flow of a *data set* - as opposed to voice - from its ultimate source – in the case of a human entered by a (dedicated) Human-Machine-Interface (HMI) – to its ultimate destination – in the case of a human displayed on a (dedicated) HMI again. The interfaces are thus integral part of the datalink communications architecture and are thus consciously reflected in datalink applications. The notion of datalink communications has been around in all modes of transport for several decades, but aviation has implemented it most stringently for more than two decades now successfully in Air Traffic Control (ATC) by a system called Controller Pilot Datalink Communications (CPDLC). It was designed to remove the need for voice communication in routine but still safety-critical use cases for several reasons to the maximum extent possible, while voice communication is still used for the remaining safety-critical use cases. Hence, CPDLC should *not* be construed as even attempting to render a voiceless ATC, but rather renders a 'voiceless*er*' ATC. The IWT fairway & navigation domain should adopt their variety of datalink communications systematically, too, thus employing the NDLC for voiceless*__er__* communications, based on proper encoding of standard IWT fairway & navigation phraseology. In particular, when migrating towards IDLs II and III, 'digital information exchange by default' will be required. In addition, NDLC introduction may be necessitated even further with the potential future proliferation of AVs and ROVs in the IWT fairway & navigation domain.
- The *IWT Infrastructure Site Architecture* is another fundamental architecture, inspired mainly by road/ITS and rail implementation examples as adapted by analogy, and is essentially a balise application in the digital domain. It supports at least the following three different use cases:
  - Co-operative position determination of the vessel passing by the IWT infrastructure site, which is also electronically identified in the process;
  - Upload of data relevant for navigation from IWT infrastructure to vessel, such as locally gained sensor data or remotely received data to vessels passing by;
  - Download of vessel data to IWT infrastructure, such as vessel sensor data at the time of passing of the IWT infrastructure site or data stored by the vessel on-board equipment for a period prior to passing by the IWT infrastructure site.

  When populated with appropriate technologies this architecture renders the 'useful combination' of a *Smart IWT Infrastructure Site* as sketched in the third part of the inventory with the example of a *Smart Hectometre Stone*.
- Moving towards higher levels of system integration, the *IWT System Interconnection Architecture (ISIA)* as inspired by ITS is adapted by analogy. Its point is to generically identify and allow proper selection of communication technologies to provide 'system interconnections' supporting the manifold operational relationships between e.g. vessels, inland waterway field infrastructure, centres, and – last but not least - humans. There are resource limitations to deploy, maintain and operate several communication technologies with similar functionality profiles simultaneously for the same system interconnection domain. Hence, the ISIA would allow selecting for deployment the *most versatile* communication technology to provide all required functionality. The ISIA, once adopted by all relevant stakeholders of the IWT fairway & navigation domain, *may thus serve as a powerful community tool for harmonisation of the descriptions, definitions, specifications, and standardisation of the functional links - in particular NDLCs – and of the physical links, supporting the operational relationships between all functional entities involved.* When populated with an optimum set of technologies, this architecture contrib-

utes to the 'useful combination' of a '*Future optimum IWT Fairway & Navigation Heterogeneous Network*'.

- Moving even higher in system integration, the *Overarching IWT Fairway & Navigation Domain Architecture* comes into view. While all modes of transport have some kind of overarching architecture, the closest one to the needs of the IWT fairway & navigation domain is the maritime example as adopted by the International Maritime Organization (IMO) during their e-navigation strategy implementation. This has been adapted to the RIS domain already by Sub-Activity 2.5, and Sub-Activity 3.5 has further amended this adaptation with the wider IWT fairway & navigation domain in mind: As the name implies, the 'overarching architecture' provides the top-level framework for both operational services and technical services/systems and identifies their mutual dependencies. *Dependencies are imposed by the co-operative nature of any operational relationship supported digitally, the number and degree of which will increase significantly with the DIWA envisaged increase of IDL. The Overarching IWT Fairway & Navigation Domain Architecture thus supports harmonisation in all regards between different stakeholders effectively*. Consequently, this necessitates a harmonised understanding of the systems employed on both sides (vessel, shore) by all stakeholders. Such a harmonised understanding again necessitates the adoption of harmonised generic architectures for the (future) shipboard equipment on one hand and for the shore systems on the other hand, while maintaining sufficient degree of inbuilt flexibility in system design, allowing for – amongst other benefits – sufficient leeway for innovation. It is thus recommended to again follow the maritime domain's example and adopt both the *Inland-SSSA* and *Inland-CSSA* to that end in due course, also incurring their inbuilt flexibilities each: Inland-SSSA stands for *IWT Standard Shipboard Navigation System Architecture*, and Inland-CSSA stands for *IWT Common Shore System Architecture*.

All above individual architectures *fit together seamlessly* within the overarching architecture, thus contributing different views relevant for harmonisation of the IWT fairway & navigation domain.

The convergence of the IWT fairway & navigation and the IWT logistics domains at whatever DIWA envisaged IDL, leading eventually to synchro-modality, is a stated goal of DIWA, and this goal has been pre-given in the context of the DIWA Maturity Model, too. The above technologically-oriented architectures intend to provide context for specific digital candidate technologies to be plugged in eventually. Technology is not an end in itself, however. Technologies and technical services employing them are always embedded in socio-technical systems: It is there, where business, operations, and technology converge. This leads to the recognition that *an architectural framework would be needed that would allow IWT domain business, operational and technical perspectives be brought together within the IWT socio-technical system background*. This postulated architecture is called *IWT Reference Architecture (IRA)* here, and its scope is the IWT domain as a whole*: It is in the IRA where IWT fairway & navigation and IWT logistics domains converge in architectural terms*. This architecture is informed by an architectural reference framework at ITS and the Maritime Architecture Framework, described and assessed in the report, and it is recommended to develop it further for introduction to the IWT domain.

Turning towards the *specific digital candidate technologies* as the second class of inventory items informed by other modes, they have been introduced by their respective functional technology family, which in turn are put into architectural context given by the Overarching IWT Fairway & Navigation Architecture. Brief summaries for particularly relevant developments are given as follows:

- *Position, Navigation, Timing (PNT) by radio navigation technologies:* There have been several developments at the maritime domain as follows:
    - The maritime domain has long established *a formal recognition process* for the PNT components that – in total - comprise their World Wide Radionavigation System (WWRNS). Thus IMO makes sure that only those PNT systems that fulfil the requirements of a contribution to their WWRNS become part thereof and thus may be used for navigation. Recently, a number of Global Navigation Satellite Systems (GNSS) have been recognised by IMO for WWRNS. With increasing IDLs in the IWT fairway & navigation domain, the demand for reliable, integrity-verified and accurate PNT data obtained by electronic means increases, too, which may be warranted by a formal recognition process for the any and all components being part of their PNT provision. Hence, the IWT fairway & navigation domain is advised to adopt such a recognition process in the future.

  - Recently, there have been several moves at IMO to improve the quality and integrity of the vessel's PNT data determination by certain stipulations for shipboard equipment entities, namely by introducing the notion of a *shipboard PNT processing entity*, the definition of *multi-system shipborne radio navigation receivers* and of *generic GNSS shipboard receivers*. It is recommended to adapt these notions to the IWT fairway & navigation domain.
  - The notion of using all kinds of 'signals of opportunity' to determine a vessel's position without GNSS, i.e. the use of the *Ranging-Mode*, has acquired attention at IMO and elsewhere. Considering the abundance of those signal sources potentially available in the IWT fairway & navigation domain in the future, this approach should be further investigated for adaptation to the IWT fairway & navigation domain.
- *Communication link technologies*
  - In answering a request from Sub-Activity 2.5, the notion of *communication profile* was investigated with specific technologies in mind: To know the communication profile of an operational relationship is essential for selecting the most appropriate communication technology or technologies.
  - The *Application Specific Messages* (ASM) originally defined for transmission by the Automatic Identification System (AIS) as a physical link can and should be *transmitted carrier-agnostically,* using a different physical link setup to be defined within the context of the above 'Future optimum IWT Fairway & Navigation Heterogeneous Network', and not even confined to the new VHF Data Exchange System (VDES) which was specifically designed as an improved physical link technology for ASM transmissions.
  - The recently finalised development of the *SECOM protocol for secure ship-shore and shore-ship data exchange communication* as defined in an international/European standard (EN IEC 63173-2) was originally developed in the maritime domain in the context of e-navigation for the provision of *data products* by shore-based organisations to shipboard applications in particular as defined in the 'S-100 World'. The benefits of the secure data exchange require a substantial IT security infrastructure to be introduced into the IWT fairway & navigation domain. The two options of introducing the full functionality of SECOM and of just a secure data protocol were considered and assessed.
  - In several modes, the transition towards latest *general purpose digital radio communication technologies for both data and voice* has been considered, and rail has decided in favour of a rail-specific adaptation of the cellular digital radio communication technology family International Mobile Telecommunication (IMT), as defined by ITU, and in particular in favour of 'IMT for 2020 and beyond' (aka '5G'). In the road/ITS domain, there is a competition pending between an ITS adaptation of IMT-2020 and an ITS adaptation of WLAN technology. The maritime domain also is confronted with a competition of at least two principle options for general purpose digital radio communication technologies, namely of the above IMT and of the Conventional Digital Land Mobile Radio technology families. For the IWT fairway & navigation domain, a need to determine the optimum future digital technology setup for data and voice emerges similarly, considering also maritime specialty developments like VDES and a (future) consolidated AIS. These developments were considered and assessed.
  - Wherever data must be exchanged in short distances in spot-like situations between a fixed and a moving position, which is often the case in the IWT fairway & navigation domain, High bandwidth Visual Light Communications (VLC) may offer an emerging solution, even it is only 'one bit' – namely the detection of presence of an (expected) vessel. It would thus contribute to the notion of a 'smart' IWT infrastructure site.
- *Sensor technologies*: *Co-operative sensor technologies* other than position determination sensors are employed in the different modes of transport for a large variety of relevant sensor data objects. 'Sensor' also has acquired *a broader sense* of the term in other modes, when not being confined to a single device. Also, similar to the position determination using (recognised) external radio navigation systems, *external systems as a whole* can be construed as a co-operative sensor. The report briefly identifies some developments regarding co-operative sensor technologies.

- *Data modelling methods & technologies*
  - The *international ASM* as defined by IMO to be legally available for use since 2013 are essentially topical data containers for vessel navigation. Using any of those topical data container within even only one application renders this application a use case of that topical data container. Hence, the IMO defined international ASM constitute internationally harmonised use cases 'in disguise'. Substantial definition work on these topical data containers has thus been provided by IMO and other participating international organisations – ready to (re-)use: The above topical data containers appear to be relevant for the IWT fairway & navigation domain, too, except some very few such as ocean weather conditions. This holds true in particular for those addressing also the logistics interface. Hence, wet-to-wet adaptation appears to be not only feasible but also attractive to salvage the definition work done. Usage stipulations given by IMO can be replaced by IWT tailored ones.
  - Learning from both rail and maritime, an approach for arriving at a *Data model for voicelesser communication using NDLC* is developed and assessed.
  - The *imminent transition of the maritime domain to the 'S-100 World'* is introduced and assessed. 'S-100' is not confined to 'another version of an electronic navigational chart', however, and thus consequently any adaptation of the S-100 framework to the IWT fairway & navigation domain would also not be confined to the import of just 'another version of an Inland-ENC or Inland-ECDIS'. The S-100 framework in fact identifies itself as the 'Universal Hydrographic Data Model' and thus as being capable to incorporate *all* data entities associated with the wet domain. It thus represents a paradigm, and the transition to it a paradigm shift. It prompts the IWT fairway & navigation domain to consider following the maritime domain *in adopting 'S-100 as a baseline'.*
  - The recently finalised *EN IEC Standard 63173-1 (S-421) on Route Plan based on S-100* is a point in case of the above data incorporation potential of the S-100 framework. Therefore, the potential impact of S-421 on operational use cases even should be known and studied by the IWT fairway & navigation domain. A decision making process at IMO was initiated by EU member countries, the EU Commission, and by the Republic of Korea. It is specifically requested that 'standardized exchange of route plans' using S-421 should be introduced by IMO. The decision regarding the exchange of route plans based on S-421 depends on the above IMO decision for S-100 transition. While the EU lead initiative at IMO formally applies to the maritime domain, only, it may not be farfetched to suggest that the potential import of a standardised exchange of route plans using S-421 in the context of 'S-100 as a baseline' be considered by the IWT fairway & navigation domain, and potentially even be adopted in due course.
  - IALA – being the international organisation responsible for setting international standards and providing relevant recommendations and guidelines for *Aids-to-Navigation and VTS provided to shipping from ashore* – has adopted the above S-100 baseline decision of IMO in 2011 early on. Since then, IALA has started to develop its contributions to the 'S-100 World' by populating their S-200 document series, a sub-set of the S-100 data product specifications. As soon as the S-100 transition decision will have been taken by IMO, the studies and assessments for potential IWT fairway & navigation adaption of S-200 world data products should be done to as a matter of priority, to potentially adopt them early on and thus avoid any redundant developments.
  - Above, different approaches for modelling data have been introduced and assessed as relevant to the digitalisation of the IWT fairway & navigation domain, namely the international ASM definitions as carrier agnostic data containers on one hand and the S-100-based data container definitions on the other hand. In addition, there are existing definitions specific to the IWT fairway & navigation domain with overlap in scope, too. There appears to be already a present and even more so in the future a substantial overlap in data object definitions between these approaches. In order to avoid any potentially critical ambiguity of data provided to IWT fairway & navigation applications, *the different approaches need to be reconciled* to arrive at a safe situation in the future for any DIWA desired digitalisation of the IWT fairway & navigation domain.

- *Data evaluation methods & technologies:* It is in particular this functional technology family that would be required to ultimately achieve the DIWA desired IDL III ('Intelligent'), which is characterised in particular by AI assisted process optimisation, prediction capabilities, and automated response to standard situations. Despite its recognised relevance, this functional technology family as employed in other modes, could not be studied in-depth due to resource limitations.

The report finally reflects its above findings to provide final conclusions as contributions to the masterplan and roadmap to be established by DIWA. The most important one is: **There is a need for harmonisation 'across the board' as *the one critical* pre-requisite for *any* increased digitalisation maturity.** It is further concluded, that the DIWA desired IDL increase (above IDL I) would only be possible in the future, if and when

- there will be clear definitions and an ideally non-overlapping distribution of responsibilities of the international organisations with relevance for the European IWT fairway & navigation domain, taking into account the pre-sets introduced by international organisations with a global (maritime) remit which cannot be easily influenced by European IWT stakeholders alone;
- architectural models will be employed that cover both operational and technical aspects seamlessly;
- there will be in place unambiguous and not-contradicting definitions, expressing themselves technology-wise in particular in terminology, data models, interface definitions;
- there will be introduced regulatory concepts and frameworks that would avoid any uneven situation (such as IDL mismatches) at implementation and deployment phase at borders between individual countries, regions, waterways etc.

In this report, the adaptation route Maritime-to-IWT was mentioned and employed several times. *But what if the (European) IWT fairway & navigation domain would absorb some notions from other modes readily and fast track some developments so that it would be ahead of maritime in due course?* This may be even required to *save own investments* by influencing maritime (regulatory) developments in order to avoid diverging developments in e.g. areas of mixed traffic as well as for *capacity building* within the (European) IWT fairway & navigation domain. The report identifies certain inventory items where this might be possible – immediate start and due diligence assumed.

2 Introduction

'In sub-activity 3.5 the technological developments in road, rail and maritime transport will be studied. In the context of ITS,[1] ERMTS,[2] e-Navigation and smart mobility, technologies are developed or implemented that might be equally useful for IWT. These technologies might even create a seamless conversion into multi-modality. Knowledge of developments, experiences and lessons learned regarding technologies in other transport domains is necessary to promote interconnectivity and harmonise standardisation' ([DIWA 2021a], 26f). This description of the DIWA Work Programme justifies the present Sub-Activity 3.5, the activities and results of which this report is presenting, and also provides a scope definition.

2.1 Objectives of this Study and Report

'The objective of this SuAc [Sub-Activity] is to describe technology developments in road, rail and maritime transport that may be useful in IWT'.[3,4] To that end, the present Sub-Activity 3.5 was supposed to

1. 'Make an inventory and study on technologies that are under development or implemented in other transport domains and assess the applicability in IWT and the effects on the digital transition in the period 2022-2032', in particular alert the project to any potentially ground-breaking technological developments, that have not yet been identified within the project setup;
2. Describe the requirements and pre-conditions for the implementation or application of these technologies to IWT;[5]
3. Create this report to reflect the results of the above individual tasks. This report is the deliverable of Sub-Activity 3.5 and it serves as an 'intermediate report (study) on the technology developments in road, rail and maritime transport'.[6]

The objectives of this study and report could thus been summarised by the following key terms:

- Take inventory of and study the relevant technologies in road, rail, and maritime transport, taking particular interest in those technologies that might potentially be supportive of a 'seamless conversion into multi-modality';
- Assess the applicability towards IWT including resulting requirements and pre-conditions, in particular alert the project for any such potential applications with an unforeseen and/or high potential; and
- Assess the effects on digital transitions in the period 2022-2032 (as a minimum time frame for consideration).

In addition, the following targets were given in the DIWA framework document ([DIWA 2021b], 6):

- "A description of the (…) optimal situation (long term) of the technology based on a greenfield situation. So without the current digitalisation levels and existing services and developments."
- "A description of the work that needs to be done needs to be included (the investment that is needed) as well as the related facilitators, stimulators and enablers have to be identified."

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[1] Intelligent Transport System(s) (ITS).

[2] European Rail Transport Management System (ERTMS).

[3] Inland Waterway Transport (IWT).

[4] All quotes in this section from ([DIWA 2021], section on Sub-Activity 3.5, 26f), as clarified with project management.

[5] This is the rendition of the second individual task of the DIWA Work Programme for Sub-Activity 3.5 after clarification with DIWA project management due to its original ambiguous task specification: The present Sub-Activity was *not* supposed to setup 'requirements and needs *for* implementing these technologies in IWT' – To develop these business and operational requirements was the task of Activity 2 as a whole and – more specifically regarding other modes of transport – Sub-Activity 2.5 (compare [DIWA-SuAc2.5 2022]). It was, however, clearly a task of the present Sub-Activity 3.5 to give an indication of the requirements and pre-requisites *of* implementations or applications of potentially relevant technologies.

[6] The Work Programme states as expected results a report 'on the business development', but that was recognised to read as given after consultation with project management.

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These goals' and targets' key terms are reflected in the headings of appropriate chapters and sections as follow as well as in the necessary criteria base for the assessments performed.

2.2 Digital Maturity, IWT Digitalisation Levels and their impacts

The DIWA stated goal is to compile a 'masterplan' for the Digitalisation of Inland Waterways in Europe. That is essentially a roadmap, on how to move the IWT fairway & navigation domain in Europe from its present state regarding digitalisation to higher digitalisation levels – called *IWT Digitalisation Level (IDL)* throughout – and what would be required in terms of studies and activities along that roadmap to accomplish that goal until 2032 or likely beyond.

Since one of DIWA's goal is to facilitate synchromodality, the IDLs are defined concurrently for the IWT logistics domain, and it is assumed that the IWT fairway & navigation and the IWT logistics domains may converge seamlessly if and when they both have reached the same IDL simultaneously. This is at least the assumption for an ideal situation: Convergence may also already happen to some degree and with certain caveats when only similar IDLs are reached by the two domains.

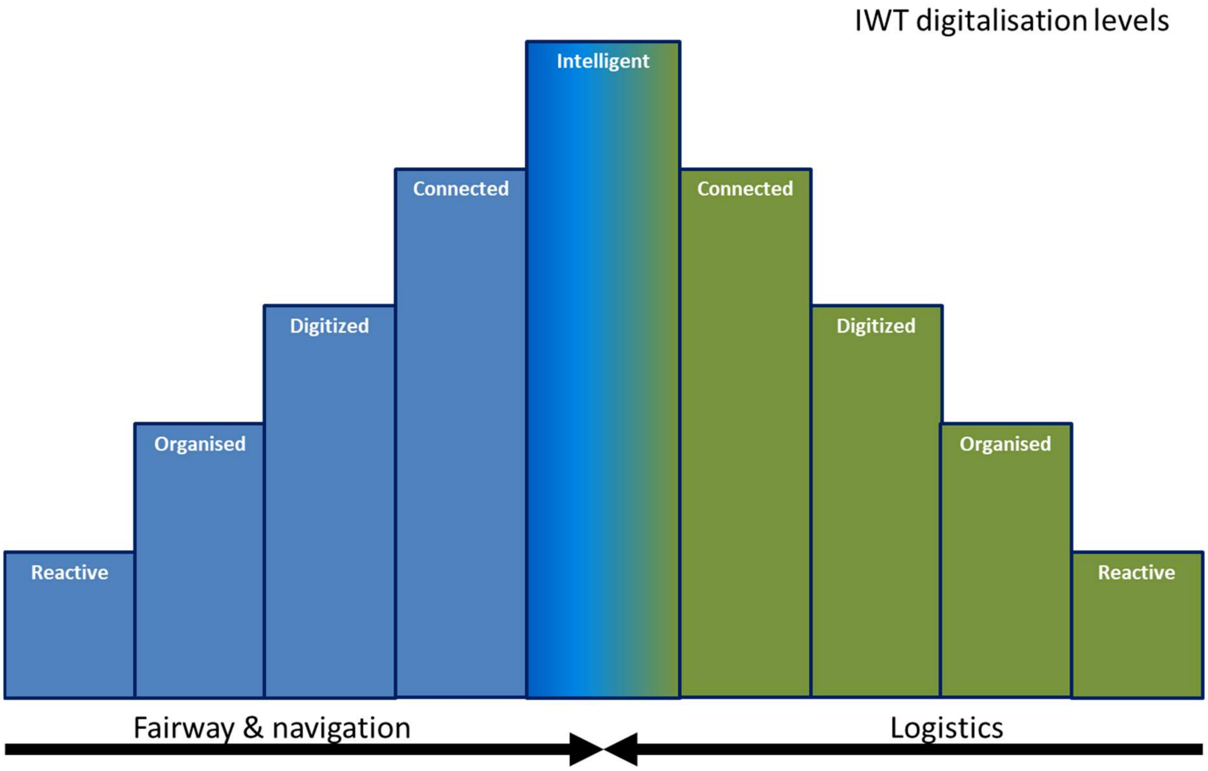

Figure 1: IWT Digitalisation Levels

From that it follows, that the IDLs are foundational regarding the assessments of the individual items studied in DIWA. The cornerstone question can be thus phrased as follows: *'What increase in terms of IDLs would be incurred when incorporating a certain item in the roadmap - specifically?'* In order to avoid that important question ending up as a hindsight consideration in a report's chapter on 'critical evaluation of results achieved' with almost inevitably unspecific conclusions as a result, it was considered how the potential increase of the IDL of the IWT fairway & navigation domain by an item could be assessed from the outset.

Even more specific, *can an 'IDL impact metric' be defined that would render a somewhat quantitative assessment* of an item in this regards even, thus *ultimately allowing the roadmapping of DIWA to focus on those items with the potential high(est) IDL increases.* And what are the costs or efforts associated with that high(est) increase of IDL? These questions culminate in the question of *what can be recommended from the study of item(s) to the roadmapping process – honestly.*

This need for assessment metrics is there for any and all items under consideration by any (Sub-)Activity contributing to the roadmapping, but in particular when there are *many* different items. The latter is the case when looking into technology developments in other modes of transport (road/ITS, rail, maritime – and to a limited degree – aviation): There is so much on the move! Therefore, the above

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questions for assessment metrics came up naturally within the Sub-Activity 3.5 dealing with technologies; and in particular how to arrive at justifiable recommendations for roadmapping in the light of their findings.

Hence, the present Sub-Activity developed and described the above methodologies as a part of this report initially. It was felt by DIWA project management that these methodologies should be lifted out into a stand-alone document for use by others and for ease of reference: Compare the '*Manual on Inland Waterway Transport Digitalisation and Assessment Methodology*' [DIWA-SuAc3.5 2022b] for that document. It contains *firstly* a study on the *consequences of the DIWA desired increase of IDL* for the IWT fairway & navigation domain, together with consequential recommendations for further study and roadmapping. *Secondly*, the above assessment methodology is introduced, that is capable of arriving at even *quantitative assessments of items* under consideration and even recommendations directly following from those assessments, again *together with consequential recommendations*. These aspects are summarised here briefly as follows.

The five different IDLs as indicated in Figure 1 are pre-given in DIWA's foundational documentation ([DIWA 2021b], 5) and are there already embedded in the pre-given DIWA Maturity Model, together with a brief characterisation as given in the right column of Table 1. Supporting explanations and illustrative examples are added in the Manual for each and every IDL.

DIWA IDL Impact = 'item has the potential to contribute to …'		Features at this Level (Summary)
III	Intelligent IWT fairway & navigation domain	Digital transformation established; AI assisted process information; Predictive digital capability; Automated response to standard situations.
II	Connected IWT fairway & navigation domain	Advanced digital features aligned with partners; Digital information exchange by default; Full real-time situational picture digitally available.
I	Digitised IWT fairway & navigation domain	Advanced digital features in silos; Overarching vision established; Digital information exchange possible; Limited real-time situational picture digitally available.
0+	Organised IWT fairway & navigation domain	Specialists deliver changes using established process; Traditional digital features; Building digital capabilities.
0-	Reactive IWT fairway & navigation domain	No overarching vision; Requires heroics to change; Management sceptical about digitalisation; Unfocused digital initiatives.

Table 1: DIWA Maturity Level impact assessment (DIWA IDL Impact)

One assessment metric can be derived from that IDL definition directly, namely the *'IDL Impact' metric* which states to which IDL an *item* under consideration contributes significantly. The different IDLs are abbreviated as follows: The IDLs 'Reactive' (0-) and 'Organised' (0+) can be frequently found presently, i.e. at 'situation zero', when a limited number of digitalisation processes have partly become effective and thus frequently constitute the starting point for any (future) increase of digitalisation maturity proper. The latter IDLs are therefore abbreviated with Roman numerals 'above zero'.

In Table 1, the entity to which the IDL was applied to as a qualifier was the IWT fairway & navigation domain as a whole. Certain other *generic entities* are part of it, namely *vessels*, *waterway field infrastructure*, *centres*, and *data objects*. Compare Figure 1Figure 2 overleaf. All of these entities have a specific IDL each, specifying their digital maturity in appropriate derivations of the general above definitions. Also, the IDL Impact metric can be applied for each entity: 'What would be the impact of an item studied in DIWA on a specific entity regarding increase of the latter's IDL'.

For example, when adapting a certain technological development (= item) to a (generic) inland waterway vessel (= entity) what impact for the IDL of the (generic) inland waterway vessel would be incurred. Another example might be: *What IDL impact would be incurred* when adapting a certain data feature treatment (=item) to a data object of the IWT fairway & navigation domain (=entity)?

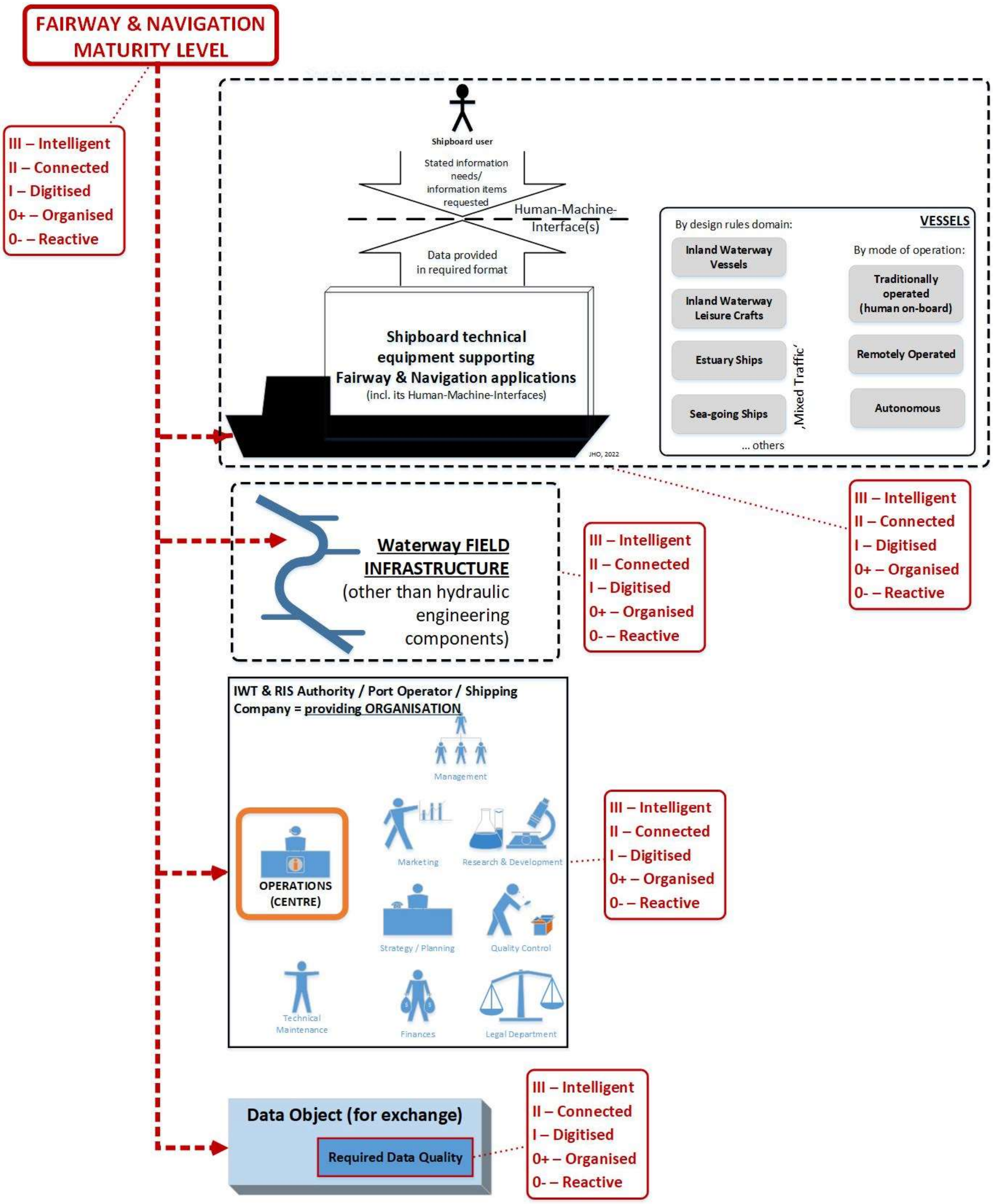

Figure 2: IDLs applied to generic entities of the IWT fairway & navigation domain

The other way round also renders meaningful results: If a (generic) inland waterway vessel (= one kind of entity) would incur an IDL impact towards a higher IDL, *what consequences would this have in terms of necessary consequential IDL impact on another kind of entity* the inland waterway vessel is dependent on that IDL, for example of a certain data object and its necessary IDL. In other words: The desired benefits of IDL increase are improved functionalities available for the IWT fairway & navigation applications and/or human users using them.

However, *IDL increase by introducing digital technologies also brings with it, by very definition, the increased variety and/or proliferation of co-operative technologies.* The benefits of the IDL increase are thus correlated by necessity with the disadvantage of increased interdependency. To mitigate this disadvantage, *certain non-cooperative technologies are still needed on a regular basis and/or for fall-back arrangements even with the advent of the highest possible IDL throughout.*

Further, the combination of the above implications of the increase of the IDL in the IWT fairway & navigation domain necessitates the IDLs of above entities, which have one or several *operational relationships* between them, to match. I.e. it is necessary *that the entities involved in the same operational relationship demonstrate the same IDL.* This principle is called *IDL-Match-Principle* here. An *IDL mis-*

match is a situation where different entities engaged in the *same* operational relationship(s) would not only be unable to use the benefits offered by the entity with the higher IDL - which could be considered a less important disadvantage -, but may result in a more severe situation where the necessary operational relationship may not even be established, whatever this may mean in practical terms.

It is important to note, that in the digital domain, there *does not exist a 'graceful degradation' by default* – as opposed to the analogue domain, which may lead to dropping from a high IDL to (very) low IDL if no graceful degradation is in place: The *assumption* that the occurrence of an IDL mismatch will still 'always' allow for 'some sort of' operational relationship being available 'somehow' is *flawed from the outset in the digital domain*. Any 'graceful degradation' needs to be designed into the desired IDL of the IWT fairway & navigation domain embracing all relevant entities and operational relationships.

Finally, as opposed to the analogue domain, *data exchange by digital technologies generally disallows ambiguities* in data object definitions and in data models governing these data objects. Since data objects and data models are just representations of the real world they intend to represent, up to the ultimate degree of creating a digital twin of an entity, the *necessary disambiguation* needs to *start with the terminology* related to the data objects and interaction concepts that govern their definitions and data models. This in turn prompts the need to *remove ambiguity from operational procedures* governing the interaction concepts as well as *from regulations* governing the operational procedures ultimately. This needs to be done to that extent induced by the desired IDL: For arriving at 'digital information exchange *as a default'*, which is a key feature of 'even only' the IDL 'Connected' (II), basically *all* relevant regulations, operational procedures, terminology and data models need to be free of ambiguities.

Admittedly, these are abstract considerations, but a high degree of abstraction is an essential feature of *digital transformation* (compare [Wikipedia 2022a]) and can thus not be avoided when embarking on it. Also, admittedly, the consequences and requirements stemming from in particular higher IDLs when introduced throughout, becoming visible by these considerations, may be scary. But again, when roadmapping towards a higher IDL for the IWT fairway & navigation domain at large, it is necessary to face those consequences upfront and potentially also find mitigation measures. The above Manual summarised here for its application in the present study and report just intended to bring that to the fore.

2.3 Learning from other modes of transport

The first task stipulation for the present Sub-Activity: 'Make an inventory and study on technologies that are under development or implemented in other transport domains and assess the applicability in IWT' can be simply rephrased as: *'What can the IWT fairway & navigation domain learn from other modes of transport in terms of technologies?'* Or in yet another way: *'If other modes of transports look into certain technologies, why should IWT fairway & navigation not look into them?'* This way to paraphrase the stipulated task has two important consequences:

- *The attitude of listeners and learners is required:* Due diligence should be exercised to identify the underlying ideas contained in a certain technology employed in a different mode of transport and a sufficient amount of phantasy should be employed in order to potentially adapt these underlying ideas to IWT fairway & navigation, even if the technology as implemented in the specific shape of a different mode of transport cannot directly be adapted to IWT fairway & navigation.
- It is *not* intended to create a purpose-free collection of technologies, or even a textbook for that matter. Rather, *a meaningful place for any technology under consideration within the IWT fairway & navigation domain must be identified, i.e. the architectural context of a potential application of a certain technology to IWT fairway & navigation must be demonstrated.* This can be best achieved, if and when architectural considerations are integral to this study and report.

2.4 Scope considerations

The relevant modes of transport to be considered here are *road transport/ITS, rail transport, maritime transport* and – to a lesser degree – *aviation.* This scope requires certain limitations as follows.

2.4.1 Answering relevant conclusions + recommendations from Sub-Activity 2.5

Sub-Activity 2.5 was tasked with the creation of 'an inventory of and study on ITS, ERMTS and e-Navigation', with the definition of the 'integral and harmonised service, information and data requirements related to the digital transition of Inland Waterways', and provide conclusions and recommendations accordingly ([DIWA 2021a], 18). During their work, Sub-Activity 2.5 recognised that the scope of their investigations should be rail, road, and maritime instead of being confined to ERMTS, ITS, and e-Navigation respectively, only ([DIWA-SuAc2.5 2022], 5). Hence, Sub-Activity 2.5's tasks are closely related to the present Sub-Activity's tasks, and their results will therefore be taken as important input: Sub-Activity 2.5 firstly created useful introductions to the different domains, as follows, and the reader is directed to those because the introductions will *not* be re-iterated here.

- Road / ITS, refer to ([DIWA-SuAc2.5 2022], 14-18);
- Rail / ERTMS, refer to ([DIWA-SuAc2.5 2022], 19-33);
- Maritime / e-Navigation, refer to ([DIWA-SuAc2.5 2022], 34-40).

In addition, Sub-Activity 2.5 suggests to specifically indicated other (Sub-)Activities the following ([DIWA-SuAc2.5 2022], 56):

- The 'Overarching e-navigation architecture' which was adapted to the RIS environment by Sub-Activity 2.5 (compare Figure 3) should be used 'throughout, [because] this architecture may be helpful for defining the context of the different IWT related technologies'. This suggestion holds true for the operational services of the IWT fairway & navigation domain, too.

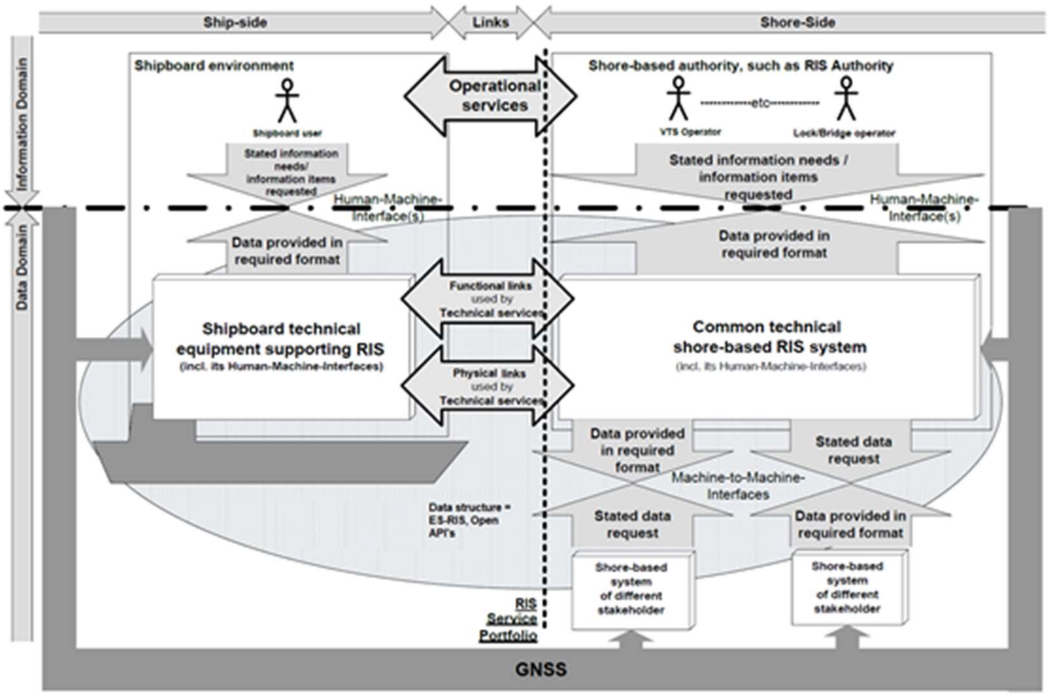

Figure 3: Overarching RIS Architecture

- 'The plan for a fall-back scenario is something that should be further discussed and elaborated within Activity 3. These activities will be able to discuss in further detail the precise technicalities of a fall-back scenario.'
- 'There appears to be a <blind spot> regarding the important (global) role of the International Telecommunication Union (ITU) regarding all radio links for mobile applications (in particular regarding ITS and rail). This <blind spot> can be investigated as far as applicable within Sub-Activity 3.5.'

Finally, Sub-Activity 2.5 provides *recommendations*, the particularly relevant of which to the present Sub-Activity are listed below ([DIWA-SuAc2.5 2022], 60f). It should be noted that *all* of those have been assigned *a high working priority* by Sub-Activity 2.5:

- 'Rec 2: Define communication profiles for the different operational and technical services.'
- 'Rec 3: Elaborate on the standardization and harmonization of the bridge layout and human-machine-interfaces on the bridge.'
- 'Rec 4: Investigate the potential of the digital twin of a vessel as explained in the Universal Hydrographic Data Model (S-100) opened by the IHO.'

- 'Rec 11: Investigate the principles and governance of the S-100 world as a baseline within the overarching architecture of RIS.'
- 'Rec 12: Investigate digital fall-back scenarios on a technical level.'
- 'Rec 13: Investigate the role of the International Telecommunication Union (ITU) regarding all radio links for mobile applications (in particular regarding ITS and Rail).'
- 'Rec 15: Define the criteria to grow from 'Digitised' to 'Connected' and ultimately 'Intelligent' in the DIWA Digital Maturity Model.' *Note: Due to its fundamental importance, this Recommendation has been taken up and the topic progressed already the Manual described above.*
- 'Rec 19: The different transport modes are applying different terms for voyage, trip, path, route, etc. Within Sub-Activity 4.1, clear and unambiguous definitions should be elaborated.'
- 'Rec 20: Process automatic alerts in case of incident or man over board.'

2.4.2 Scope considerations regarding inventory items for specific consideration

To state, as is done in the present Sub-Activity's objectives, as a scope 'technologies that are under development or implemented in other transport domains' was considered too general; certain more specific criteria were considered necessary to limit the scope to be both feasible in terms of time and resource constraints, to avoid inappropriate overlap or even extensive redundancy with other Sub-Activities, and - last but not least - also to be meaningful to the highest degree possible in terms of learning from other modes of transport as indicated above.

As introduced above, **firstly** this study and report focusses on those technologies relevant for the *IWT fairway & navigation domain* (compare left part of Figure 1), i.e. *not* on those technologies relevant for the IWT logistics domain (compare right part of Figure 1). Those technologies specific to the IWT logistics domain, such as cargo related technologies including cargo state and cargo tracking sensoring, are thus beyond the scope of this study and report.[7]

Secondly, the versatile 'new technologies' as studied with the goal to broadly assess their applicability to the IWT fairway & navigation domain by Sub-Activities 3.1 (IoT, AI, Big Data, DLT, IMT-2020), 3.2 (internet technologies for portals and platforms), 3.3 (smart sensoring and PNT) were generally excluded *unless for the purpose of indicating specific relevant developments or considerations underway in the other modes of transport in order to satisfy the 'alert objective'* of the present Sub-Activity. This means, that there might have been performed a more in-depth study at other Sub-Activities 3, but the point here is that a *different mode of transport* has already done something with that general technology, thus rendering it a potential inventory item: What has been done by the different mode of transport will be briefly introduced, key documents referenced[8] and the inventory item assessed here, but any more detailed consideration will be passed on.

Thirdly, 'under specific consideration' at another mode of transport would further require a certain degree of consideration, not just passing interest. This means, that a potential inventory item has already left a *'significant trace'*, i.e. this consideration has generated a sufficient documentation available for assessment by the present Sub-Activity as follows:

- A different mode *already uses* a certain potential inventory item.
- A different mode *has started investigating the applicability* of a potential inventory item intended for general use, for example, a technology that did not originate in that mode but has attracted sufficient attention for applicability by that mode. This does not imply, that the consideration at that mode needs to have been finalised, however.
- Whenever, in particular, *the maritime domain* already employs or has started considering a certain technology because of the special 'wet-to-wet' proximity between maritime transport and IWT fairway & navigation domain. This proximity has expressed itself in the past and will continue to express itself by the following effects:

[7] There may be certain technology families to be used by both domains, such as general purpose technologies under consideration by other Sub-Activities 3.

[8] Intensive documentation of interaction with sources is required and references are therefore implemented throughout that point to the Bibliography in the supportive apparatus. The reader is invited to double-check statements contained herein with the sources given as deemed appropriate.

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- *Mixed traffic situations,* i.e. because of unavoidable interactions using any kind of technology between sea-going ships and inland waterway vessels, in for example estuary environments under maritime rules – Both affect each other directly because they operate in the very same fairway. Hence, the inland waterway vessels must be capable of the unavoidable interactions using the technology or technologies, the sea-going ships use or will use.[9]
- *Factual presence of maritime technology in the IWT fairway & navigation domain that cannot be ignored for operational reasons* disregarding the present regulatory status of that technology within the existing IWT fairway & navigation regulatory framework. An example for the (emerging) factual presence of maritime technology is the usage by the public of man-over-board search-and-rescue devices using the Automatic Identification System (AIS).
- *Creep-in-effect over time* via standardisation of maritime technology for the IWT fairway & navigation domain that is driven by stakeholders (strongly) willing to adopt the maritime technology available.

But still with these principles employed, the scope for the present Sub-Activity is still considerably sizeable. Hence, fourhtly, just only due to the study time and resource constraints imminent, the present Sub-Activity focussed on *recent* relevant developments in other modes of transport – as opposed to fully scan of what has been implemented in the past in these modes.

Within the scope thus limited, the present Sub-Activity behaved quite generously when *identifying* items of other modes of transport with potential relevance for the IWT fairway & navigation domain. These items are *technology-oriented architectures, individual technologies or technological families* (henceforth called *Candidate Technologies (CT)),* and *useful combinations* thereof, including fall-back arrangements.

Obviously, due to the inherent mobility of any vehicle of any other mode of transport, *radio communication technologies* and *architectures providing frameworks to them* constitute a major part of the scope, in particular those tailored to specific needs of the other modes to solve their respective tasks of mobile vehicle/infrastructure (V2I), infrastructure/mobile vehicle (I2V) and mobile vehicle/mobile vehicle (V2V) interactions taking into account their respective mobile environments.[10]

2.4.3 Scope considerations regarding Remotely Operated and Autonomous Vessels

In all modes of transport under consideration the respective remotely operated and autonomous vehicles have arrived. This is also the case for the 'wet' domains, i.e. maritime and IWT fairway & navigation domains. Of particular relevance for DIWA is the maritime domain: There are under consideration or even already operational Remotely Operated Vessels (ROV) and Autonomous Vessels (AV). Since developments in this regards are of broader interest for DIWA at large, a *generic* methodology for *capturing* ROVs and AVs *within the exiting framework of the traditionally operated vessels and associated shore centres* has been developed by the present Sub-Activity – as a stand-alone *'Guideline on capturing Remotely Operated Vessels (ROV) and Autonomous Vessels (AV) for Inland Waterway Transport future planning'* that also contains associated recommendations [DIWA-Sub-Activity 3.5 2022b].

While the development of the conceptual framework contained therein will not be re-iterated here, two important generic figures developed there are essential for the present study and report and are thus reproduced as follows for further reference throughout. Figure 4 overleaf shows a *conceptual framework in generic terms* of all types of vessels as well as all relevant types of centres conceptually operative in the IWT fairway & navigation domain – well-known existing and the new ones. For explanations refer to the glossary of the present report and to [DIWA-SuAc3.5 2022a].

[9] This situation may be covered by IWT fairway & navigation regulatory framework (already); otherwise this would be incentive to recommend its coverage by means of a recommendation.

[10] It is recognised that there may be *fixed communication technologies* employed when vehicles are parked or moored in any mode. It is assumed, however, that, in terms of telecommunications, fixed land lines are capable *at least* of what radio communication link technologies deliver.

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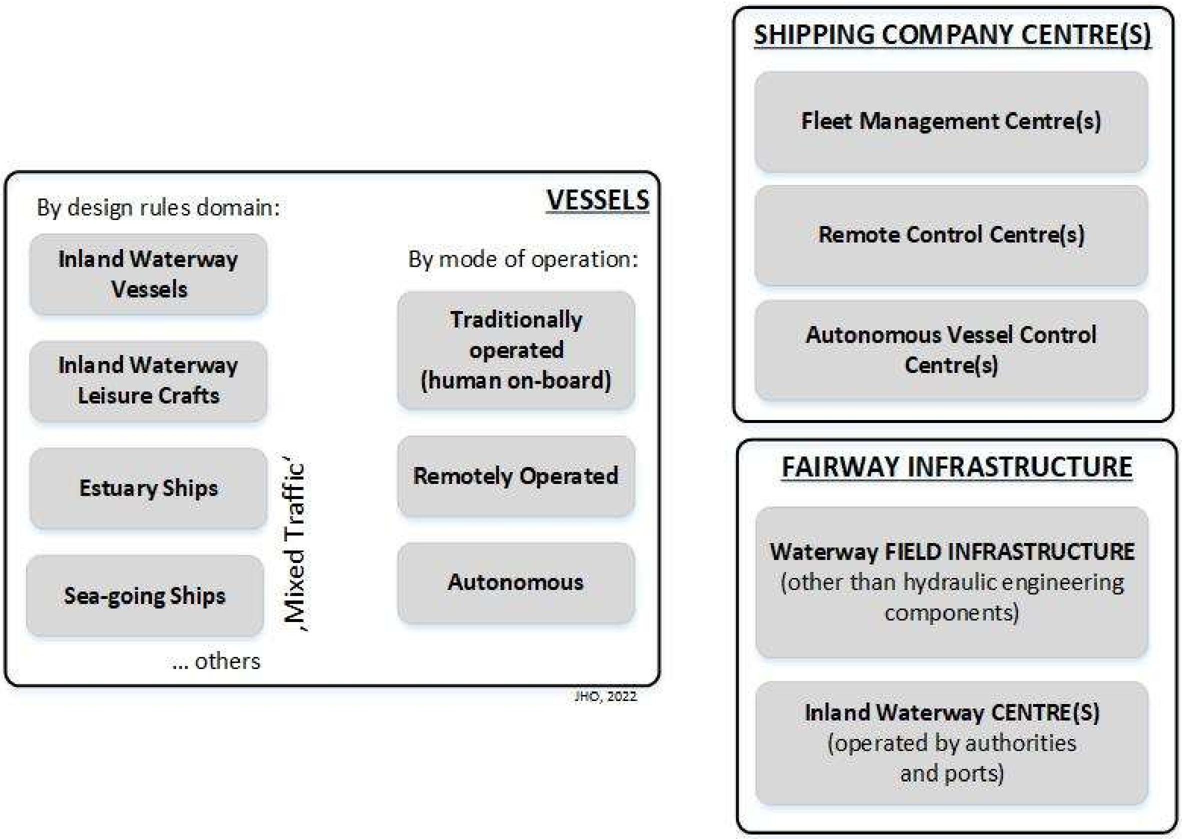

Figure 4: Relevant operational entities in the IWT Fairway & Navigation domain

Figure 5 overleaf generically shows the operational relationships, the resulting functional and physical link(s) between the entities introduced in Figure 4 by the advent of the ROVs and AVs in a generic way. For explanations again refer to the glossary of the present report and to [DIWA-SuAc3.5 2022a].

2.4.4 Scope considerations regarding potential useful combinations

A single CT may not provide all required functionalities for all relevant cases. This most likely holds true for even the most versatile CTs, like, for example, the general purpose cellular radio communication technology family. Hence, it is necessary to purposefully combine different promising CTs together to fulfil the functional requirements with an optimum set of CTs, whatever the criteria for optimal might be. The way to combine the CTs may be defined by a technology-oriented architecture, as introduced in Chapter 3. A special case of useful combinations are fall-back arrangements. Useful combinations are discussed in Chapter 5, but any aspiration of comprehensive or even complete coverage would be beyond scope. Also, in keeping with other above scope considerations, there will be discussed only those useful combinations that are under consideration in some other mode of transport or that follow from the assessments made and reflected in the preceding parts of the item inventory.

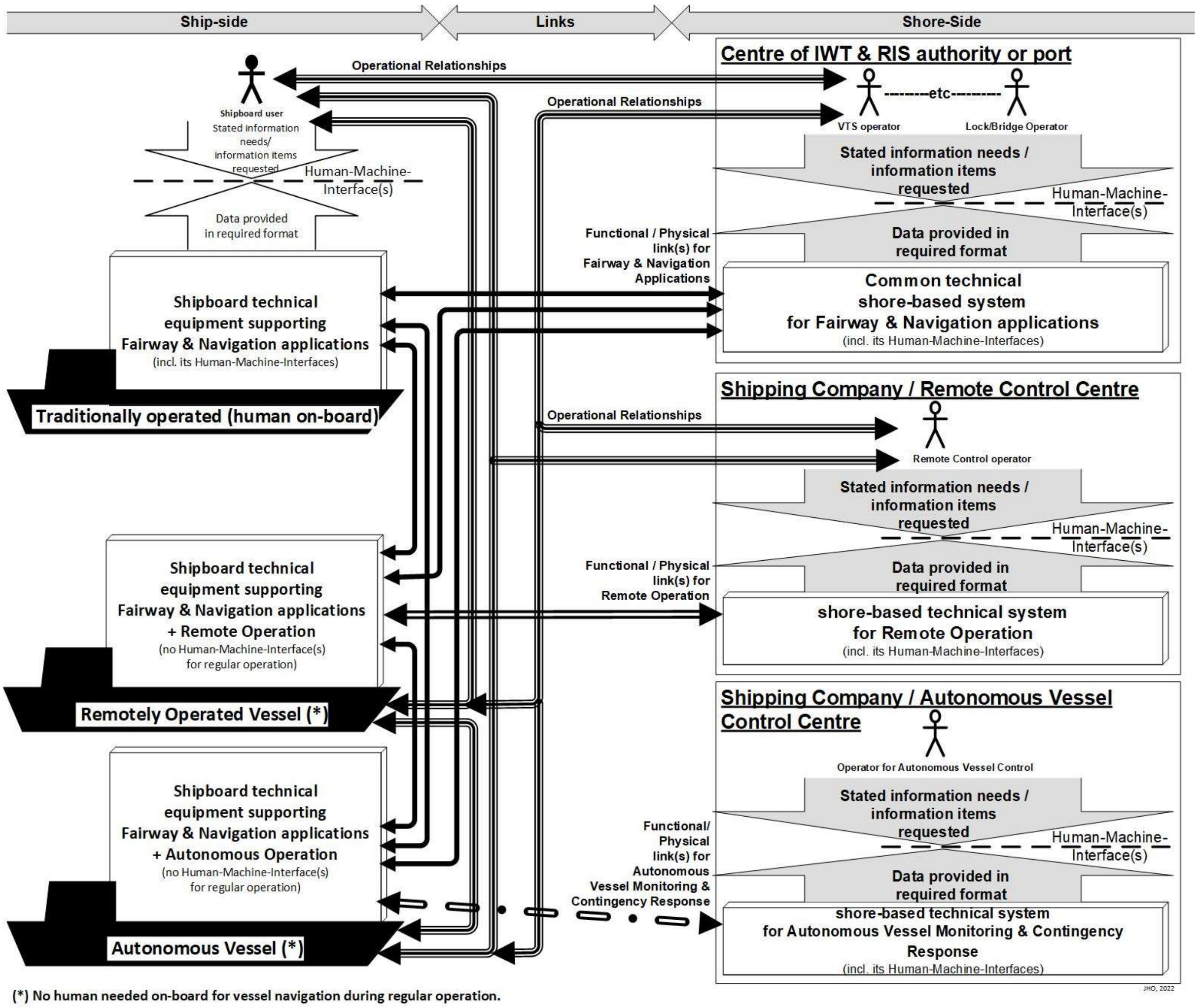

Figure 5: Operational relationships and required functional/physical links due to the advent of remotely operated and autonomous vessels

2.5 Assessments of an inventory item

All inventory items as introduced above are to be described briefly by means of introduction and as far as relevant to meet the present Sub-Activity's objectives. This will include references to key documents of relevant organisations, mostly international organisations that have an important role in the definition and regulation of the inventory item under consideration.

Subsequently, each inventory item will be assessed as detailed in the above mentioned 'Manual' ([DIWA SuAc-3.5 2022b] refers). A brief summary is given here to explain the usage of that assessment methodology in the following chapters. The *IDL Impact* of an inventory item, as introduced above, was the starting point and can thus be considered the most important assessment metric. There are other assessment metrics required, though. They rest on the three different additional rationales as follows:

- What is the *inherent maturity* of an item? I. e. what is – for example – the maturity of a technological development 'in itself'? Resulting from this are the metrics *Hype Cycle Phase* and the *Technology Readiness Level*.
- What is the degree of *adaptability* of an item to the IWT fairway & navigation domain, and what resources would this require (if possible at all)? Resulting from this are the metrics *Adaptability* and *Adaptation Demands*. (NB: Adaptation should not be confused with deployment.)
- Looking into the future, when will be a certain item potentially fully deployable or even deployed in the IWT fairway & navigation domain assuming 'due diligence' to that end and taking in the necessary efforts? Resulting from this is the *Radar metric*.

Table 2 overleaf shows all assessment metrics used. For further detail consult [DIWA-SuAc3.5 2022b].

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DIWA Assessment metric (short names)	Assessment results
DIWA- Hype Cycle Phase	5 - Plateau of Productivity 4 - Slope of Enlightenment, 3 - Trough of Disillusionment, 2 - Peak of Inflated Expectations, 1 - Technology Trigger
DIWA-Technology Readiness Level	9 (Market expansion) 8 (Initial market introduction) 7 (Pilot production demonstrated) 6 (Pilot production – pre-production product) 5 (Prototyping & Incubation – testing prototype in user environment) 4 (Concept Validation – lab prototype) 3 (Concept Validation – first assessment feasibility) 2 (Invention – Technology concept formulated) 1 (Invention – Basic principles observed)
DIWA-Adaptability	++ (Seamless Adaptability) + (Adaptability with minor modifications) 0 (Adaptable with substantial modifications) - (Adaptable by redesign in analogy) -- (Not adaptable)
DIWA-Adaptation Demands	++ (Little adaptation resource/time demands) + (Intermediate adaptation resource/time demands) 0 (Substantial adaptation resource/time demands) - (High adaptation resource/time demands) -- (Not feasible)
DIWA-Radar	2022-2026 2027-2032 'Future Box'
DIWA-IDL Impact	Supportive for transformation into III (Intelligent IWT fairway & navigation domain) II (Connected IWT fairway & navigation domain) I (Digitised IWT fairway & navigation domain) 0+ (Organised IWT fairway & navigation domain) 0- (Reactive IWT fairway & navigation domain)

Table 2: Assessment metrics as defined for DIWA

Last but not least, the assessments results of the different (potentially many) items can be directly put into a *decision making context* by using the *4-Quadrant-Matrix model*. How recommendations can be derived from it directly, is finally introduced in this manual.

2.6 Report Chapter Overview

The inventory created in this study and report to fulfil the objectives of this study and report has three parts, each of which is addressing one kind of inventory items, as follows: *Chapter 3* as the first part of introduces the relevant *technology-oriented architectures* that have been developed at other modes of transport and assesses their potential adaptation to the IWT fairway & navigation domain. *Chapter 4* as the second part introduces the CTs within architectural context and assesses them as described above. The previously introduced architectures allow to structure the CT inventory into functional technology families and thus provides context to any individual CT. *Chapter 5* as the third part of the inventory introduces *useful combinations* of inventory items, that are prompted by the recognition that only a combination may achieve the desired full functionality in regular operation or that only a fall-back arrangement as a special case of a useful combination may still provide at least some functionality during failure mode operation.

Chapter 6 compiles the results of the various previous *assessments into conclusions from which recommendations are derived in turn*. *Chapter 7* as the final chapter performs a *critical reflection* on how the tasks given to Sub-Activity 3.5 were met by its results. The *supportive apparatus* at the end of this report contains in particular the *List of Abbreviations*, a *Glossary of Terms*, the *Bibliography*, and the synopsis of *Recommendations*.

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2.7 Recommendations

The goal of this study and report is to provide meaningful recommendations for taking further studies and/or actions due to the conclusions. Recommendations will to be lifted out of the context of this report for incorporation into the DIWA envisaged masterplan eventually, however. In order not to render them context-free and thus potentially meaningless by then, recommendations were drafted to reflect their context, specifically state what is recommended, and to reflect the suggested priority of the recommended activity. Recommendations are subdivided into recommendations for further action (**Action-REC-**) or for further study (**Study-REC-**). In the Annex, there are two lists, one for each kind of recommendations. In addition, for each Recommendation, an assessment of the work load incurred, is given.

2.8 From Study to Report – work process and constraints

One major stipulated objective for this study and report was to make an inventory. An inventory, by all common standards, has to be complete. Applying this requirement to the different modes of transports and considering their many-fold technology-oriented activities each, this expectation could not possibly be fulfilled, even with scope limitations imposed as introduced above. But even with these scope limitations and considering the many different activities of the modes, a sizeable inventory reflected in a substantial report were to be expected from the outset.

The study essentially was performed as desk research involving experts in the application of electronic technologies in several modes, including IWT itself. The list of experts is given on the front page as Main Author and Contributors.

This report essentially is result-oriented, and it is therefore reflecting the working process only in brief: The potential adaptability of relevant inventory items was the focal point as indicated above.

The present Sub-Activity took place between March and September 2022. The Sub-Activity worked under considerable time pressure because the summer vacation period on one hand as well as the impacts of the Corona Pandemic on the other hand needed to be taken into account as a limiting factor to experts' availability. To execute the tasks at hand efficiently, there was setup a flow of workshops as given in Table 3, the participants of which were the above experts.

Major topic of workshop	March 2022	April 2022	May 2022	June 2022	Aug 2022	Sep 2022
Methodological considerations / initial inventory of CTs	30/31					
Inventory of CTs/CT assessments		20/21				
Inventory of CTs /CT assessments			31.05/01.06.			
Inventory of CTs / CT assessments				23/24		
CT assessments , conclusions + recommendations					24/25	
Finalisation conclusions + recommendations						19

Table 3: Timeline Sub-Activity 3.5

2.9 Other introductory matter

British English is used throughout which results, e.g. in the usage of transport (instead of transportation).

The references to the Bibliography are given by a token, which is defined in the Bibliography. The token is either the author-year-combination for articles or monographs, or the document identification used by the issuing organisation.

In order to avoid any Copyright or Trademark issue, only generic terms are used throughout this document. Generic terms for technologies and technology families are generally provided by the relevant international / United Nations organisations.

It is necessary to use clear terminology when referring to IWT as opposed to maritime terminology throughout this report. Unfortunately, in English it appears that the term 'ship' invariably carries a maritime connotation, while the term 'vessel' can mean both 'an inland waterway vessel or a sea-going ship' ([UNECE-Res61], 1-2.2 'vessel'). 'Barge' on the other hand, which is given in some dictionaries as an appropriate translation,[11] carries a clear and strong IWT connotation without any ambiguity and therefore might have been a candidate for designating inland waterway vessels throughout this report. However, 'barge' is defined as 'a dumb barge or tank barge' ([UNECE-Res61), 1-2.11), with 'dumb barge' being defined as 'a vessel (…) intended for the carriage of goods and built to be towed, either having no motive power of its own or having only sufficient motive power to perform restricted manoeuvres' ([UNECE-Res61, 1-2.13), thus essentially rendering it a passive entity and therefore undesirable for the purposes here. The United Nations Economic Commission for Europe (UNECE) uses the two terms 'inland waterway vessel' defining 'a vessel intended solely or mainly for navigation on inland waterways' ([UNECE-Res61], 1-2.3) and 'sea going ship' as 'a vessel intended mainly for navigation at sea' ([UNECE-Res61],1-2.4). In this report, *the UNECE defined terminology will be followed*, i.e. using *'inland waterway vessel'* and *'sea-going ship'* (or just *'ship'* if the context is unambiguous), as defined by UNECE. Compound terms like 'autonomous inland waterway vessel' vs. 'autonomous (sea-going) ship' will be used similarly. 'Shipboard' or 'shipborne' and 'ship-shore/shore-ship' will be used for both alike, however. Should there be other relevant terminology to be used, the well-established and internationally recognised UNECE terminology ([UNECE-Res61], 1-2) will be followed as a default.

[11] Of e.g. the German 'Binnenschiff'.

3 Structured Inventory of technology-oriented architectures

3.1 Introduction

This chapter considers technology-oriented architectures employed in other mode of transport with the view to learn from them for use in the IWT fairway & navigation domain. The aim of any architecture is to structure the different entities within its scope into a contextual framework: *Architecture thus provides both structure and context. Different architectural models highlight different points of view. Therefore, they co-exist with different scopes and thereby mutually complement each other.*

The need for architecture increases with the increase of co-operative interactions as introduced above, i.e. the need for architecture increases with the DIWA's desired increase of IDL: Even IDL I already requires an architecture as part of its 'overarching vision', whether it is explicitly stated, or not. IDLs II and III are not conceivable without solid architectural foundations. *Each of the individual technology-oriented architectures introduced in this chapter, if and when applied to the IWT fairway & navigation domain, contributes to increasing the IDL.* The specific degree of which are assessed here as introduced in the previous chapter, applied here to technology-oriented architectures being the inventory items. As a result, this chapter *represents an inventory of technology-oriented architectures developed in other modes of transport and – even more important – adapted to the IWT fairway & navigation domain by the present Sub-Activity.* Hence, this chapter constitutes the first part of the inventory.

3.2 The Nautical Datalink Communications architecture

Each mode of transport has developed a notion of the most fundamental architecture which reflects the entities involved in an operational relationship when it comes to communication: mobile side – infrastructure side – links in-between. In all modes of transport, this *'three-sides-of-the-coin architecture'* shows the vehicle under consideration, being traditionally operated by a human, a human operator in one operational centre, and how the communication in-between is done by a *datalink* as the default means and – *in addition* – by voice ('words of mouth'). This most fundamental architecture thus can be called a ***datalink communications architecture.*** It should be noted, that a datalink communications architecture may be employed by a mode of transport without labelling it that way. The defining point of a datalink communications architecture is, that it includes the *full chain of the data flow from its ultimate source* – in the case of a human entered by a (dedicated) HMI – *to its ultimate destination ('sink' in ITC parlour)* – in the case of a human displayed on a (dedicated) HMI again. *The interfaces to the ultimate sources or sinks of the data are thus integral parts of the datalink communications architecture and are thus consciously reflected in datalink applications* as illustrated below.

3.2.1 Datalink communications architecture at ITS

Figure 6 illustrates this datalink communication architecture at ITS for the case of a vehicle involved in an incident: When triggered, a *'minimum set of data',* including the vehicle's position as obtained from (at least) GNSS as indicated by the satellites, is transferred via a radio communications network to a human in a centre, called 'most appropriate public safety answering point'. Obviously, this 'minimum set of data' transferred via a *datalink communication* must be made visible to the human in the centre by a HMI. The human answers by voice via the radio communications network, and a bi-directional voice communication between the humans on both side is established.

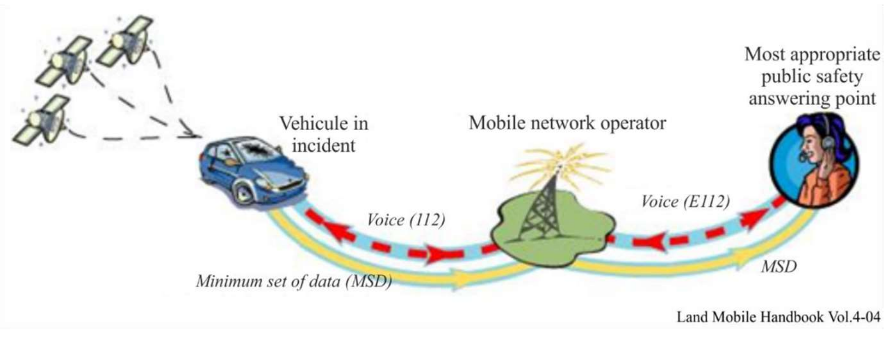

Figure 6: Datalink communications architecture at ITS

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3.2.2 Datalink communications architecture at rail

Figure 7 illustrates a datalink communications architecture at rail, illustrated for a case of emergency as well. Basically, the process is the same as with the ITS: The human train driver detects an emergency and 'presses RED button', which in turn obviously initiates a *data message* to be transmitted from the alerting train via a 'train radio system' toward a (human) 'train controller' in a centre, who has seen the red button message on the HMI there and thus is alerted to the emergency. The 'train controller' then 'takes the call' which is obviously also *relayed by data messages* to the other trains in 'close range' in parallel, and the 'train controller' then processes the emergency *also by voice* communication.

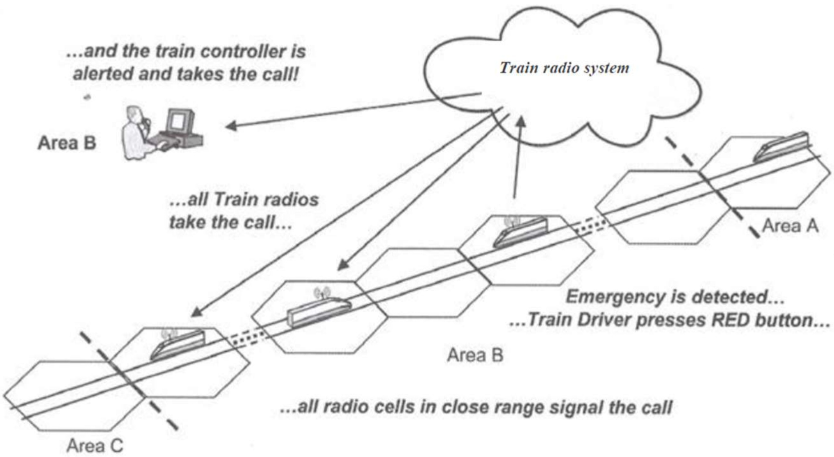

Figure 7: Fundamental rail communications architectural structure

3.2.3 Datalink communications architecture at maritime

At maritime, datalink communications have been used for decades now; just two examples as follows:

- In the context of the *Global Maritime Distress and Safety System (GMDSS)* and there in particular by means of the terrestrial *Digital Selective Calling (DSC)* technology: In case of an emergency, a human member of the shipboard bridge team presses an alert button at a *dedicated HMI,* which initiates an emergency call via the DSC datalink communications to be displayed on another *dedicated HMI* at the receiving station (another ship, shore centre) to a human on the watch, who then may reply via datalink communications and/or voice and take further search & rescue actions, as appropriate.
- In the context of *Automatic Identification System (AIS),* another maritime system exclusively using data messages to support its operational ends, a dedicated HMI labelled '*Minimum Keyboard & Display (MKD)'* was included as an integral part of an AIS shipboard station for seagoing ships subject to the SOLAS mandatory carriage requirement from the beginning, thus allowing for the full communication chain to be covered, at least in ship-ship AIS-datalink communications. The wish to integrate the AIS data into shipboard HMIs which are much more powerful than the MKD, such as *Integrated Navigation Systems (INS),* was there from the beginning, too. However, as opposed to the MKD, this dataflow integration from *a shipboard HMI other than MKD* to the shipboard AIS station was not made mandatory by IMO up to present. This deficiency may also be one of the main reasons for the *Application Specific Messages (ASM)* not being used to their full potential, although they have been defined for extensive bi-directional datalink communications. This deficiency to cover the full datalink communication chain at AIS was recognised at IMO, and it was suggested to fully establish the datalink communications architecture for AIS in the future (see Chapter 4).

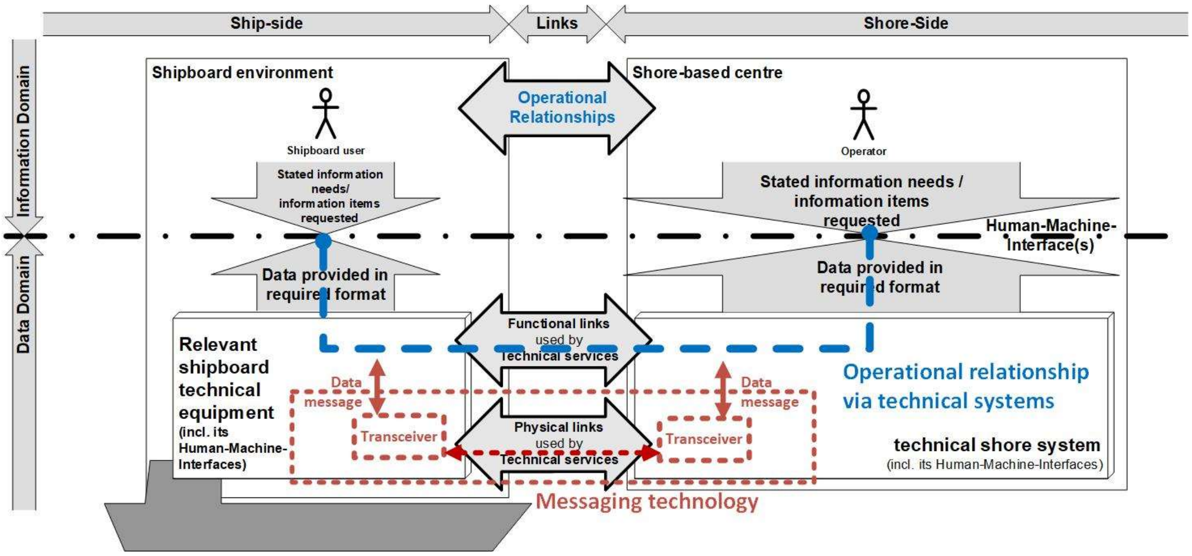

Figure 8: Voice and datalink communications implied by overarching e-navigation architecture

With the advent of e-navigation, this long established notion of maritime datalink communications *has been generalised and made foundational* to the overarching e-navigation architecture, not excluding voice communications conceptually, however. Thus, a datalink communications architecture is underlying the IMO adopted overarching e-navigation architecture, as explained in e.g. [IALA-G1113].

Above Figure 8 illustrates the human-to-human datalink communications supporting the operational relationship (as functional links) via appropriate technical systems (as physical links), which in case of the datalink communications are certain messaging technologies, in combination with appropriate HMIs on both sides.

3.2.4 Datalink communications architecture at aviation

At aviation, the full chain covered by the datalink communications architecture from the ultimate source of data – e.g. an air traffic controller at an Air Traffic Control (ATC) centre – to the ultimate sink of data – e.g. at the cockpit crew - has been used operationally for several decades now in a system called Controller Pilot Datalink Communications (CPDLC). It comprises *dedicated HMIs* on both sides together with an internationally standardised but essentially carrier-agnostic datalink technology for the functional links, which in turn are using as physical link(s) one or more radio communication technologies such as aviation VHF for short range, but also HF and/or communication satellites for long range. For further information in particular for the creation of CPDLC compare [Wikipedia-EN 2022b] or [SKYbrary 2022].

While CPDLC is employing a datalink communications architecture common to all modes of transport as indicated above, it differs in one important operational regard: *The CPDLC was designed to remove the need for voice communications in ATC – a safety application with very high standards! – in* ***routine*** *use cases for several strong reasons to the maximum extent possible and use voice communication for the critical use cases remaining. Hence, CPDLC should* ***<u>not</u>*** *be construed as even attempting to render a* ***voiceless*** *ATC, but* ***rather renders a 'voiceless<u>er</u>'*** *ATC.* The operational use of CPDLC for several decades now in regions with high air traffic density has proven that this intention works even in safety applications with very high standards. CPDLC – and its underlying datalink communications architecture - may thus be an example for IWT fairway & navigation domain.

3.2.5 Nautical Datalink Communications for the IWT fairway & navigation domain

The above comparison between different modes shows, that all include the datalink communications architecture by necessity. However, aviation has gone much further by implementing the datalink communications architecture conceptually from ultimate data source to ultimate data sink to arrive at 'voiceless*<u>er</u>*' solutions for operational relationships in ATC with well-known very high safety standards - with more than 20 years practice now. It is also important to note, that the datalink communications architecture is *carrier-agnostic* by definition, thus rendering several different physical links possible for application, as required by the specific mode of transport.

The conclusion to be drawn is, that the IWT fairway & navigation domain should adopt their variety of datalink communications as systematically as in some other modes, too. The resulting architecture would be called *Nautical Datalink Communications (NDLC) architecture*. The IWT fairway & navigation variety of the datalink communications henceforth is called *Nautical Datalink Communications (NDLC)*, and the human-to-human case – abbreviated *H2H-Nautical Datalink Communications (H2H-NDLC)* is illustrated in Figure 9.

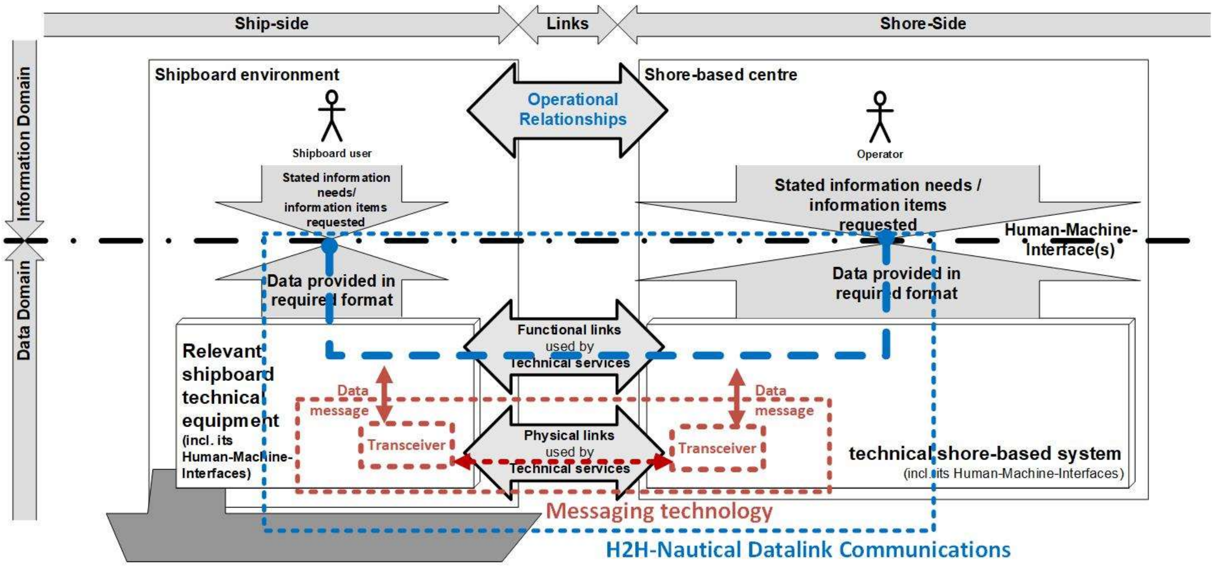

Figure 9: Human-to-Human Nautical Datalink Communications in architectural context

Within the datalink communications architecture, ultimate data source can be a machine and ultimate data sink can also be a machine. This leads to the recognition of *Machine-to-Machine Nautical Datalink Communications (M2M-NDLC)* and *Human-to-Machine Nautical Datalink Communications (M2H-NDLC)*, the latter of which would be a common name for the human or machine on either end.

The assessment of the NDLC architecture, i.e. of the datalink notion to be found in all modes under consideration to various degrees of implementation, as adapted to the IWT fairway & navigation domain is given in Table 4.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion)
DIWA-Adaptability	++ (Seamless Adaptability)
DIWA-Adaptation Demands	++ (Little adaptation resource/time demands)
DIWA-Technology Radar	2022-2026
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain)

Table 4: Assessment results for the Nautical Datalink Communications architecture

The elaboration of the NDLC will be taken up in consecutive chapters. From the above discussion, there are recommendations derived as given in the Annex under *REC-NDLC*.

3.3 The IWT Infrastructure Site Architecture

This section discusses what can be learned at the IWT fairway & navigation domain from ITS and rail when considering their road- or track-side balise communications architectures respectively.

3.3.1 Introduction to the gate communications architecture at ITS

Where road toll is collected electronically, the necessary data exchange between vehicle and infrastructure is done in the brief time the vehicle passes underneath a gate. In that instant, a functional link is established between the roadside field equipment and a dedicated on-board unit (OBU) using a radio communication technology capable of instantaneously, i.e. without any relevant latency, and reliably establishing the functional link. This is illustrated in Figure 10.

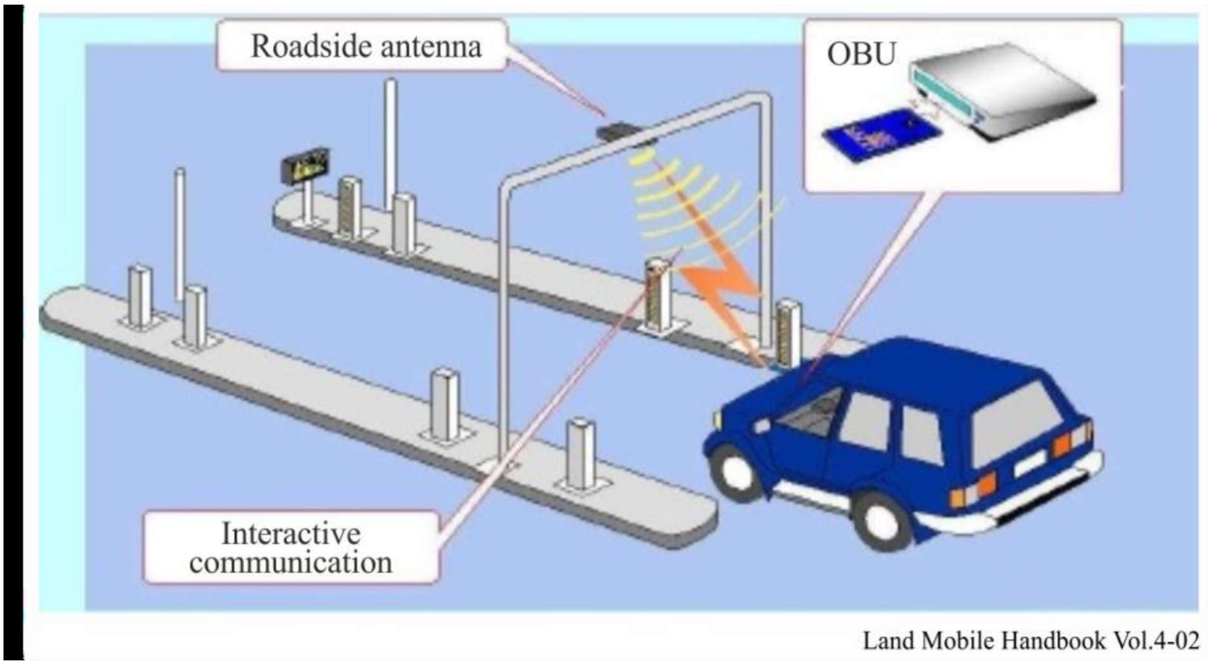

Figure 10: Architecture of the ITS gate for Electronic Toll Collection

The bandwidth required for that functional link may not be large, however, because it would suffice for the toll collection application to exchange some identification and status data items. The gate's position and – due to the very short range of the radio communication technology used – the vehicle's position are known within a confined margin implicitly. The technology family in use at ITS is called Dedicated Short Range Communication (DSRC). For further details compare [ITU-R-ITS-HDB-2021], 25ff, and the supportive documents referenced there.

3.3.2 Introduction to the trackside balise communications architecture

At rail, technologies relevant for the topic of this study and report are described at ITU-R by the scope term 'Railway Radiocommunication Systems between Train and Trackside (RSTT)'. One such RSTT technology with a similar general functionality as above ITS gate is the balise technology. A balise there is defined as 'a passive or active device normally mounted in proximity to the track for communications with passing trains. Balise is a vital spot transmission based system conveying information between train and trackside. The system consists of the balise and the transmission equipment. Balises can provide fixed or variable content. The on-board transmission equipment consists of the antenna unit and the Balise Transmission Module (BTM)' ([ITU-R-REP-M.2418], 5). Figure 11 illustrates the balise system.

Figure 11: Example of railway balise

3.3.3 Introducing the IWT Infrastructure Site Architecture

The common underlying architecture of the ITS's DSRC and of rail balise radio communication systems can be adapted to the IWT fairway & navigation domain, because the distances between the IWT infrastructure site and the vessel's shipboard equipment can be considered as sufficiently short range *eve-*

rywhere in the IWT fairway & navigation domain, although generally not as short as in the case of ITS and rail. The resulting architecture may be called the ***IWT Infrastructure Site Architecture***. It supports at least the following three different use cases:

- *co-operative position determination* of the vessel passing by the IWT infrastructure site, which is also *electronically identified* in the process;
- *upload of data relevant for navigation from IWT infrastructure site to vessel*, such as locally gained sensor data or remotely received data for broadcast to all passing vessel or remotely retrieved data for identified vessel, if sufficient time available for retrieval process;
- *download of vessel data to IWT infrastructure site*, such as vessel sensor data at the time of passing of the IWT infrastructure site or data stored by the vessel on-board equipment for a period prior to passing by the IWT infrastructure site.

The IWT Infrastructure Site Architecture is illustrated by Figure 12.

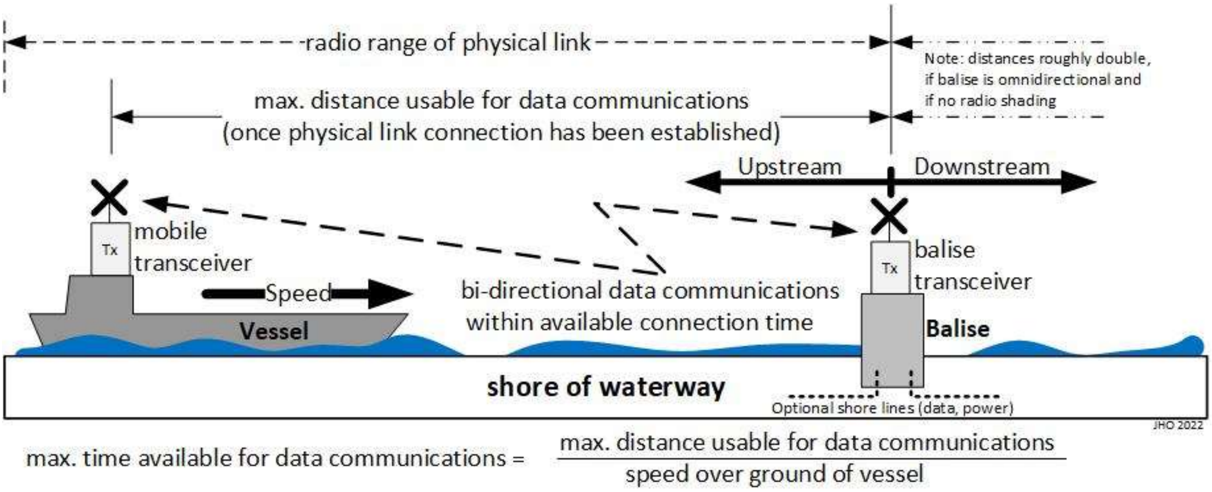

Figure 12: the IWT Infrastructure Site Architecture and working principle

In order to give an indication for timing requirements when selecting a suitable short range radio communication technology to support the IWT Infrastructure Site Architecture's use cases, the following example calculations for vessels of different speeds over ground at an example maximal distance usable for data communications are given.

Max. time available for data communications V2I [s] | [min]	Max. distance usable for data communications V2I [m]	Vessel speed over ground [km/h] | [m/s]
360 | 6	100	10 | 2.8
10 | 0.18	100	36 | 10

Table 5: Example calculations for time available for data communications at IWT Infrastructure Site Architecture

The assessments of the adaptation of the above architecture to the IWT fairway & navigation domain rendering the **IWT Infrastructure Site Architecture** are given in Table 6.

DIWA assessment metrics	Assessment results
DIWA-TRL	**9** (Market expansion) Note: Well established balise concepts at rail and ITS.
DIWA-Adaptability	- (Adaptable by redesign in analogy) Note: Dry-to-Wet adaptation required.
DIWA-Adaptation Demands	- (High adaptation resource/time demands)
DIWA-Technology Radar	**2022-2026 (optimistic assessment)** Note: Architecture adaptation feasible in this period, although technological integration populating the balise bundle may need more time. **2027-2032 (conservative assessment)**
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain).

Table 6: Assessment results for the IWT Infrastructure Site Architecture

The IWT Infrastructure Site Architecture will be used in Chapter 5 when considering specific useful combinations of technologies populating the site.

3.4 The IWT System Interconnection Architecture (ISIA)

So far, fundamental architectures were considered and adapted to the IWT fairway & navigation domain. When it comes to multiple co-operative communication relationships operative simultaneously, as is regularly the case at any mode of transport, architectures for complex co-operative technical systems are needed to tackle the complexities involved.

3.4.1 Learning from ITS: the C-ITS system interconnection architecture

To that end, at ITS, there was developed the 'C-ITS system interconnection architecture' ([ITU-R-ITS-HDB-2021] , chapter 3, section 'physical view'): The participating generic functional entities are identified as 'vehicles', 'traveller devices', 'field equipment', 'centres', and 'support systems' (compare Figure 13). Then all possible operational relationships between these entities are identified by lines representing the functional and physical links between them, including self-referencing ones. The latter are necessary, because there regularly are several different classes of the same entities which may have an operational relationship and therefore require functional and physical links. Finally, all are labelled, in some cases taking into account their communications profiles, such as 'short range wireless' or 'wide area broadcast'.

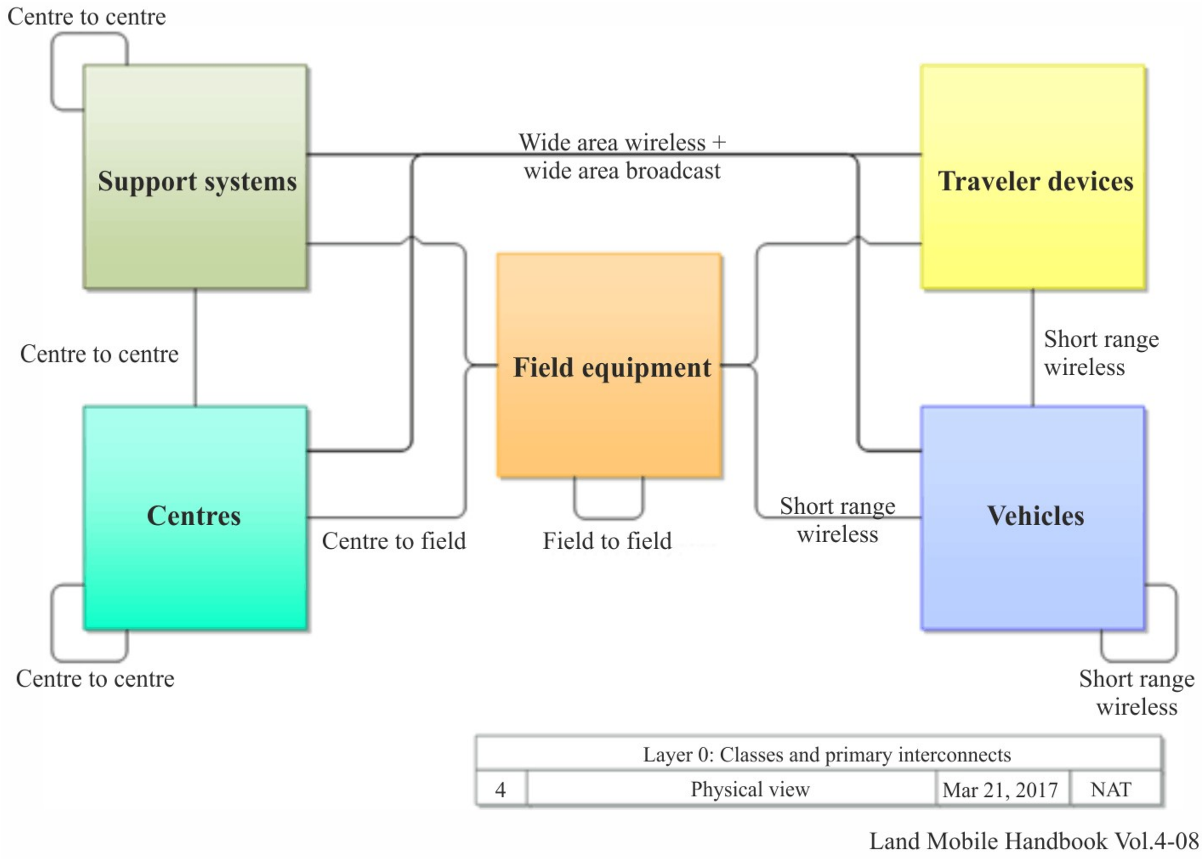

Figure 13: Functional communication links supporting functional entities at ITS

There is a striking correspondence of this with the IWT fairway & navigation domain as shown in Table 7 overleaf.

Functional entity of ITS in Figure 13	Corresponding functional entity in IWT fairway & navigation domain	Example(s)
Support systems	Self-contained RIS IT systems	EuRIS, BICS, NaMIB, …
Centres	Centres introduced in Figure 5/ Figure 6	VTS Centre, Remote Control Centre, …
Vehicles	Vessels as introduced in Figure 5	Inland waterway vessels, traditionally operated vessels, autonomous inland waterway vessels, …
Field equipment	Waterway Field Infrastructure (other than hydraulic engineering components)	Aids-to-Navigation with remote monitoring/control; 'smart' IWT infrastructure sites (compare Chapter 5)
Traveller devices	Passenger devices for on-board use	Man-over-Board devices

Table 7: Correspondence between functional entities in ITS and IWT regarding functional entities

At ITS, as a next step, the different kinds or classes of the entities are identified as far as relevant for the identification of the functional and physical links needed to establish operational relationships – or interconnections as they are called at ITS. This is illustrated in Figure 14. This figure thus represents the *System Interconnection Architecture* at ITS. Its strength is, that it allows to determine the respective communication profiles of the functional and physical links, which in turn is essential to determine the most appropriate technology or technologies providing those links.

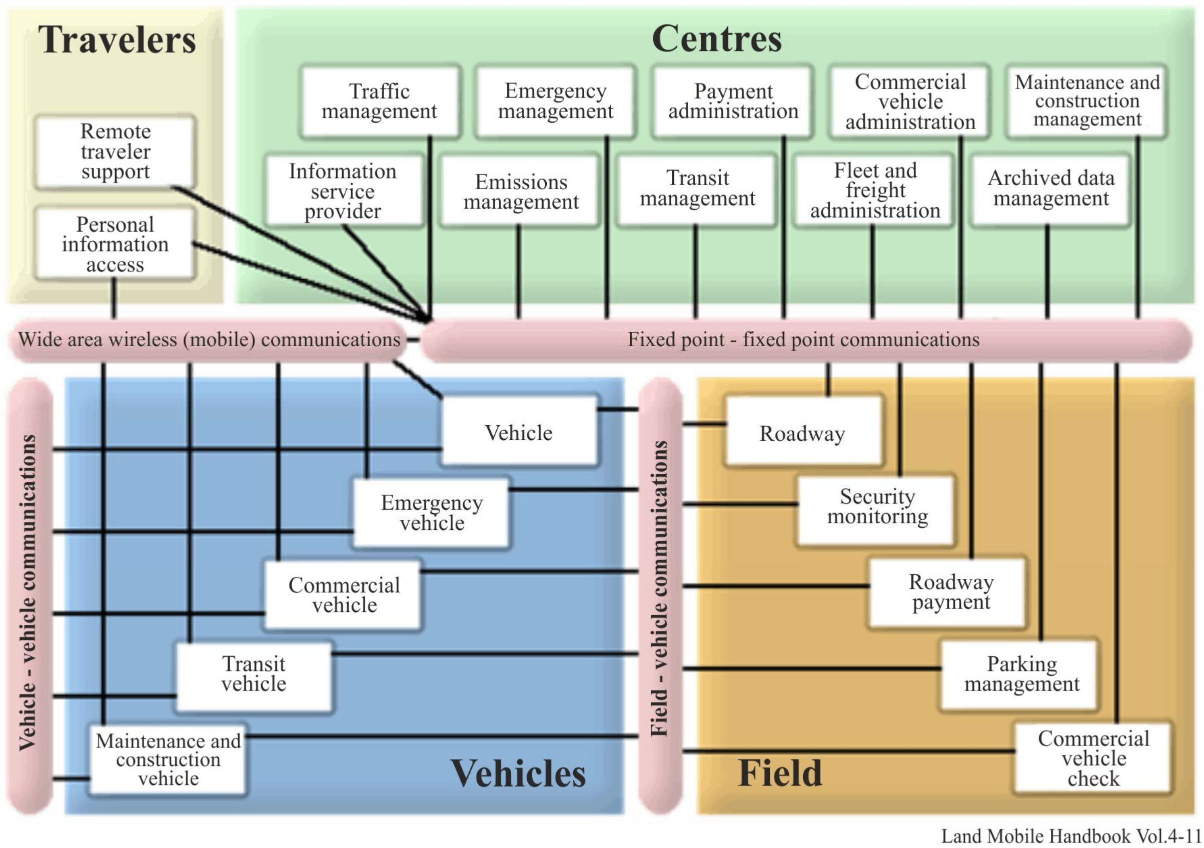

Figure 14: ITS system interconnection

3.4.2 Introducing the IWT System Interconnection Architecture (ISIA)

The ITS System Interconnection Architecture, as introduced above, can be adopted with some amendments to the IWT fairway & navigation domain, thus rendering the **IWT Fairway & Navigation System Interconnection Architecture (ISIA)**, compare Figure 15 overleaf.

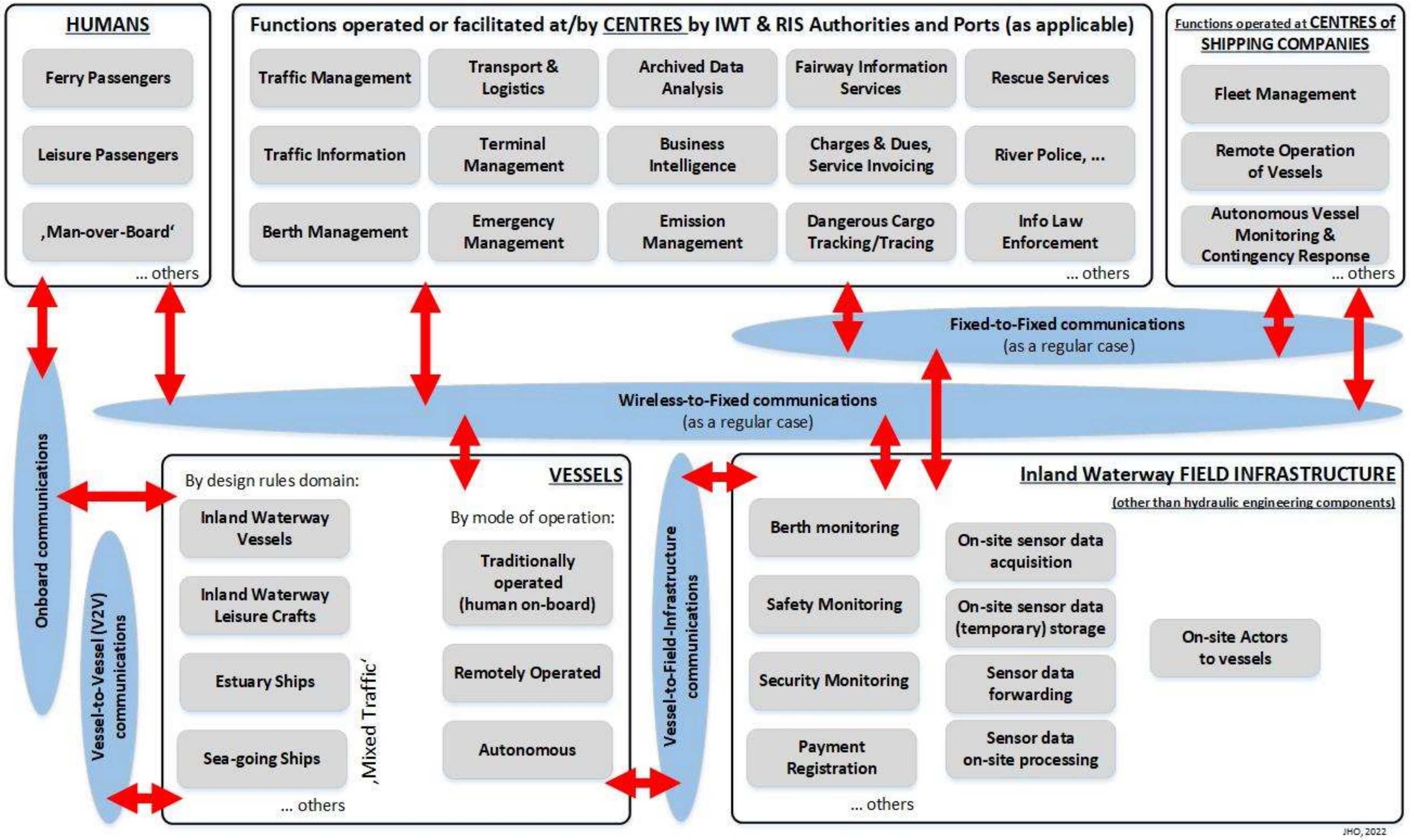

Figure 15: IWT Fairway & Navigation System Interconnection Architecture (ISIA).

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Figure 15 defines the context of the following **IWT fairway & navigation communications domains**:

- *Vessel-to-Vessel (V2V) communications domain,*
- *On-board communications domain,*[12]
- *Vessel-to-Field-Infrastructure communications domain,*
- *Wireless-to-Fixed communications domain,* and
- *Fixed-to-Fixed communications domain.*

Using the ISIA for all operational relationships supported by communications domains has benefits as follows:

- By assigning every *(digital) communication technology* under consideration *to one or more* of the ISIA communications domain(s), the versatility of every (digital) communication technology – or their lack thereof – becomes apparent.

  Since there are obvious multi-facetted resource limitations to deploy, maintain and operate several communication technologies with similar functionality profiles simultaneously for the *same* communications domain, the ISIA would *allow to select for deployment* ***the most versatile*** *communication technology for one but potentially several communications domain(s) as long as all required functionality can be provided.* 'One-trick-pony' communication technologies may still have a justification in functional niches, i.e. when they are the only option available.
- *Nautical Datalink Communications* could use one or more functional link path(s) between the entities they connect, and, in addition, possibly use as relays. This would not only *show the resulting need for interfacing, specification, and standardisation throughout their functional link path(s)* to fulfil the requirements of the supported NDLCs. This would also *indicate potential fall-back routes for each and every NDLC* using different functional links and potentially entities acting as relays.
- *The ISIA, once adopted by all relevant stakeholders of the IWT fairway & navigation domain, may serve as a powerful community tool for harmonisation* of the descriptions, definitions, specifications, and standardisation of the NDLCs, the functional and the physical links, supporting the operational relationships between all entities involved (compare Figure 5).

Obviously, the ISIA provides a powerful architectural means to create and justify *useful and potentially even optimal combinations of communication technologies* to be further discussed in Chapter 5.

The assessment results for adapting the ITS system interconnection architecture to the IWT fairway & navigation domain rendering the ISIA are given in Table 8.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion)
DIWA-Adaptability	+ (Adaptability with minor modifications)
DIWA-Adaptation Demands	+ (Intermediate adaptation resource/time demands)
DIWA-Technology Radar	2022-2026
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain)

Table 8: Assessment results for the IWT Fairway & Navigation System Interconnection Architecture (ISIA)

From the above discussion, recommendations are derived as given in the Annex under *REC-IWT-Fairway & Navigation-System-Interconnection-Architecture*. The ISIA will be used in Chapter 5 when considering specific useful combinations of (radio) communication technologies.

[12] Regarding humans (passengers, human-over-board) it is implied, that they use appropriate user terminal equipment as systems allowing the system interconnection.

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3.5 The Overarching IWT Fairway & Navigation Domain Architecture

To handle even higher complexity, each mode of transport has developed an overarching architecture.

3.5.1 Introduction to the overarching architecture at ITS

An ITS overarching architecture providing context to the defined ITS services and ITS entities is given in Figure 16. This overarching architecture appears to be self-explanatory, but a further description can be found at ([ITU-R-ITS-HDB-2021], chapter 2). The notion of the V2I data exchange while passing through an appropriately equipped gate has been adapted to the IWT fairway & navigation domain already above when developing the IWT Infrastructure Site Architecture. Some individual technologies indicated in the ITS overarching architecture are being considered in the next chapter.[13]

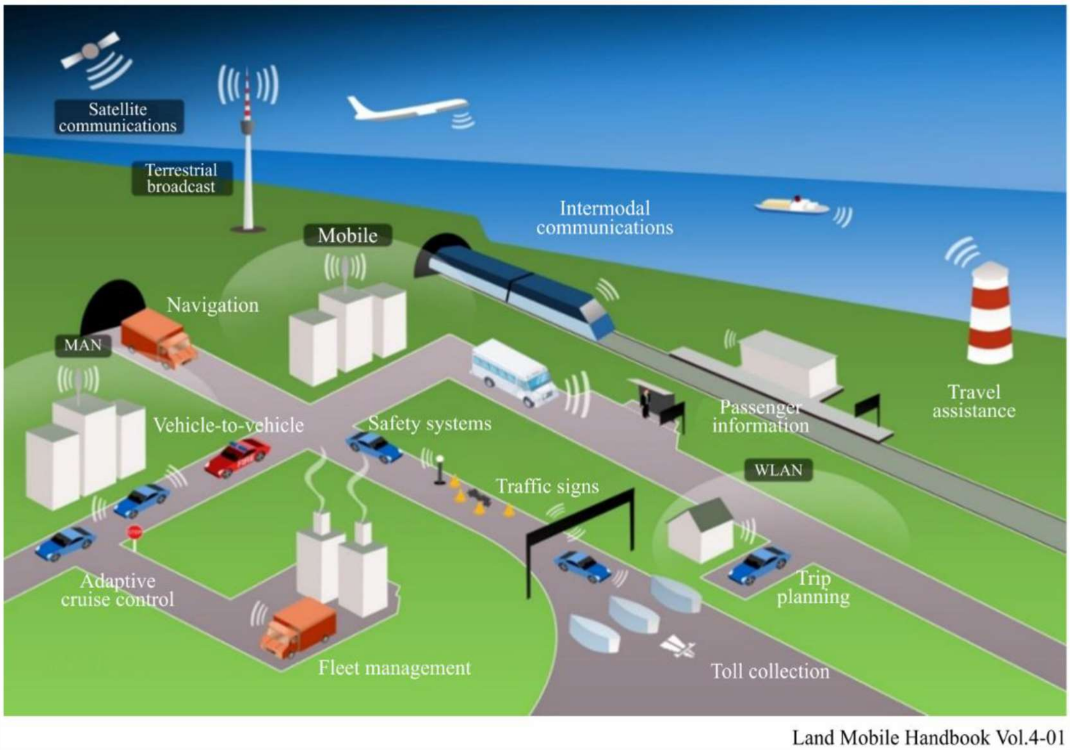

Figure 16: Overarching architecture of the ITS domain

3.5.2 Introduction to the overarching architecture at RSTT

An overarching architecture of the technology level between train and trackside (V2I) is given in Figure 17 overleaf. The focal point of this overarching architecture are the use cases of different technologies available in the railway domain. This appears to be self-explanatory, again. The notion of the train position determination by using a balise system has been adapted to the IWT fairway & navigation domain already above when developing the IWT Infrastructure Site Architecture. Some individual technologies indicated in the RSTT overarching architecture are being considered in the next chapter as CTs.

[13] Interestingly, this ITS overarching architecture doesn't show any pedestrian (with relevant mobile equipment to participate). Considering, the IWT fairway & navigation domain's functional equivalent to a pedestrian at ITS, this would be a leisure craft (with equipment).

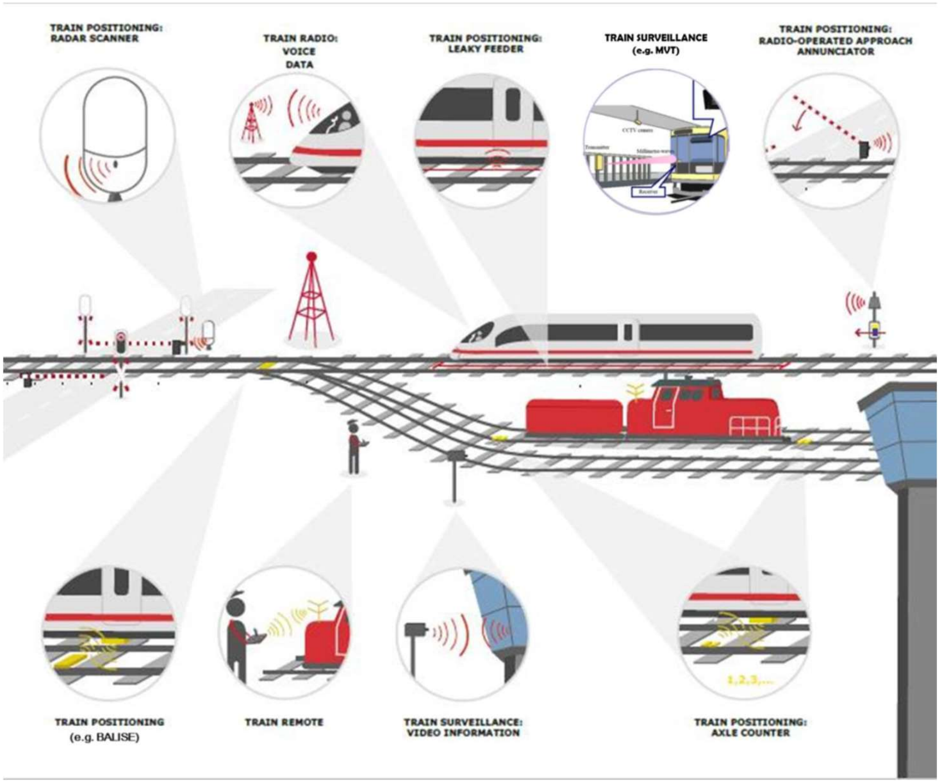

Figure 17: Overarching architecture of RSTT

3.5.3 Introducing the Overarching IWT Fairway & Navigation Domain Architecture

The above ITS and RSTT overarching architectures were provided for information, but are not further used as such here, because there is a fully developed maritime architecture, even adapted already to some extent to the IWT fairway & navigation domain.

One major result of Sub-Activity 2.5, was the adaption of the overarching architecture developed for e-navigation and adopted by IMO to the RIS domain (Figure 3), but also – none the less - to make that architecture a guiding principle for the RIS domain, too. The study of the present Sub-Activity revealed a need to slightly adapt that architecture (Figure 3) in following regards:

- The scope of this overarching architecture needs to cover *a broader scope of operational relationships and services than RIS*, namely the IWT fairway & navigation domain at large, including the 'new arrivals' of ROVs and AVs (compare section 2.4.3). Since this overarching architecture supports this broader notion, the term 'IWT fairway & navigation (domain)' was introduced, not entirely replacing RIS however.
- The original IMO overarching architecture contained the term 'World Wide Radio Navigation System (WWRNS)' to designate the '*PNT bracket*'; Sub-Activity 2.5's version replaced this by 'Global Navigation Satellite System (GNSS)', however, due to the absence of a similar concept and procedure of recognition of PNT system fulfilling the required performance standards in the IWT fairway & navigation domain as is established since long at IMO.

  The reduction to GNSS was considered too narrow a term, because it does not take into account the (equally) existing satellite-based and/or terrestrial augmentation systems to GNSS, leave alone the domain of backup systems on one hand. On the other hand, it was considered necessary for the IWT fairway & navigation domain in the future, in particular if and when higher IDLs (above I) are envisaged, to have this notion of recognition of contributing PNT systems introduced.

  Hence, this rationale lead to the renaming of the 'PNT bracket' to read: Recognised Position-Navigation-Timing provision (GNSS and satellite-based and/or terrestrial augmentation and backup systems). Further details will be discussed in the following chapter.
- Regarding the Service Portfolio concept, a clarification was introducing the two notions of a service portfolio being declared to be provided by an authority or port to inland waterway vessels

as opposed to such a service portfolio being provided. Only by *service portfolio declarations* made, operational relationships (compare Figure 5) can rely on that service provision and this in turn is an incentive to develop applications. This in turn is a stringent requirement for progressing the IWT fairway & navigation domain into higher IDLs, namely II and III.[14]

With these amendments, Figure 18 was created, and it was labelled 'Overarching IWT Fairway & Navigation Architecture'. It will be provide guiding architectural context in following chapters, in particular for the CT inventory in the next chapter by highlighting the entities affected by the specific CTs.

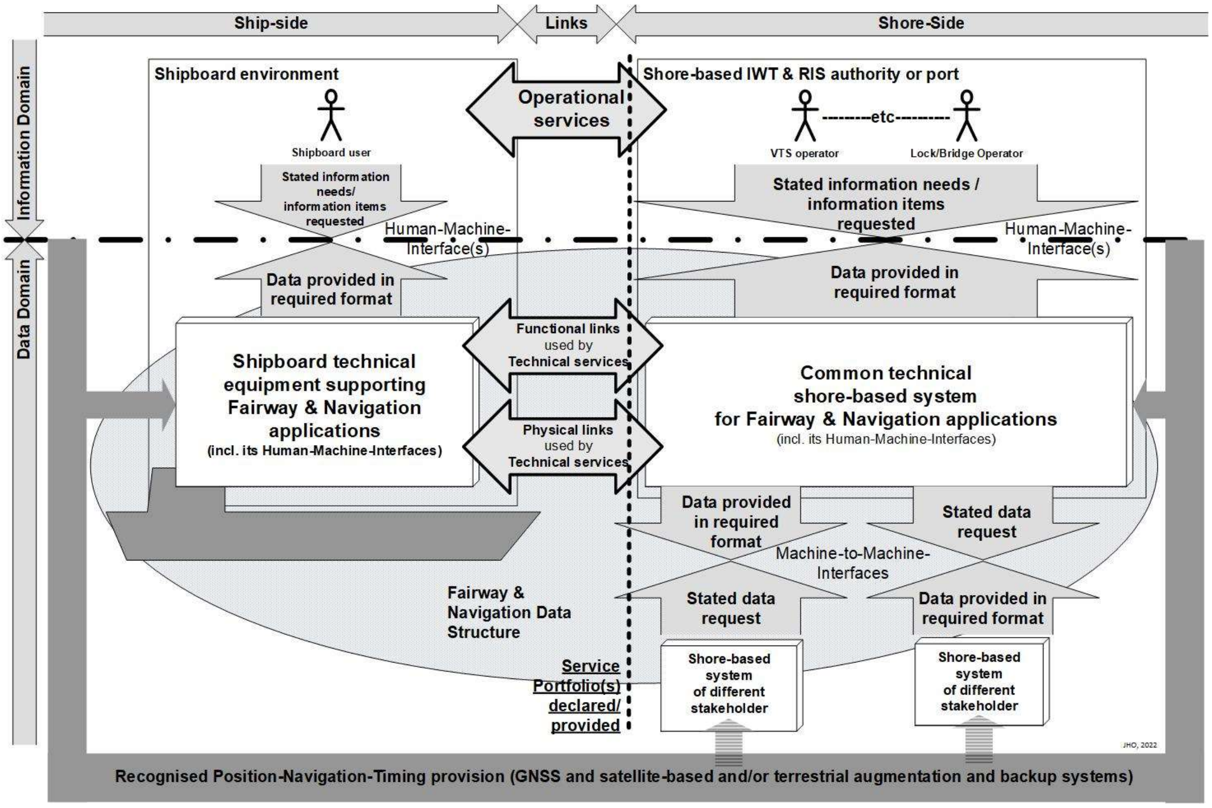

Figure 18: Overarching IWT Fairway & Navigation Architecture, as adopted by Sub-Activity 2.5 and ***further amended***

The assessments of the adaptation of the maritime overarching architecture, as already amended by Sub-Activity 2.5, to the IWT fairway & navigation domain rendering the **Overarching IWT Fairway & Navigation Architecture** are given in Table 9.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion)
DIWA-Adaptability	++ (Seamless Adaptability)
DIWA-Adaptation Demands	++ (Little adaptation resource/time demands)
DIWA-Technology Radar	2022-2026
DIWA-IDL Impact	III (Intelligent IWT fairway & navigation domain).

Table 9: Assessment results for the Overarching IWT Fairway & Navigation Architecture

From the above discussion, recommendations are derived as given in the Annex under *REC-Overarching-IWT-Fairway&Navigation-Architecture*. PNT will be addressed again in the Chapter 4.

3.6 The IWT Standard Shipboard Navigation System Architecture (Inland-SSSA)

In the above Overarching IWT Fairway & Navigation Domain Architecture, the two 'black boxes' for the technical systems of the shipboard and of the shore-side are further investigated here. Again, in both

[14] The subtlety should be noted, that a provision without explicit declaration may be construed as a 'silent declaration', but this will be an 'operational assumption', only.

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cases the maritime domain has already addressed this. To start with, it needs to be considered what can be learned from the internationally harmonised maritime shipboard system architecture.

3.6.1 Introduction to maritime architecture for shipboard navigation equipment

'To ensure effective decision-making and safe navigation [by the bridge team], the proper integration and presentation of information received (…) is essential' ([IMO-MSC.1-Circ-1593], 93; bracket insertion by present author). In full recognition of this, IMO, over the past two decades, has extensively addressed the harmonisation of a ship's bridge layout in general,[15] but also down to the harmonisation of symbols on navigational displays. As a consequence, any generic architecture for shipboard navigation equipment needed to be embedded in the IMO stipulations for 'Bridge Equipment and Systems, their arrangements and integrations (BES)' [IMO-SN.1/Circ-288], that – in turn - was arranged in accordance with the 'Modular Concept' previously defined by IMO to assist in that harmonisation task [IMO-SN.1/Circ-274]:

- Module A – Configuration of work station: allocation and grouping of tasks; also references Bridge Alert Management;
- Module B – Arrangement and Design – Human-Machine-Interface: Bridge design, Layout and physical arrangement of workstations, design of bridge equipment;
- Module C – Fault tolerance: System failures and fall back arrangements;
- Module D – Interfacing: Data transfer;
- Module E – System configuration and integration
- Module F – System and equipment documentation: System configuration, familiarisation.

This list alone brings to the fore a number of aspects that *continue to gain more and more weight with the increased usage of co-operative systems due to digitalisation,* as introduced above. In order to address these existing and further expanding issues more precisely, i.e. down to the level of functions and functional component, a more detailed architecture for shipboard navigation equipment is needed.

During the preparation of the first edition of IMO's e-navigation strategy implementation plan, a generic architecture for the shipboard navigation system was created by a working group of the German Institute of Navigation (DGON) and submitted to the correspondence group on e-navigation at IMO NAV [IMO-NAV58/6]; compare Figure 19 overleaf. Subsequently, a generic architecture for shipboard navigation equipment was not specifically adopted by IMO as such, because it was felt by then that its major components have been in place and described in relevant IMO instruments, thus being implicitly stipulated. While this is certainly true, the generic architecture for shipboard navigation equipment is introduced here since 'a picture sometimes tells more than thousand words' (proverbial wisdom).

This generic shipboard navigation system architecture is structured hierarchically in three functional layers in the vertical dimension, which are from bottom to top:

- *Sensor / Source Layer:* Here reside all shipboard sensors as well as the pre-processing entities for their data as well as the radio communication front ends to the physical radio links. This layer provides – generally speaking – the technical interfacing to the physical and operational environment of the ship.
- *Data Processing Layer:* This core layer is specialised in processing, storing, and retrieving data relevant for the navigation of the ship, including the selection, filtering, and routing of the available physical radio communication links as well as the handling of all relevant alerts from navigational systems but also from other bridge equipment as received from Bridge Alert Management (BAM).
- *Operational Layer:* This layer provides the HMI to the bridge team to support their navigational tasks as indicated.

[15] Compare, for instance, [IMO-MSC/Circ.982] addressing ergonomic criteria for bridge equipment and layout.

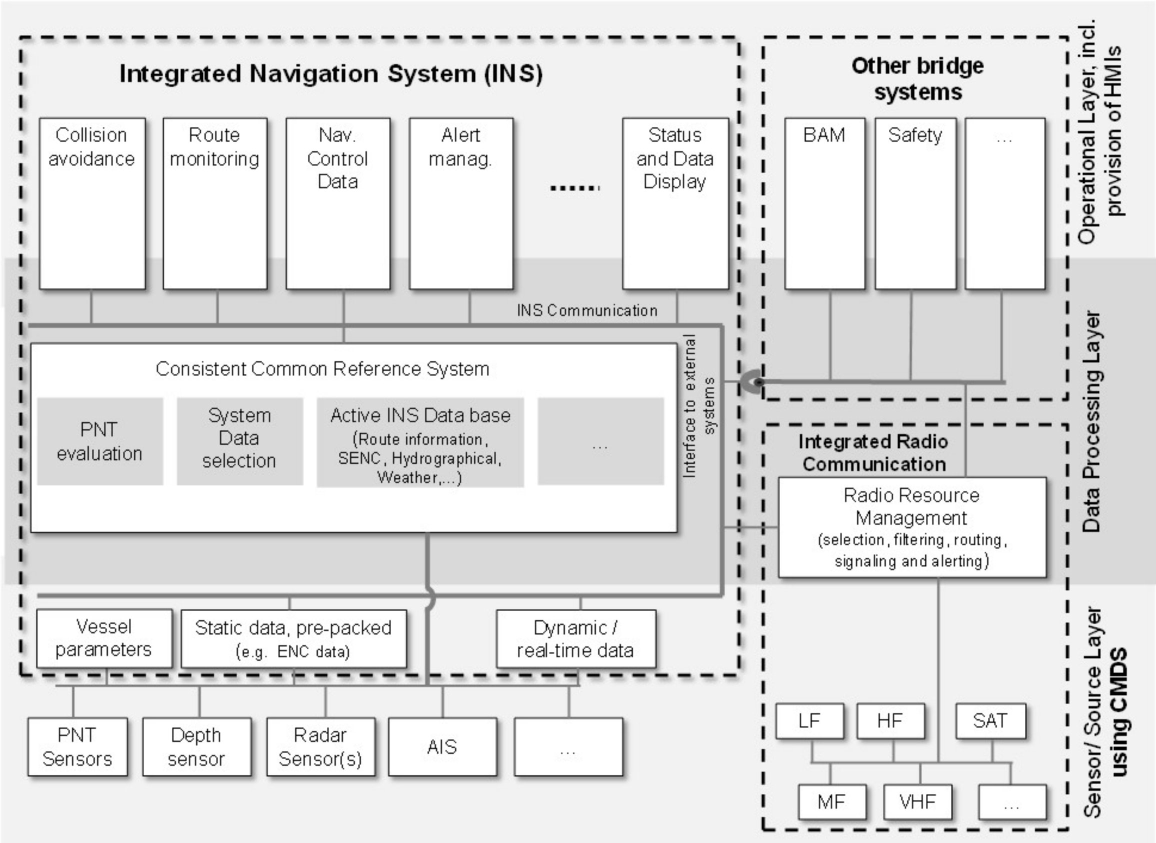

Figure 19: generic shipboard navigation system architecture in the context of e-navigation

The reference to the Common Maritime Data Structure (CMDS) was introduced due to the e-navigation vision of a fully harmonised data structure, which has been adapted to the IWT fairway & navigation domain as well (in the context of the overarching architecture). While the CDMS is supposed to be operative between all participating entities (ships, shore systems etc.), within the individual ship's navigation system there may be different data structures used at the equipment manufacturer's discretion. This is indicated by pointing out 'using CDMS' at the Sensor/Source Layer, only.

More detailed key requirement documents for the navigational systems indicated above have been introduced up until recently as follows (but with no aspiration of completeness):

- 'Guidelines for the *Standardization of User Interface Design for Navigation Equipment'* [IMO-MSC.1-Circ/1609], which was brought into force by [IMO-MSC-Res-466(101)], both of 2019. This document list many references to further relevant IMO documents (some of which are mentioned below due to their importance for the topic at hand) and documents of supporting standardisation bodies such as IEC and ISO (not individually listed here).
- The 'Guidelines for the *presentation of navigational-related symbols, terms and abbreviations'* have been revised recently to bring them up to date to the latest developments [IMO SN.1/Circ.243/Rev.2].
- The Appendix 4 of [IMO-MSC.1-Circ/1609] addresses *'functions that must be accessible by single or simple operation action'*, sometimes dubbed 'S-Mode' during the e-navigation strategy development, and aims at improving mode awareness.
- The 'Guidelines for *Shipborne Position, Navigation and Timing (PNT) data processing'* [MSC.1/Circ.1575] are explicitly referenced in the above guidelines for the user interface due to their importance of PNT for the operational tasks of the bridge team. The guidelines will be discussed in the next chapter regarding their technological significance.
- The 'Interim guidelines for the *harmonized display of navigation information received via communication equipment'* [MSC.1/Circ.1593] have as one focal point the integration of Maritime Safety Information (MSI), which has traditionally been printed on the bridge, into navigation displays: 'It is clear from user requirements, such as those gathered during the user needs analy-

sis of e-navigation, that there is a need to portray such information in a harmonized way on appropriate navigation displays.' ([IMO-MSC.1/Circ1593], para 2.3).

- The Integrated Radio Communication System (IRCS) was originally defined by IMO in 1995 [IMO-A.811(19)], but within IMO's e-navigation strategy a task is scheduled on 'seamless integration of *all currently available communications infrastructure* and how they can be used (e.g. range, bandwidth, etc.) and what systems are being developed, along with the revised GMDSS (e. g. maritime connectivity platform) and could be used for e-navigation' ([IMO-MSC.1/Circ.1595], Annex, Task 15, emphasis added), that likely will eventually lead to a revision of the relevant IMO documentation.
- The requirement base for *BAM* was adopted by IMO in 2010 [IMO-MSC-Res-302], and the technical standards for type approval were created by IEC in 2018 [IEC-62923-Series].
- 'Guideline on *Software Quality Assurance and Human-Centred Design* for e-navigation' have been introduced [MSC.1/Circ.1512].
- Very important for keeping the relevant shipboard systems current regarding their software are the 'procedures for *updating shipborne navigation and communication equipment'* [MSC.1/Circ.1389].

A comprehensive overview of shipboard navigation and communication equipment stipulations by IMO and of the associated international testing standards can be found in Annex 4 of [IMO-MSC.1/Circ.1595].

3.6.2 Shipboard navigation equipment architecture adapted to the IWT fairway & navigation domain

Obviously, IMO and supporting international standardisation organisations have created a substantial and mature body of guidelines, performance standards, regulations, even mandatory carriage requirements for select components, as well as technical standards for type approval testing for the shipboard navigation system domain. Turning towards the question of adaptability to the IWT fairway & navigation domain, the *need for a human-centric design of the inland waterway vessel's wheelhouse and of the navigation systems* has been recently highlighted by a study in the IWT fairway & navigation domain that was done in cooperation with CESNI. The study summarises as follows the 'root causes' of accidents:

- "1) Design of wheelhouses and HMI's is not following a common design approach and is not according to state-of-the-art ergonomics and human factors standards in other transport modalities leading to (potential) errors and musculoskeletal disorders" ([Intergo 2021], 42).
- "2) The availability, reliability, usability, and integration of information at the helmsman's position is not optimal leading to (potential) errors in interpreting information, over-trust in information/automation, ignoring alerts, distractions, and false sense of safety" ([Intergo 2021], 43).

Interestingly, while other modes of transport are mentioned expressively as being part of the scope of the study quoted, 'maritime' is addressed therein only generally, and the IMO is not even referenced once. Hence, the body of relevant international work done in the other 'wet' domain as introduced above, is not considered at all, even though certain technological imports from maritime, such as (Inland-) ECDIS and (Inland-) AIS are mentioned. It is re-iterated here, and in addition to the rationale provided by the study quoted, that inland waterway vessels also need to interact with sea-going ships in mixed traffic situations, thus requiring mutually consistent situational awareness which in turn requires consistency of the shipboard navigational systems on-board inland waterway vessels interacting electronically with those of sea-going ships. This requirement will become more intense and stringent with increasing IDLs in the future (see discussion in Chapter 2).

Anyway, the present study and report is tasked to bring the relevant work done in other modes, including maritime as the mode of transport with closest proximity to the IWT fairway & navigation domain, to the attention. The present Sub-Activity is not in a position, however, to define a generic shipboard navigation equipment architecture adapted to the IWT fairway & navigation domain, henceforth called **IWT Standard Shipboard Navigation System Architecture (Inland-SSSA)**, in any relevant detail.

This would require in particular to perform a gap analysis between the existing relevant stipulations in the IWT fairway & navigation domain with the maritime stipulations as introduced above. Therefore, the present study and report suffice to postulate an Inland-SSSA in very basic terms as follows (compare Table 10 overleaf); and by populating it by certain functionalities in Chapter 5.

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Operational Layer (including HMI at 'helmsman's position')
Data Processing Layer (including M2M-interfaces to other shipboard systems of the same inland waterway vessel)
Sensor / Source Layer (including M2M-interfaces to the physical links)

Table 10: Most fundamental structure IWT Standard Shipboard Navigation System Architecture (Inland-SSSA)

The assessments of adaptation of the maritime shipboard navigation equipment architecture as a Wet-to-Wet adaptation to the IWT fairway & navigation domain rendering the **IWT Standard Shipboard Navigation System Architecture (Inland-SSSA)** are given in Table 11.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion) Note: well established concepts at maritime.
DIWA-Adaptability	0 (Adaptable with substantial modifications) Note: compares with Inland-ECDIS / Inland-AIS introduction in this regard.
DIWA-Adaptation Demands	0 (Substantial adaptation resource/time demands)
DIWA-Technology Radar	2027-2032
DIWA-IDL Impact	III (Intelligent IWT fairway & navigation domain) Note: even required to achieve IDLs II and III at all.

Table 11: Assessments for the IWT Standard Shipboard Navigation System Architecture (Inland-SSSA)

The Inland-SSSA initially populated with certain functionalities is thus construed as a 'useful combination' and will be further discussed in Chapter 5. Also, Chapter 6 will re-visit Inland-SSSA.

3.7 The IWT Common Shore System Architecture (Inland-CSSA)

The second 'black box' of the above Overarching IWT Fairway & Navigation Domain Architecture, namely that on the shore-side, needs to be considered now.

3.7.1 Introduction to the Common Shore-based System Architecture (CSSA)

As a consequence of the adoption of the overarching architecture for e-navigation by IMO, the need emerged to have an internationally harmonised eco-system for technical shore systems in place capable of seamlessly incorporating new functionalities stemming from e.g. e-navigation as well as operating and further developing classic services, while specifically taking into account the demands of long-term technical operation (as opposed to setting up a trial installation of some hyped technology, for example). Therefore, life-cycle management considerations feature prominently.

Hence, IALA started with the development of a 'common shore-based system architecture' – both in a broad generic sense and in a sense of a more specific architectural solution, then labelled Common Shore-bases System Architecture (CSSA). IALA's work in this regards is geared towards those of its members, most often national authorities, that deploy and operate shore systems or technical services of various kinds – ranging from visual aids-to-navigation via PNT and radio communication services to VTS, to name a few – and need to continue to do so even with the advent of new technologies and the legacy issues associated with phasing-out classic one, if at all possible.

The necessary architectural framework to achieve that is a three-layered service-oriented architecture geared towards the data/information flow implied by the overarching e-navigation architecture and therefore functionally similar to the three-layered shipboard navigation system architecture. The top level structure of the CSSA is illustrated in Figure 20 overleaf, where the arrows indicate data/information flow between its different functional components.

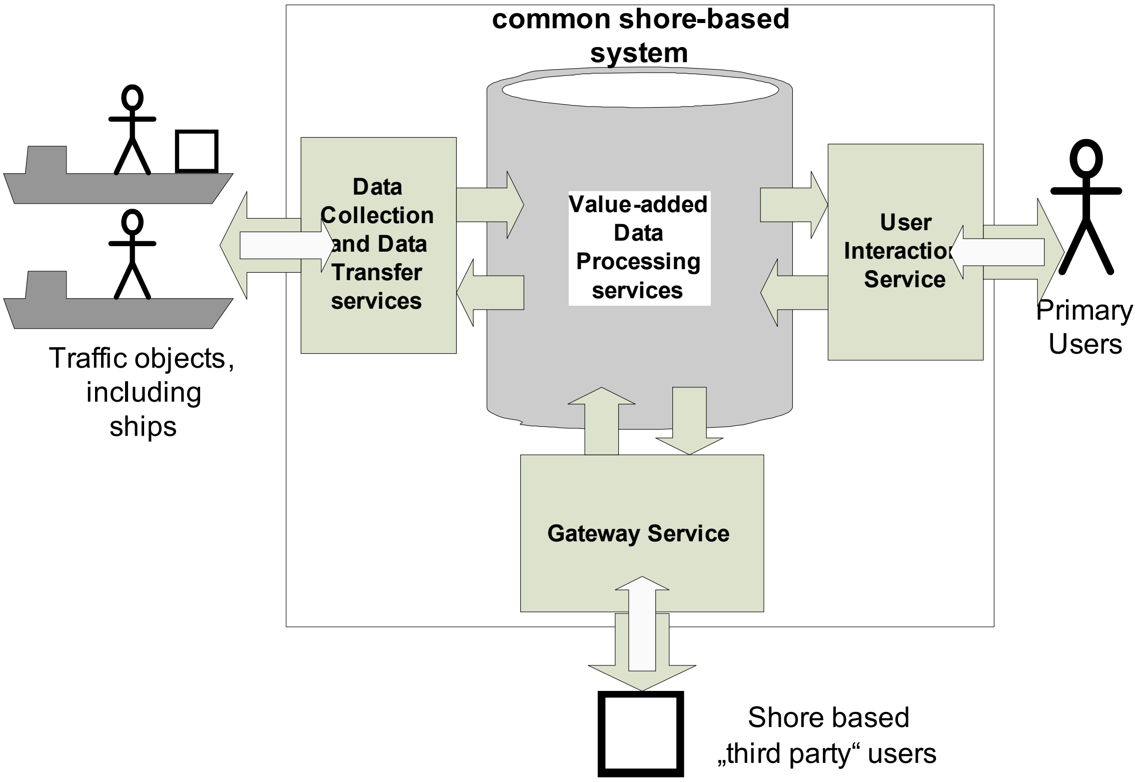

Figure 20: Structural overview on Common Shore-based System Architecture (CSSA)

The group of Data Collection and Data Transfer services interface with the waterway, the traffic objects including vessels, and with the physical environment. Their data is pre-processed, evaluated and stored in the Value-Added Data Processing services with the purpose their very name implies. They are the data/information core of the CSSA. Via the Gateway Service data can be exchanged with systems of other shore-based stakeholders and with any kind of external information and/or telecommunications or internet providers. The User Interaction Services finally provides the HMI to the primary users of the CSSA, namely those operators in centres operated by authorities that also operate the shore system, hence their 'primary users'.

Besides the introduction of the CSSA in current edition of IALA's NAVGUIDE for a general audience ([IALA NAVGUIDE 2018], 74-76), IALA – over the course of more than a decade by now – has created a suite of mature documents that provides further details as follows:

- IALA Recommendation R0140 while reflecting on the results of IMO's e-navigation strategy and IHO's development of S-100 introduces general and generic and yet precise recommendations for authorities when planning, deploying and operating a shore system [IALA-R0140];
- The CSSA as introduced above is derived from IALA R0140 in IALA Guidelines G1113 on 'design and implementation principles for harmonised system architectures of shore-based infrastructure' [IALA-G1113] and G1114 on 'a technical specification for the Common Shore-based System Architecture (CSSA)' [IALA-G1114].
- To support the fundamental recommendation for a 'user requirements driven system design, including statements on human-centred design and/or quality levels of service, and a system engineering process' ([IALA-R0140], Recommends No. 2), IALA created an additional guideline on requirement traceability [IALA-G1133].
- The many different technical services potentially populating the CSSA are described in [IALA-G1114] generically but specifically and in many cases also with an outlook into the future spanning at least the DIWA scope. Technical services not foreseen by the present version of the CSSA due to entirely new technological developments can be introduced in due course due to the versatility of the ser-

vice-oriented architecture employed, and, since not all authorities have the same service setup, the technical services listed in [IALA-G1114] need to be tailored to the authority's needs at hand.[16]

In the past years, CSSA has been adopted as an architectural framework by authorities like Rijkswaterstaat (NL), the Wasserstraßen- und Schifffahrtsverwaltung (DE), and China Maritime Safety Agency ([China-MSA 2021], section 'An Intelligent Navigation Service Plan based on e-navigation').

3.7.2 CSSA applied to the IWT fairway & navigation domain

The CSSA as an architectural framework is agnostic of the specific wet mode of transport it is applied to: It can thus be useful as a harmonised common architectural reference framework for all IWT fairway & navigation authorities, too. Many of the technical services described in IALA's CSSA had the maritime domain in view; however, many of these are relevant for the IWT fairway & navigation domain as well. Therefore, the IWT fairway & navigation domain can thus already benefit from IALA's document suite, thus often reducing the adaptation task to different configurations needed for the IWT fairway & navigation domain. It is therefore proposed to apply the CSSA of the maritime domain to the IWT fairway & navigation domain to become the **IWT Common Shore System Architecture**, or abbreviated **Inland-CSSA**. The assessment of that Wet-to-Wet adaptation is given in Table 12.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion)
DIWA-Adaptability	++ (Seamless Adaptability)
DIWA-Adaptation Demands	++ (Little adaptation resource/time demands)
DIWA-Technology Radar	2022-2026
DIWA-IDL Impact	III (Intelligent IWT fairway & navigation domain) Note: even required to achieve IDLs II and III at all.

Table 12: Assessment results for the Inland-CSSA

The Inland-CSSA will be used in Chapter 5 for specific useful combinations for the shore system(s): An initial sketch of an Inland-CSSA populated with (new) CTs and IWT fairway & navigation domain specifics will be introduced there. Also, Chapter 6 will re-visit Inland-CSSA.

3.8 The IWT Reference Architecture (IRA)

3.8.1 Introduction

So far, the architectural considerations focussed on technically oriented architectures with the intent in mind to provide places for new technologies to be plugged in seamlessly eventually. Technology is not an end in itself, however. Technology and technical services employing them are always *embedded in socio-technical systems,* and this prompts the need to reflect this fact in architectural terms, too. This need has been recognised in other modes of transport, too, and therefore there have been efforts made to reflect that in transport mode specific architectures with their respective socio-technical system background in view: It is there, where in particular business, operations, and technology are merged.

Turning towards the IWT domain as introduced in Figure 1, this leads to the recognition that *an architectural framework would be needed that would allow IWT domain business, operational and technical perspectives be brought together within the IWT socio-technical system background.* This postulated architecture shall be called **IWT Reference Architecture (IRA)** henceforth. Note, that the scope of the architecture here is the IWT domain at large as indicated in the Figure 1 as a whole, 'not just' the IWT fairway & navigation domain which was the scope of the architectures introduced so far. *It is in the IRA*

[16] It should be noted, that IALA maintains two different notions of a 'technical service' in their documentation: Firstly, a technical service as deployed by an authority along the waterway to be covered comprising layered hardware such as radio front ends and base stations and processing stages, as well as software to provide the data gained to other services; this notion of a technical service is employed here. An example from IALA is their description of the shore-based AIS Service [IALA R0124]. The other notion of a 'technical service in the context of e-navigation' is a pure software-based functionality interacting via internet with platforms like and in particular the Maritime Connectivity Platform (MCP); this notion of a technical service is described in [IALA-G1128]. Both notions co-exist and can thus be reconciled; this was demonstrated as a part of the ACCSEAS project ([ACCSEAS 2015], para. 3.4).

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where convergence of IWT fairway & navigation and IWT logistics domains can be expressed in architectural terms and harmonisation thus be facilitated.

The above 'business, operational, and technical perspectives' ideally are expressed in documents that are either just informative or even normative to differing degrees, with a legal norm or a standard as the ultimate instances. However weak or binding a document might be, the more important point is, *that it is recognised by basically everybody operative in the socio-technical system under consideration*. Hence, a socio-technical architecture framework is capable of *bringing together the documentations of the different business, operational, and technical stakeholders* of that socio-technical domain, thus providing a structure which in turn allows for

- *targeted harmonisation of existing but potentially even conflicting documents* which have often been developed by different stakeholder domains over a time period but have never before been brought into contact with each other ('silos'); and/or
- *targeted development of missing documents* to cover 'empty spaces', the formats and necessary strengths of which are subject to the customs of the socio-technical system at hand.

Hence, *a framework architecture in general and the IRA as applied to the IWT domain is a means to overcome 'silos' within the socio-technical system under consideration*, and is *thus required to achieve any IDL higher than I (Digitised)*, as introduced in Chapter 2.

3.8.2 Architectural reference framework at ITS

As one mode of transport within the scope of the present study and report, the ITS domain has developed an 'architectural reference for cooperative and intelligent transportation' (Figure 21). It brings together the 'enterprise view', the 'functional view', the 'physical view' and the 'communications view' of the ITS as a socio-technical system. There appears to be a hierarchy between the different 'views'. The entities that are interacting within a specific 'view' are given as the more detailed level, and it is indicated by arrows that they all interact with each other – at least in principle. As a result of making visible the various interactions within and between the different 'views' so-called 'service packages' can be tailored for the different 'views' to be used for their respective tasks within the socio-technical system of ITS.

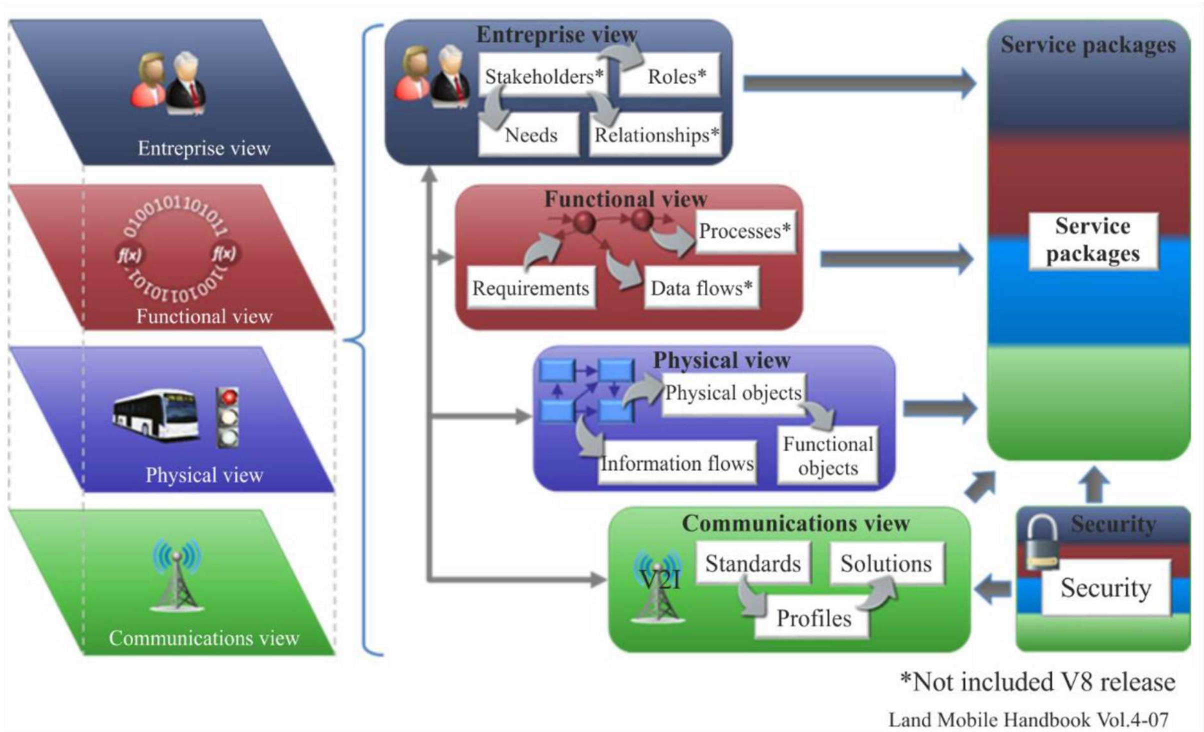

Figure 21: 'Architecture reference for cooperative and intelligent transportation (ARC-IT)'

3.8.3 Learning from Maritime – the Maritime Architecture Framework

While the ITS domain architecture framework provides a good illustration of the principles introduced above, a wet-to-wet adaption is expected to produce less resources and time demands for creating the IRA. Indeed, there has been developed an architecture framework for the maritime domain which has been informed by the 'RAMI cube' of the manufacturing industry's digitalisation initiative called 'Industry 4.0' and by its successful CEN-CENELEC-ETSI governed Smart Grid adaptation.

3.8.3.1 Background information

3.8.3.1.1 The 'RAMI cube' framework architecture of the 'Industry 4.0' initiative

The Reference Architecture Model for Industry 4.0 (RAMI) has been defined by the 'Industry 4.0' initiative by *bringing together* previously existing relevant IEC standards on *Life Cycle Value Stream* and on *Hierarchy levels* as two dimension in the 'RAMI cube', while the third dimension is represented by the *different layers of interest which were called 'views'* in the ITS example above (compare Figure 22 overleaf).

The resulting three-dimensional architecture framework is capable of capturing all relevant aspects (and their documentations) of even the most complex socio-technical systems, such as manufacturing industry, Smart Grid networks, and – with a significant change of meaning of one dimension – the maritime transport domain. According to its proponents, the RAMI cube is capable to 'ensure that all participants involved (…) understand each other' ([Schweichhart 2016], 4) by – amongst other features – 'breaking down complex processes into easy-to-grasp packages, including data privacy and IT security' ([Schweichhart 2016], 5).

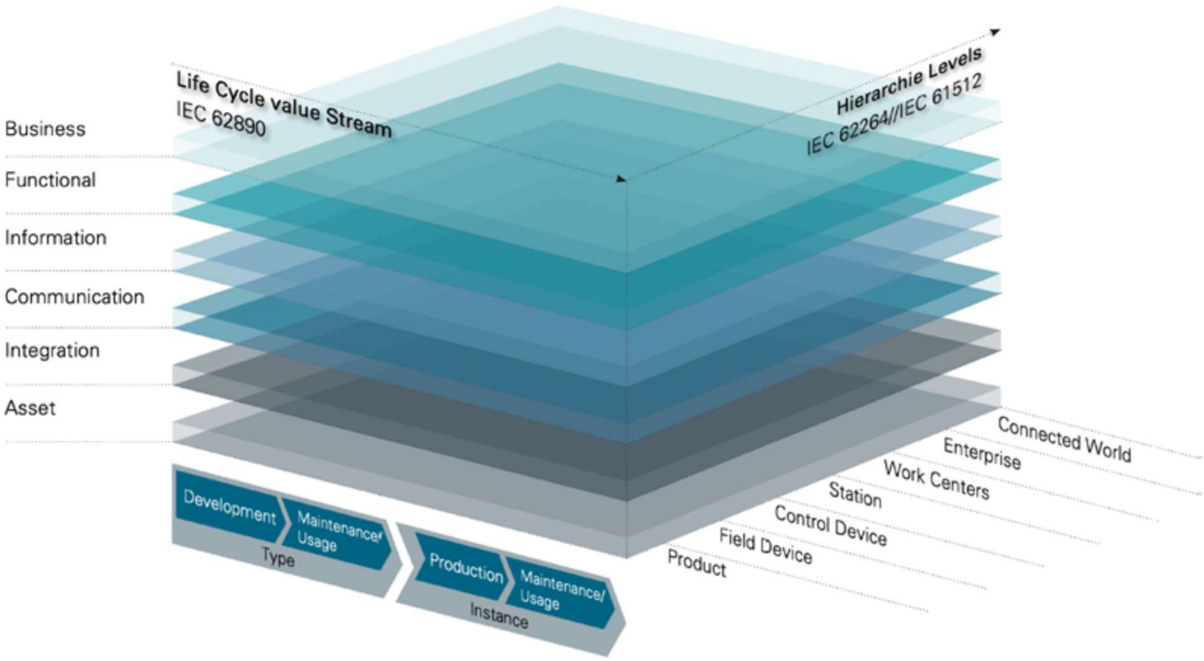

Figure 22: Representation of Reference Architecture Industry 4.0 as a 'RAMI cube

The different axis have the following meanings in the present author's brief summary:[17]

- *Hierarchy Axis:* In the manufacturing industry, this axis shows the hierarchy from 'product', i.e. that entity the manufacturing industry bases its revenues on, up through various level of gaining even more control over the production process and its organisation to the enterprise level at large and even beyond into the (market) environment which is expected to be connected, thus being labelled 'Connected World'. This axis is similarly present in all domains, although with different number of levels potentially and also with different names to the levels most likely.
- *Product Life Cycle Axis:* This describes the product's life cycle 'from the first idea to the scrapyard' ([Schweichhart 2016], 8). This axis will not be described in more detail here because

[17] For a more elaborate description compare e.g. [Schweichhart 2016] and [Megow 2020]

of all axis it is the most domain-specific. Therefore, it will be replaced by a different one once leaving the manufacturing industry for adaptation to a different domain.

- *Axis of Views:* This axis takes up the notion of the 'views' from the ITS's framework architecture, but is more elaborate because this axis in the RAMI cube also allows to capture the exact positions where digitalisation hits: This means it shows, which parts of that axis (may/will) reside entirely in the digital domain - to the extreme of becoming digital twins - and which parts will always reside in the physical world, only. A compilation of this notion is given Table 1Table 13.

Business	Organisation and business processes	'Digital World'	
Functional	Functions of the asset		
Information	Necessary data		
Communication	Access to data		
Integration	Transition from 'real world' to 'digital world'		Digitalisation hits here (the most)!
Asset	Physical things in the 'real world'	'Real World'	

Table 13: Compilation of meaning of the Axis of Views

*This representation of the Axis of Views clearly renders it **IDL III** when considering IDL definitions – i.e. **this means that the RAMI cube – as well as its instances for the wet domains – provides a tool to capture the transition of a whole domain into the highest IDL**.*

3.8.3.1.2 Smart Grid adaptation on European standardisation level

The RAMI Cube has not remained a theoretical exercise as might be concluded from its admittedly abstract substance, nor has it remained the 'hobby horse' of one European country's industry. Its adaptation to the smart grid domain was jointly orchestrated by the three 'officially recognized European Standardization Organizations'[18] CEN, CENELEC and ETSI based on a task received from the EU Commission as follows: 'CEN, CENELEC, and ETSI are requested to develop a framework to enable European Standardization Organizations *to perform continuous standard enhancement and development* in the field of Smart Grids, *while maintaining transverse consistency and promote continuous innovation.*' ([CEN-CENELEC-ETSI 2012], 5; emphasis added).

The highlighted parts exactly reflect the intention of the IDL as introduced in Chapter 2 and can thus be paraphrased to read as a task stipulation applied for the IWT domain: ***'to develop an IWT Reference Architecture Framework (IRA) to enable different stakeholders and relevant international organisations to perform continuous standard enhancement and development in the IWT domain, while maintaining transverse consistence and promote continuous innovation'.***

The three organisations set up a joint Smart Grid Coordination Group that was tasked with the creation of a Smart Grid Architecture Model (SGAM), which was delivered in 2012 and which resembles the RAMI Cube (compare in particular [CEN-CENELEC-ETSI 2012], Figure 8, page 30). This document also provides a detailed description on the usage of the SGAM and of the RAMI cube (and – if adapted by analogy - of any 'wet' adaption eventually). The 'product' (of the RAMI cube) here is electricity. The SGAM's story's continuation is given in [CEN-CENELEC 2022], but that's not really relevant here.

3.8.3.2 Adaptation to Maritime Architecture Framework

The work on the Smart Grid was adapted to the maritime domain in the years up until 2018 in the context of the EU co-funded efficienSea2 project and at IALA; compare [Weinert et al 2017]. This adaptation work resulted in the 'Maritime Architecture Framework (MAF)' (compare Figure 23 overleaf).The RAMI cube informed MAF cube has the following axis:

- *Hierarchical axis* with the entities from bottom to top: transport objects, sensors & actuators, technical services, systems, operations, and fields of activity.

[18] https://www.cencenelec.eu/european-standardization/ Accessed 18 October 2022.

- *Interoperability axis* with the entities from bottom to top: component, communication, information, function, and regulations & governance.
- *Topological axis* only has three entities, namely 'ships and other maritime traffic objects', 'link' and 'shore'. This axis alone departs from the life cycle axis of the original RAMI cube by exchanging the life cycle notion of an industrial product by the places of relevant entities, i.e. by a topology orientation that is informed by the most fundamental 'three-sides-of-the-coin' architecture (see above).[19]

For further information consult the IALA NAVGUIDE for a detailed introduction for a general audience ([IALA NAVGUIDE 2018], 71-74) and [Weinert 2018] for an expert level derivation of the MAF.

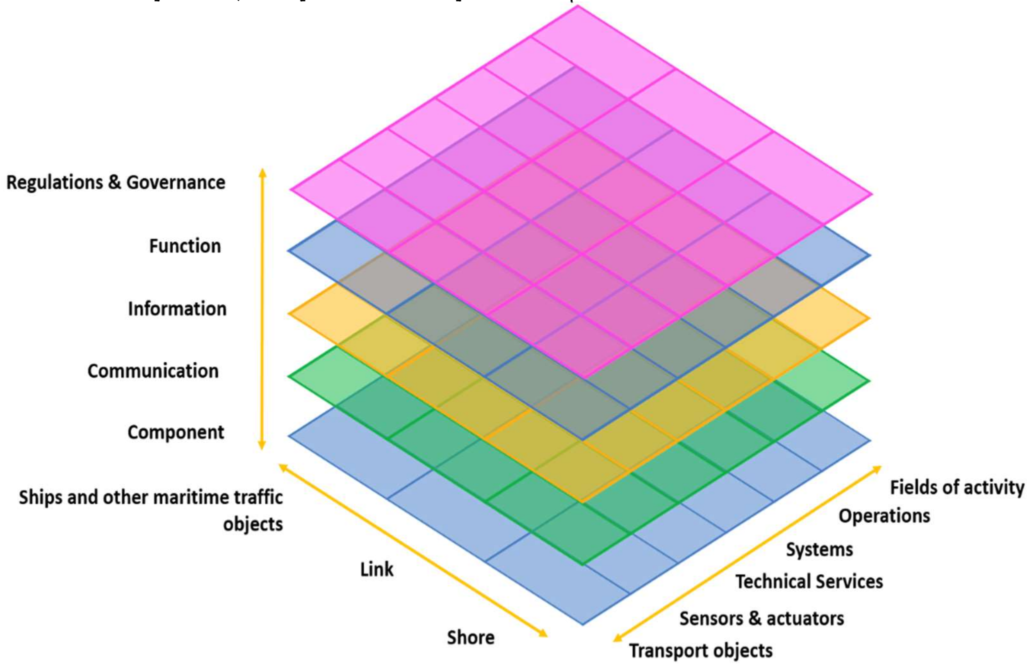

Figure 23: Maritime Architecture Framework

3.8.4 Adaptation to the IWT domain – the IWT Reference Architecture (IRA)

The need for an IRA spanning the IWT domain at large has been demonstrated above, and the conceptional sources to inform the IRA have been introduced, too. Building on the work on the MAF at IALA and elsewhere specifically, an initial sketch of the IRA is given in Figure 24.

[19] It should be noted, however, that the notion of topology at this axis was introduced already in the SGAM adaptation of the RAMI cube to some extent by the distinction between centralised vs. decentralised generation of electricity.

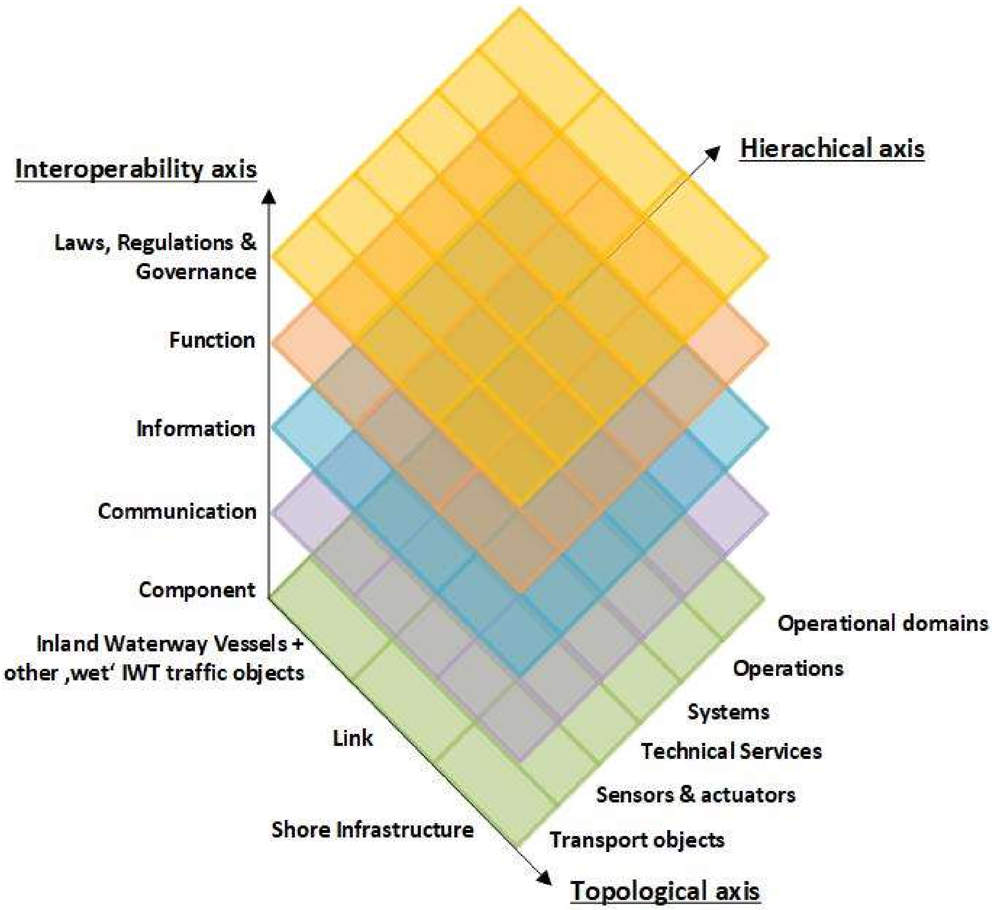

Figure 24: IWT Reference Architecture (IRA) (informed by Maritime Architecture Framework)

An adaptation to the IWT domain can be done straightforward by replacing 'maritime' by 'Inland Waterway Vessels + other <wet> IWT traffic objects'. This retained proximity of the proposed IRA and the MAF would also allow for seamless harmonisation in mixed traffic situations.

Any attempt to populate the IRA is clearly beyond the scope of the present Sub-Activity.

The assessments for adaptation of the RAMI-informed MAF as a Wet-to-Wet adaptation to the IWT domain rendering the IRA are given in Table 14.

DIWA assessment metrics	Assessment results
DIWA-TRL	4 (Concept validation in maritime domain 'in lab environment')
DIWA-Adaptability	0 (Adaptable with substantial modifications)
DIWA-Adaptation Demands	0 (Substantial adaptation resource/time demands) (conservative)
DIWA-Technology Radar	'Future Box'
DIWA-IDL Impact	III (Intelligent IWT fairway & navigation domain). Note: Even required for DIWA's desired convergence of the two domains IWT Fairway & Navigation with IWT Logistics on IDL II and III at all.

Table 14: Assessment results for the IWT Reference Architecture (IRA)

This IRA would not be confined to the IWT fairway & navigation domain but would also allow to capture relevant regulations, architectures, standards, definitions etc. from the IWT logistics domain – thereby facilitating the convergence ultimately envisioned by DIWA (compare Figure 1). Hence it is labelled 'IWT Reference Architecture' as opposed to 'IWT Fairway & Navigation Reference Architecture'.

Chapter 6 will re-visit the IRA. There, recommendations will be derived.

4 Structured Inventory of Candidate Technologies

This chapter contains the CT inventory which is structured by functional technology families which in turn are put into architectural context by applying the Overarching IWT Fairway & Navigation Architecture. Each CT is introduced within its functional technology family and assessed for its potential contribution to the IWT fairway & navigation domain.

The functional technology families are ordered in 'bottom-up' fashion, i.e. considering the most fundamental CTs first, and functional technology families building and therefore relying on them later:

- *Position, Navigation, Timing (PNT) by radio navigation technologies;*
- *Communication link technologies;*
- *Sensor technologies* (including position sensor technologies other than radio navigation);
- *Data modelling methods & technologies;*
- *Data evaluation methods & technologies.*

The coverage of technologies in this chapter *cannot be complete but must remain a bit eclectic:* Covering all technologies employed by all three different modes of transport within scope and even excluding aviation technologies already, was not feasible regarding the limited resources available. *As a general rule,* such technologies of other modes were selected, that appeared to have some *specific support for the operational requirements raised by Sub-Activity 2.5's recommendations* (compare section 2.4.1) and/or *have fundamental strategic importance* for the DIWA scope and maybe even beyond and/or – if coverage of all modes of transport was not possible - *recent relevant developments in the maritime domain* were introduced and assessed.

4.1 Position, Navigation, Timing by radio navigation technologies

When aspiring to reach higher IDLs in navigation proper, it is essential for all modes of transport that their vehicles are able to determine their position electronically at all times, often also together with other essentially required navigation data such as speed over ground and course over ground. Today, *GNSS* are the main means in all modes to acquire that data at the vehicles. There are different reasons for GNSS to fail, namely space-born at the space segment itself, due to failure of the space-to-earth-downlink, and terrestrial at the user segment, and this has been studied in considerable detail. IMO recently issued a warning against deliberate interference of GNSS [IMO-MSC1-Circ1644].

Recently, in particular at aviation, there has been a growing awareness for the potential threats of space weather affecting the space segment of GNSS, and space weather sensors have been developed to mitigate those potential threats.

To mitigate certain integrity issues of the on-board own position determination as well as to improve its accuracy, *Differential-GNSS (DGNSS) augmentation services* are provided within defined regions either by one or several satellite and/or terrestrial radio communication means. These augmentation systems are meaningful as long as the thus augmented specific GNSS itself is available. Should the specific GNSS itself or its reception at the vehicle fail, then the vehicle electronics may revert to the usage of a different GNSS, if that capability is implemented in the vehicle's mobile equipment.

Should – even worse – all GNSS be affected by the same cause simultaneously due to one of their common modes of failure, then *radio navigation backup systems* are required, that do not have the same mode of failure as GNSS to provide the above essential data. These radio navigation backup systems regularly are provided by terrestrial radio communication means. A useful overview of the maritime situation is given in [IMO-MSC.1/Circ.1575], Figure 4.

When introducing the Overarching IWT Fairway & Navigation Domain Architecture in the previous chapter, the different components of the 'PNT bracket' have been introduced as expanded above and as indicated in Figure 25 overleaf.

Following the above selection criteria, only specific topics are discussed as follows: Considering the 'dry' modes, it can generally be concluded that any potential Dry-to-Wet(IWT) adaptation of their respective PNT solutions can only be done by adaptation in analogy in the case of road/ITS and may be even pointless by definition in the case of rail because of it being physically track bound. Only from the maritime domain there is a direct Wet-to-Wet adaption possible, either seamlessly or with some modifications, and here only recent developments at maritime will be introduced.

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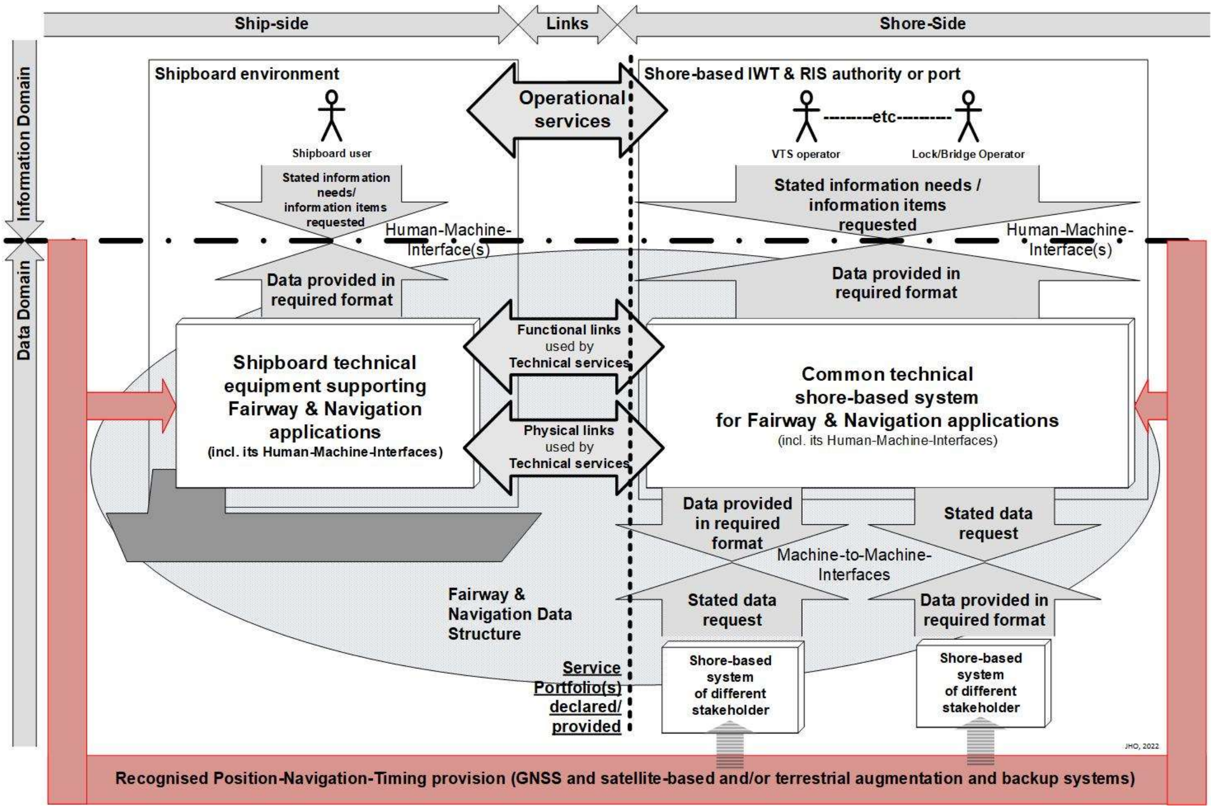

Figure 25: Overarching IWT Fairway & Navigation Architecture with PNT by radio navigation technologies highlighted

4.1.1 Learning from the maritime domain

There are the following facets of PNT where the present Sub-Activity assumes a potential for the IWT fairway & navigation domain to learn from recent developments at maritime:

- *Formal recognition process of components of the 'PNT Bracket';*
- *Generic functional setup of the shipboard PNT equipment* supporting the Inland-SSSA; and
- *Terrestrial backup by introduction of a Ranging-Mode.*

4.1.1.1 Formal recognition process of PNT components

The maritime domain has established *a formal recognition process* for the components that – in total - comprise their World Wide Radionavigation System (WWRNS). [20] Thus IMO makes sure that only those systems that fulfil the requirements of a contribution to their WWRNS become part thereof and thus may be used for navigation and associated purposes. Recent examples of radio navigation satellite components being thus recognised by IMO are the Galileo, BDS, and the Indian Regional navigation satellite systems (compare [IMO-SN.1/Circ.329], [IMO-SN.1/Circ.334], [IMO-SN.1/Circ.340]).

With increasing IDLs in the IWT fairway & navigation domain, the demand for reliable, integrity-verified and accurate PNT data obtained by electronic means increases, too, which may be warranted by a formal recognition process for the any and all components being part of their PNT provision. Hence, *the IWT fairway & navigation domain may be well advised to adopt such a process in the future,* following the example of IMO's formal recognition process. The assessment of the adaptability of that is given in Table 15 overleaf. Recommendations are given in the Annex under *REC-IWT-Recognised-PNT-Provision*.

[20] The IMO Assembly in particular "REQUESTS the Maritime Safety Committee to recognize systems conforming with the requirements set out in the Annex to this resolution, and to publish information on such systems" ([IMO-A.1046(27)], paragraph 4).

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (fully developed since decades at IMO)
DIWA-Adaptability	++ (Seamless Adaptability)
DIWA-Adaptation Demands	+ (Adaptable with minor modifications) (optimistic) 0 (Adaptable with substantial modifications) (conservative)
DIWA-Technology Radar	2027-2032 (optimistic) - 'Future Box' (conservative)
DIWA-IDL Impact	I (Digitised IWT fairway & navigation domain) Note: Higher IDLs build on resilient PNT, hence IDL II and III definitions no longer specifically addressing that but consider this as a given.

Table 15: Assessment of the adaptability of the IMO concept of the WWRNS including the formal recognition process to the IWT fairway & navigation domain equivalent of an IWT Recognised PNT Provision

4.1.1.2 Generic functional setup of the shipboard PNT equipment

Recently, there have been several moves at IMO to improve the quality and integrity of the vessel's PNT data determination by certain stipulations for shipboard equipment entities, all of which are not mandated at this point but have acquired considerable formal standing already:

- *shipboard PNT processing entity*,
- *multi-system shipborne radio navigation receivers*; and
- *generic GNSS shipboard receivers*.

4.1.1.3 Shipboard PNT processing entity

This is the most important recent development at IMO: Hereby, IMO has created a requirement base for the core components of any shipboard PNT related equipment, as introduced in the previous chapter in the context of the SSSA. The IMO guidelines for shipboard PNT processing entity describe it as follows and as illustrated by Figure 26: "The shipborne provision of resilient PNT data and associated integrity (…) and status (…) data is realized through the combined use of onboard hardware (…) and software (…) components. The shipborne PNT Data Processing (PNT-DP) is the core repository for principles and functions used for the provision of reliable and resilient PNT data. The PNT-DP (…) is defined as a set of functions facilitating: (1) multiple sources of data provided by PNT-relevant sensors and services (e.g. GNSS receiver, DGNSS corrections) and further onboard sensors and systems (e.g. radar, gyro, speed and distance measuring equipment (SDME), echo-sounder providing real-time data) to exploit existing redundancy in the PNT-relevant input data; and (2) multi-system and multi-sensor-based techniques for enhanced provision of PNT data" ([IMO-MSC.1/Circ.1575] paragrahs 2 +3).

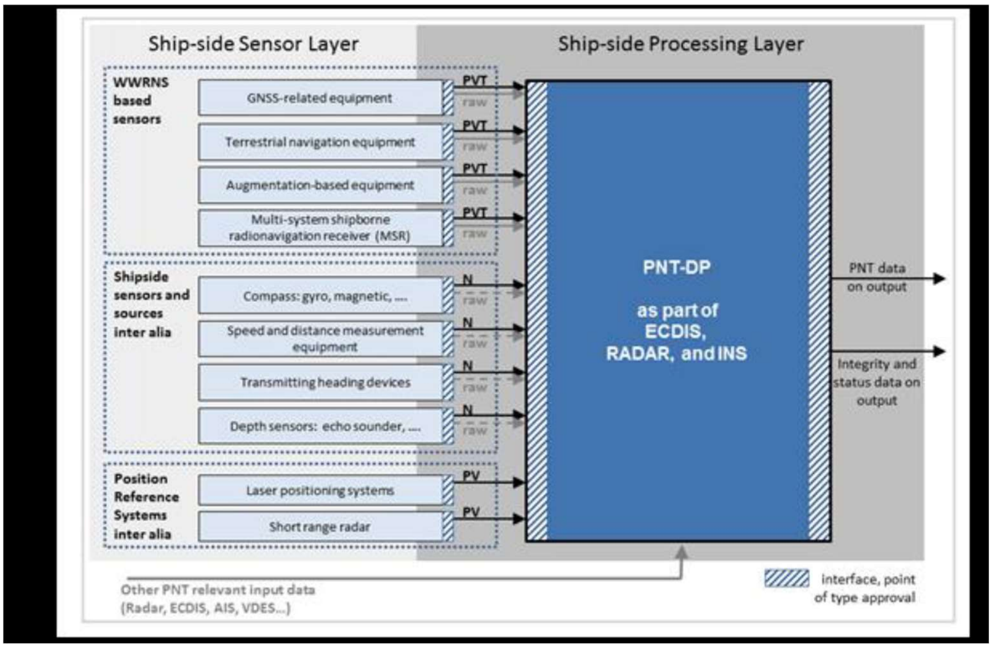

Figure 26: Shipborne PNT Data Processing (PNT-DP) integrated as software into INS, ECDIS, or Radar

In the context of the SSSA, the two layers 'ship-side Sensor Layer' and 'Ship-side Processing Layer' in Figure 26 are the same as the two lower layers in the SSSA in Figure 19. This consistency demonstrates the applicability of the generic maritime shipboard architecture – and via adaptation to the Inland-SSSA – the applicability of the generic functional setup of the shipboard PNT equipment to the IWT fairway & navigation domain in general, too.

4.1.1.4 Multi-system shipboard radio navigation receiver

Considering the different individual radio navigation systems in use and recognised at the maritime domain, IMO developed performance standards for a shipboard radio navigation receiver that uses several radio navigation sources as input, hence – multi-system shipboard radio navigation receiver (compare IMO-MSC-Resolution [IMO-MSC-Res-401] as amended by IMO-MSC-Resolution [IMO- MSC-Res-432]). The *multi-system shipboard radio navigation receiver* allows for integration of both satellite and terrestrial radio navigation systems. This multi-system shipboard radio navigation receiver can be construed as an intermediate step towards the above Shipboard PNT processing entity by at least integrating the radio navigation receiver domain.

4.1.1.5 Generic GNSS Shipboard Receiver

Considering the variety of recognised GNSS for which IMO has developed individual performance standards over time, it appeared that they are quite similar in substance, Therefore, IMO concluded to develop performance standards for a *Generic GNSS Shipboard Receiver* and commissioned a correspondence group to accomplish that task: 'This document (….) provides a functional approach and modular structure for performance standards for shipborne satellite navigation system receiver equipment providing position, navigation and time data and associated information. The applicability of the approach is proved by the exemplary implementation of a performance standard for shipborne Quasi-Zenith Satellite System (QZSS) and BeiDou Navigation Satellite System (BDS), as well as Galileo receiver equipment, into the proposed modular documentation structure. (…) The comparison of all up-to-now developed and recognized performance standards for shipborne radionavigation equipment, due to the fact that all are describing satellite navigation equipment, has shown that, apart from system-specific information, the existing performance standards are based on identical text passages. In this context, NCSR 5 considered the possibility of consolidating performance standards for all receiver equipment using global and/or regional satellite navigation systems, addressing the functional recommendations in a generic manner, and system-specific, if required.' ([IMO-NCSR-9-5]], preamble + para. 7). As opposed to the Shipboard PNT processing entity and the Multi-system shipboard radio navigation receiver, these IMO performance standards don't integrate different radio navigation sources, but simplify the GNSS related setup of shipboard PNT solutions.

4.1.1.6 Potential adaptation to IWT fairway & navigation domain

The assessment of potentially adapting these maritime shipboard PNT developments, but in particular the *Shipboard PNT processing entity* which carries the greatest weight, is given in Table 16.

DIWA assessment metrics	Assessment results
DIWA-TRL	5 (Prototyping & Incubation – testing prototype in user environment) (optimistic) 4 (Concept Validation – lab prototype) (conservative)
DIWA-Adaptability	++ (Seamless Adaptability)
DIWA-Adaptation Demands	++ (Little adaptation resource/time demands)
DIWA-Technology Radar	2027-2032 (optimistic) 'Future Box' (conservative)
DIWA-IDL Impact	I (Digitised IWT fairway & navigation domain) Note: Higher IDLs build on resilient PNT, hence IDL II and III definitions no longer specifically addressing that but consider this as a given.

Table 16: Assessment of the adaptability of the generic functional setup of the shipboard PNT equipment

Recommendations are given in the Annex under *REC-Shipboard-PNT-Processing-Entity*.

4.1.2 Learning from Maritime: terrestrial PNT system by R-Mode

The Ranging-Mode (R-Mode) uses a range estimation between the known radio transmitter location and the mobile radio receiver location to be determined by measuring the time that has elapsed between the emission of the radio signal (Time of Emission) and its arrival (Time of Arrival). Using a number of different such range measurements, a triangulation can be done, thus rendering the mobile's position. The mobile's position gains quality, if and when the time of reception is known precisely and the different transmitters used are more or less evenly distributed around the receiver.[21] This concept works for any kind of radio signal emitted with precise timing and for which the emission time can be made known to the receiver. Hence, no dedicated radio system would be required, if this data can be added to an existing radio system's signal, hence the R-Mode is an instance of a signal-of-opportunity concept. When using terrestrial radio system, the R-Mode is capable of becoming a terrestrial radio navigation system independent of GNSS, although synchronised to GNSS ideally ('GNSS disciplined'), if and when available.

Already well established terrestrial radio systems on a global scale and in particular 'under land' available for R-Mode in *maritime shipping* are for instance the MF DGNSS transmissions from the IALA Beacon System and the VHF transmissions of AIS shore services (compare e.g. [IALA NAVGUIDE 2018], 98). In the future, transmissions from VDES shore services may also provide an R-Mode source.[22] The R-Mode has been accepted in maritime shipping in recent years, and has thus been incorporated in above Shipboard PNT processing entity ([IMO-MSC.1/Circ.1575], Figure 4). Also, progress on the developments of R-Mode for maritime shipping has been reported comprehensively to IMO MSC recently as a contribution to Resilient PNT, pointing out specifically results from R-Mode trials in the Baltic Sea region by the partly EU-funded R-ModeBaltic and R-ModeBaltic2 projects ([IMO-MSC105-INF.10]). Further, the global usage and protection of frequencies for R-Mode is under consideration at ITU-R World Radiocommunication Conferences (WRC) since WRC-2019 and will be on the preliminary agenda of WRC-2027.[23,24] Finally, R-Mode has become a standing topic at IALA.

When considering a potential adaptation of the R-Mode from the maritime domain to IWT fairway & navigation domain, there are certain supportive and challenging circumstances: *In the IWT fairway & navigation domain basically all waterways are 'under land' everywhere and therefore terrestrial radio coverage can be achieved – in principle – everywhere* – as opposed to the maritime domain. Thus this becomes supportive of an introduction of R-Mode for Resilient PNT there. The required transmitter distribution geometry in the IWT fairway & navigation domain due to the topology of rivers and/or canals tends to be challenging, however, as opposed to sea basins in the maritime domain. This challenge can be overcome only by using more suitable transmitters of *any* kind situated along the rivers and/or canals – remember: R-Mode exploits suitable signals when an opportunity offers itself. Besides the maritime radio systems mentioned above which are introduced in the IWT fairway & navigation domain, too, there may be used additional radio signals from the following systems available or potentially available in the future in the IWT fairway & navigation domain:

- *Use suitable radio signals emitted from 'smart' IWT infrastructure sites deployed potentially along the inland waterways in larger numbers for R-Mode purposes:* Compare the IWT Infrastructure Site Architecture in Chapter 3 above and Chapter 5.
- *Adapt the use of the IMT-2020 radio communication systems for R-Mode purposes:* Since IMT-2020 digital cellular radio communication systems are already deployed on land and full coverage of inland waterways is promised in the political domain in some countries, there may be the option to use IMT-2020 signals for R-Mode. IMT-2020 uses its own frequency setup independent of the maritime mobile service VHF frequency band. This option will thus be available independently of the deployment of 'smart' IWT infrastructure site, but may as well be integrated there.

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[21] A full description of this principle can be found in the IMO Performance Standards on the Shipboard PNT processing entity [IMO-MSC.1/Circ.1575].

[22] Compare [IMO-MSC 105/INF.10], para. 6, [IMO-NCSR9/12/9], para. 9-11, and [IMO-NSCR9-INF.13], the latter bringing [IALA-G1158] on the VDES R-Mode to the attention of IMO.

[23] 'The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) is developing ranging mode (R-Mode), which is a radionavigation system that is intended to provide a contingency system in case of temporary global navigation satellite system (GNSS) disruption, to support e-navigation.' ([ITU-WRC2019-Res-812], considering h).

[24] 'Consider possible changes to the Radio Regulations for implementation of R-Mode as a new maritime radionavigation service' ([ITU-WRC2019-Res-363], Resolves #2).

The assessment for adapting R-Mode for resilient PNT from the other modes to IWT fairway & navigation domain is given in Table 17.

DIWA assessment metrics	Assessment results
DIWA-TRL	5 (Prototyping & Incubation – testing prototype in user environment regarding maritime)
DIWA-Adaptability	+ (Adaptability with minor modifications regarding the working principles)
DIWA-Adaptation Demands	0 (Substantial adaptation resource/time demands); - (High adaptation resource/time demands if at least one of options for achieving coverage as mentioned above is available)
DIWA-Technology Radar	2027-2032 (optimistic) 'Future Box' (conservative)
DIWA-IDL Impact	I (Digitised IWT fairway & navigation domain) Note: Higher IDLs build on resilient PNT, hence IDL II and III definitions no longer specifically addressing that but consider this as a given.

Table 17: Assessment of the adaptability of the notion of Ranging-Mode under consideration at maritime

Recommendations are given in the Annex at *REC-R-Mode-For-IWT-Fairway & Navigation-Domain*.

4.2 Communication link technologies

4.2.1 Introduction

The consideration of communication link technologies as CTs for adaptation to the IWT fairway & navigation domain in this section is structured in accordance with the Overarching IWT Fairway & Navigation Architecture following the distinction between functional and physical links as follows:

- *Communication profiles*
- *Functional links in radio communications: pre-defined data containers*
- *Functional links in radio communications: protocols for data communication*
- *Physical links using radio communication technologies*
- *Physical links using light – High bandwidth Visual Light Communications*

4.2.2 Communication profiles for selecting communication technologies

To know the communication profile of an operational relationship (compare Figure 5) is essential for selecting the most appropriate communication technology or technologies. As a direct contribution to answering the REC 2 from Sub-Activity2.5 the following attributes are offered:

- *Direction of communication:* One-way or bi-directional.
- *Addressee of communication:* Broadcast (to everybody or a group) vs. individually addressed.
- *Confidentiality vs. timing of a transmission in relation to the time characteristics of an operational relationship:* These two attributes have become particularly important. Timing of a transmission in relation to the time characteristics of an operational relationship is essential for any real-time remote operation and/or control process, such as are required by remote operation of ROV and monitoring of AV. This attribute means that the actual occurrence of the transmission would
  - Either be allowed a certain degree of latency while still being 'in time' for the time characteristics of the supported operational process itself;
  - Or be required to happen instantaneously without any sensible latency. *Ultra-low latency* would thus mean being synchronous with fast real-time processes.

Figure 27 maps different radio communications technologies in a matrix mainly composed by the two latter attributes. The addressee(s) of the communication is incorporated, where this makes a difference.

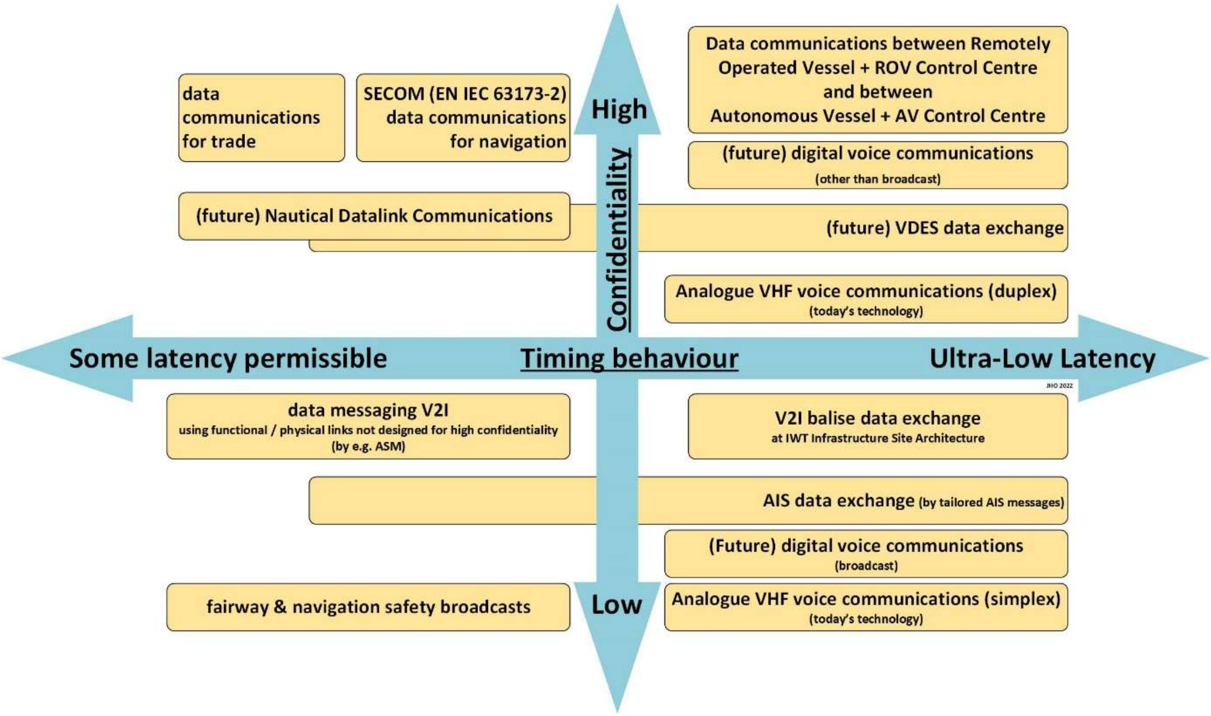

Figure 27: Confidentiality vs. Timing Behaviour in communication profiles

Recommendations from this discussion are given in the Annex under *REC-Communication-Profiles*.

4.2.3 Functional links in radio communications: pre-defined data containers

The functional links provide to the *Nautical Datalink Communications* the (bi-directional) radio communications links as highlighted in Figure 28.

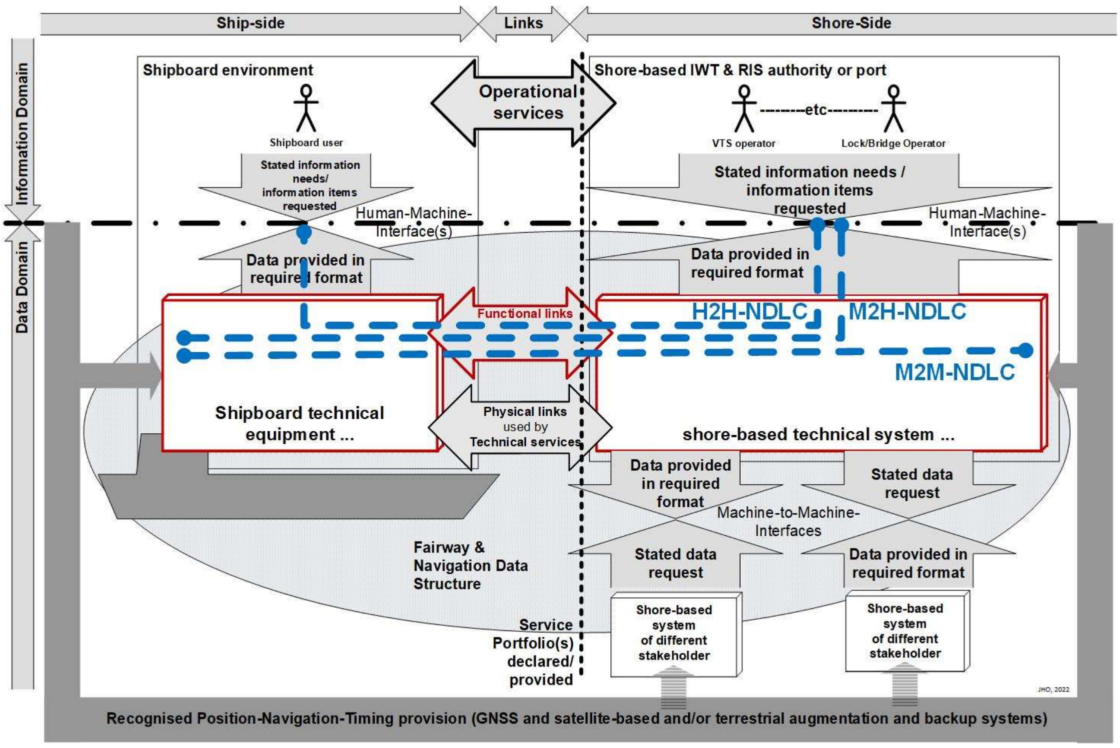

Figure 28: Overarching IWT Fairway & Navigation Architecture; functional links highlighted + NDLCs introduced

The functional links are *carrier-agnostic*, because the carrier for the functional links is provided by the physical links of the radio communications is a separate entity (compare Figure 9). Functional links contribute two features to successful radio communications, namely

- pre-defined data containers and
- defined protocols for data communications.

The first feature will be addressed in this section, the second in the following section. Here, only the maritime domain will be considered, because only the wet-to-wet adaptation of data container content definitions as well as associated protocols appears to be meaningful.

4.2.3.1 Application Specific Messages for carrier agnostic use

The Application Specific Messages (ASMs) were defined for the AIS [ITU-R-REC-M1371]. Thus the ASMs can be used directly in the IWT fairway & navigation domain by the existing AIS service using AIS protocol. When *using them as carrier-agnostic topical data containers via a different physical link technology*, the bits reserved in them to specifically support the AIS protocol can simply be omitted or ignored.

It has been observed in the maritime domain, that the transmission of ASM via AIS, in particular from shore to ship, has not developed as was originally planned and implemented in the AIS, even in those regions where ample bandwidth on the dedicated AIS frequencies is available to that end.[25] The recognition of the potential of the ASM,[26] this has led to recent moves in the maritime domain that effectively render ASMs as carrier-agnostic topical data containers:

- The VHF Data Exchange System (VDES) has been specifically developed to be a prime candidate for transmitting ASM as a different carrier to the extent of allocating frequencies in the VHF maritime mobile service band to that purpose [ITU-R-REC-M2092].
- There have been recent contributions made to IMO suggesting to disentangle the ASM from the AIS core to different degrees: 'To enable the maritime industry to make better use of ASMs, a discussion should be encouraged on which channels messages should be transmitted, noting that the AIS channels may, in certain areas, be used for navigation purposes up to the AIS capacity limit. It is further noted that ITU-R has already reserved two channels for the purpose of ASMs, which are identified as ASM 1 and ASM 2 in appendix 18 to the ITU Radio Regulations. To enable wide use of ASM, a discussion should take place in which way a wider usage could be promoted' ([NCSR9/12/7], Annex, paragraphs 23-24).

The assessment for using ASM as topical data containers to be used carrier agnostically in the IWT fairway & navigation domain is given in Table 18. (The assessment done here does not cover any content.)

DIWA assessment metrics	Assessment results
DIWA-TRL	**9** (Market expansion)
DIWA-Adaptability	**++** (Seamless Adaptability)
DIWA-Adaptation Demands	**++** (Little adaptation resource/time demands)
DIWA-Technology Radar	**2022-2026** (optimistic) **2027-2032** (conservative)
DIWA-IDL Impact	**II** (Connected IWT fairway & navigation domain)

Table 18: Assessment of the adaptability of the carrier agnostic use of ASM in the IWT Fairway & Navigation domain

Recommendations from this are given in the Annex under *REC-Carrier-Agnostic-Usage-Of-ASM.*

4.2.4 Functional links in radio communications: protocols for data communication

This section now discusses one CT for the protocol part of the functional links in radio communications.

4.2.4.1 SECOM – secure communications protocol

SECOM is a protocol for secure ship-shore and shore-ship data exchange communication recently defined in an international/European standard (EN IEC 63173-2) and originally developed in the maritime

[25] Which is also the case in the IWT fairway & navigation domain due to its topology.

[26] IMO 'has established rules for the development of ASMs. Some of these messages are described in IMO circulars. Further messages had been developed by other organizations and a list of these messages and their status is held by IALA. In many documents the usefulness of this tool has been described, however the usage is not widespread. How successful a systematic implementation could be is shown by the use of AIS for inland waterways within Europe, which may serve as a good example of a well-thought and thorough implementation' ([NCSR9/12/7], Annex, para. 22).

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domain in the context of e-navigation, namely for the provision of *data products* by shore-based organisations to shipboard applications in particular as defined in the 'S-100 World'.[27] To that end, a shipboard application interfaces to the *'SECOM information service interface'* by standard internet technologies such as REST and JSON for the data exchange. Special attention is being paid to the security of the data exchange, i.e. safeguarding against tampering with requested data, making sure the data provider is a trusted source – by accessing and using a Public Key Infrastructure (PKI) – and the requestor has sufficient rights to access the data. SECOM supports direct retrieval of 'small' amounts of data (max 350kB) and retrieval of larger amounts of data via a download link the recipient can activate when sufficient connectivity is available.

Regarding its function as a communications protocol, SECOM acts as an intermediate layer between the application and its carrier domain – just labelled 'Internet' in the standard. The supporting lower layers of the standard internet communication stack and the physical link(s) proper are accessed by SECOM using current internet technology basic services and functionalities such as HTTP and SSL/TLS. For proper operation and if small latencies are desired, SECOM thus requires the provision of a considerable bandwidth compared to what is available in the 'wet' domains today: When applied to 'wet' mode of transport mobile applications as intended, these requirements can only be met by future introduction of high bandwidth physical link technologies as carriers adapted to the 'wet' mode of transport, such as a 'wet' derivative of a general purpose digital radio communication technology, high bandwidth satellite links, high bandwidth Visual Light Communications (VLC) systems, and potentially by the VDES.

Applications can access data products provided by shore-based organisations, which are considered in the standard to be *'vendors'*, i.e. charging the individual shipboard users for their service provision is assumed to be the regular case in the *SECOM data product ecosystem.*: SECOM does not offer any data products itself. It supports shipboard applications upon request, however, to search a data product service registry by its *'SECOM service discovery interface'*. Thus SECOM expects a data product ecosystem defined by the SECOM standard itself in following regards:[28]

- Vendors of data products have to provide interfaces to this data, compatible with the 'SECOM information service interface';
- Other parties have to provide service registries compatible with the 'SECOM service discovery interface'.
- Other parties have to provide identity registries compatible with the *'SECOM security interface';*
- Shipboard equipment has to access the 'SECOM information service interface' as prescribed in the standard.
- All financial transactions regarding the data exchange (e.g. membership fees for service registries, payments for data products or services, etc.) are to be handled via other means external to the SECOM defined data product ecosystem.

This functional setup embedded in its generic data product ecosystem is shown in Figure 29 overleaf.

SECOM is *not* a NDLC as introduced above, but could be part of NDLC applications, as its functional link.

Regarding SECOM's connectivity profile, the protocol and security interactions introduced in SECOM render a certain time latency for data exchange. Hence, SECOM can be used for applications where this time latency is permissible.

[27] SECOM originally was even considered the default means of data exchange shore-ship/ship-shore for the maritime S-100 based ECDIS by just footnoting the IEC63173-2 standard as a reference without any introduction or discussion of the likely imports of any such normative reference (compare [IMO-NCSR9/16/1], Annex, para 11.3.4, footnote 9), but this reference was removed, and the present draft revision of the maritime ECDIS performance standards does not contain any reference to any specific means. It can be expected, that the topic, i.e. whether SECOM should be made the default means for shipboard access to shore-provided data products of the S-100 World, will re-issue latest when the IEC test standard on ECDIS will need be revised accordingly (compare section below).

[28] As is assumed to be eventually at least partly provided by the MCP for the maritime domain.

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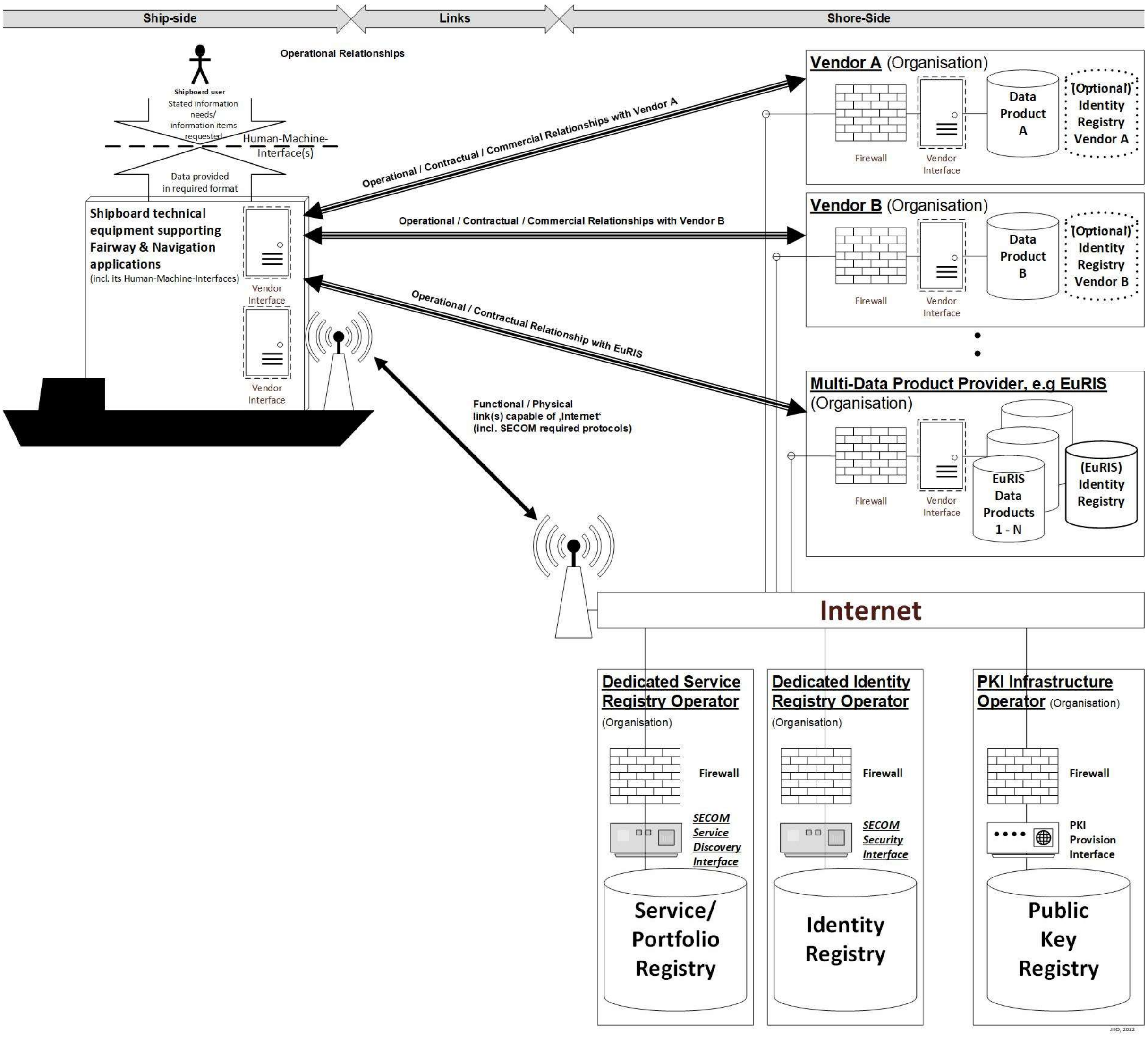

Figure 29: Overview of SECOM protocol's ecosystem with required entities

Regarding the assessment of SECOM's potential adaptability to the IWT fairway & navigation domain, this is done in a two-fold way:

a) *Option 'Full Functionality':* Usage of the full SECOM implied functionality would require substantial tasks in the IWT fairway & navigation domain to set up the SECOM data product ecosystem as indicated above;

b) *Option 'Just Secure Data Protocol':* The secure data transfer part of SECOM could probably be used to facilitate secure data transfer without the complete SECOM data product ecosystem, for example to access European River Information Services (EuRIS) web services, to retrieve or provide sensitive data, or as a secure means to exchange navigation intentions with infrastructure. This would still require to deploy and operate a PKI infrastructure interacting with the 'SECOM security interface'.

This means, that the following assessment of the DIWA-TRL takes into account the need to deploy and operate the SECOM required data product ecosystem that is apparently not available at IWT fairway & navigation domain presently. In addition, since the SECOM standard was only recently published, it is likely that the SECOM is not yet operational widely. The SECOM standard does, however, contain examples referring to a vendor implementation of maritime data exchange services, therefore the cautious estimation of the DIWA-TRL, applicable to both options.

The assessment of the adaptability of the SECOM standard as such would not be affected by these necessary efforts, thus rendering the same assessments for DIWA-Adaptability and DIWA-Adaptation Demands for both options. The resulting assessment is given in Table 19 overleaf.

DIWA assessment metrics	Assessment results
DIWA-TRL	5 (Prototyping & Incubation)
DIWA-Adaptability	++ (Adaptability with minor modifications)
DIWA-Adaptation Demands	++ (Minor adaptation resource/time demands)
DIWA-Technology Radar	2027-2032 (Just Secure Data Protocol option) 'Future Box' (Full functionality option)
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain)

Table 19: Assessment of the adaptability of the SECOM protocol options to the IWT Fairway & Navigation domain

While the above assessment indicated the applicability of SECOM to the IWT fairway & navigation domain in principle, the necessity for its introduction together with the SECOM implied and required ecosystem needs to be established:

- Currently, a lot of data exchange in the IWT fairway & navigation domain does not seem to require secure communications. Data is provided via open data web services in many cases, for example water levels, Notices to Skippers, actual status of locks & bridges. It is expected that certain open data transmissions will be still required in the future, too (Compare communication profile above).
- In case of sensitive data, already today, a dedicated connection using the same internet technologies as SECOM is established between the data supplier system and the data recipient system. The identity of both is known in the systems, i.e. every system/organisation has its own identity registry.
- Further, the recently launched EuRIS platform offers a one-stop-shop for a large number of fairway authority supplied services, thus requiring a data recipient to only have one EuRIS identity and account to access the services. The SECOM offered mechanism to 'discover' available services would not be required.
- When introducing SECOM, this would require adapting existing shipboard and shore equipment and their interfaces for data exchange to conform to the SECOM standard and to the functionalities mandated by the SECOM implied ecosystem.

Recommendations from this discussion are given in the Annex under *REC-SECOM-Impact*.

4.2.5 Physical links using radio communication technologies

4.2.5.1 Introduction

The physical links are the carriers of the data for the functional links between shipboard and shore technical systems and/or between technical systems of at least two vessels as highlighted in Figure 30 .

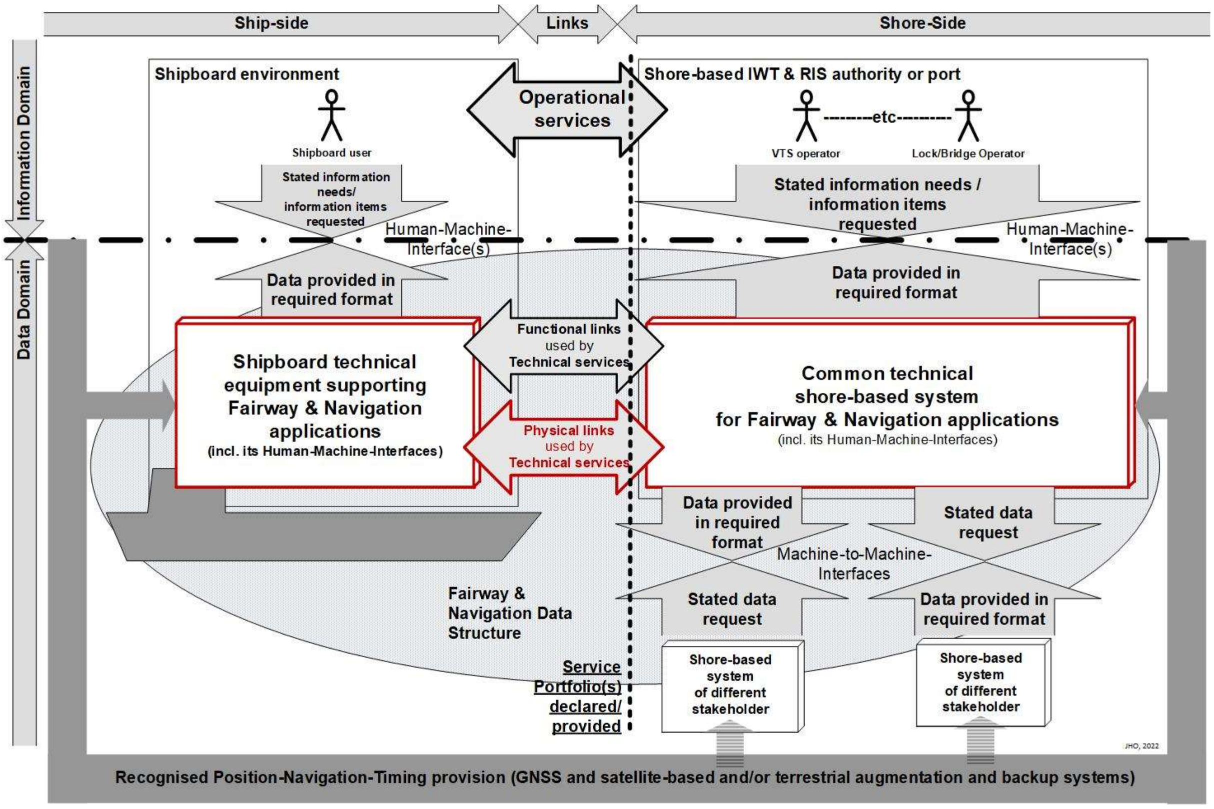

Figure 30: Overarching IWT Fairway & Navigation Architecture with physical links highlighted

Physical links provide a transparent (digital data) transmission function with defined performance features such as transmission bandwidth, range, time/latency behaviour, availability, reliability, and cyber security degree (secure vs. open). Physical link technologies discussed here are strictly V2V and/or V2I (and vice versa) for safety purposes of the vessel operations and vessel traffic, while recognising that some digital radio communication systems are capable to seamlessly support other purposes, such as general passenger services.

Looking towards physical link technologies introduced, being in the process of introduction, and under consideration in other modes of transport, there can be identified two fundamental categories of mobile digital radio communication technologies, namely

- *Specialties of the specific mode of transport,* i.e. physical link technologies tailored to the specific *operational and physical* needs of that domain. Since already the physical conditions of the physical links of the different modes differ largely between 'dry' and 'wet' modes in particular, there are relevant several maritime specialties, while there are only a few or even none purpose-tailored terrestrial digital radio communication technologies relevant of 'dry' modes.
- *Mode of transport specific adaptations of general-purpose digital radio communication technology families:* Families falling into this category are the *Conventional Digital Land Mobile Radio (CDLMR)* family and *International Mobile Telecommunication (IMT)* family,[29] using the generic terms defined by the ITU, where in both cases the fundamental standardisation and regulation work is done with a global scope. Being under consideration for adaptation to maritime plus at least one other mode, these are considered relevant for IWT fairway & navigation domain, too. The fundamental features of the technology families will be introduced briefly in this section, but transport mode specific introductions will be given in the following sections. Assessments of the potential adaptability to the IWT fairway & navigation domain will be done only after that with the adaptations by all modes of transport in comparison.

Not covered in this study and report are the following general purpose physical link technology families:

- *Low-Power Wide Area Network (LPWAN) Family:* LPWAN is an ITU defined generic term for a family of technologies, that allow for transmission of small data packages at intervals from re-

[29] Also known by technology generation abbreviations: 5G, 4G (e.g. LTE), 3G (e.g. UMTS), 2G (GSM).

motely located shore infrastructure sites with no fixed power supply infrastructure, thus requiring to balance the trade-offs between on-site power availability and the desired data package transmission frequency [ITU-R-REP-SM2423]. LPWAN technologies support the notion of the Internet-of-Things (IoT).

- *Short* Range *Devices (SRD) Family:* SRD is an ITU defined generic term for a family of technologies, which regularly offer a (very) high data transmission bandwidth but are limited in range to a relatively short distance ranging from centimetres to some hundred meters, depending on their (very) high operating frequencies ([ITU-R-REC-SM2103], [ITU-R-REP-SM2153]). Certain SRD family members are well known by their generic names, such as Wireless Local Area Network (WLAN) technologies.
- *Communication satellite systems* due to scope limitations and in full recognition of their continued proliferation to several modes of transport.

4.2.5.2 CDLMR Family – brief general introduction

An overview of the main CDLMR systems available globally is given in [ITU-R-REP-M2474]. There, a CDLMR system is defined as a Conventional Land Mobile Radio (CLMR) system, 'that transmits and receives using digital techniques'. A CLMR system is a 'non-cellular radiocommunications system where two or more CLMR stations communicate on a predetermined frequency channel(s), without the use of any controlling station and/or control frequency channel, with push-to-talk and group communication capabilities' ([ITU-R-REP-M2474], para. 3). They 'were developed for business users who need to communicate over limited geographical areas', employ 'the most basic and simplest two-way radio system for the user', and 'can be categorized into two types: simplex operation for direct peer-to-peer communications; and repeater operation where repeater(s) is (are) used to extend the communication reach', and 'multiple repeater sites are deployed to provide extended coverage' ([ITU-R-REP-M2474], para. 4.1).

'Operation of CDLMR radio equipment is based on open standards such as APCO P25, dPMR [Digital Private Mobile Radio] and DMR [Digital Mobile Radio] which are designed for dedicated use by specific organizations, or standards such as NXDN intended for general commercial use. Typical examples are the radio systems used by police forces and fire brigades. (…) Many systems operate with the remote or mobile stations being able to hear all the calls being made. This may not always be satisfactory and a system of selective calling may be needed. (…) Because the base station' antenna may be mounted on a high tower, coverage may extend up to distances of fifty kilometres. This is helpful especially when there is no signal in a public cellular mobile phone. Assignments can be made for operation on a particular channel or channels.' ([ITU-R-REP-M2474], para. 6.1)[30]

dPMR, as a typical example, is 'capable of voice, data and voice+data modes of operation', that latter meaning that 'it is possible to embed data into a voice call or automatically append it at the end of a call' ([ITU-R-REP-M2474], para. 6.2.4).

CDLMR can either use licence-free frequency bands, for example around 446 MHz in Europe, or can be tuned to another frequency below 1 GHz, the allocation of which needs to be provided by the domain representing organisation intending to deploy the CDLMR system – the latter is relevant for the current discussions in the maritime domain.

4.2.5.3 IMT-2020 – brief general introduction

IMT-2020 is the latest offspring of the IMT family which consists of different generations of general-purpose digital cellular radio communication systems, i.e. systems where digital communication is performed by point-to-point communications from a mobile station to a base station, spanning up a radio 'cell', using a specified Radio Access Technology (RAT), while communication between the base stations is done by a fixed core network. IMT-2020 also comprises both a terrestrial and a satellite component, but here the terrestrial network is considered alone. Therefore, IMT-2020 should be construed as a system of several sub-systems each of which is highly optimised for their respective tasks.

In the midst of the current plethora of 5G hype publications often biased by manufacturers' and service providers' interests, it is not easy to determine the capabilities of IMT-2020 in a neutral way. However, ITU as the United Nation's agency driving this development at its core globally has 'established the vision for IMT for 2020 and beyond' by 'describing potential user and application trends, growth in

[30] TETRA is another CDLMR system standardised by ETSI, also described in [ITU-R-REP-M2474].

traffic, technological trends and spectrum implications, and by providing guidelines on the framework and the capabilities for IMT for 2020 and beyond' ([ITU-REC-M2083], para 1). ITU also acted as the 'gate-keeper' to validate the technical specifications submitted for IMT-2020 by several global standardisation organisations and initiatives as being conforming to the vision. Figure 31 shows this vision 'in a nutshell' in generic terms.

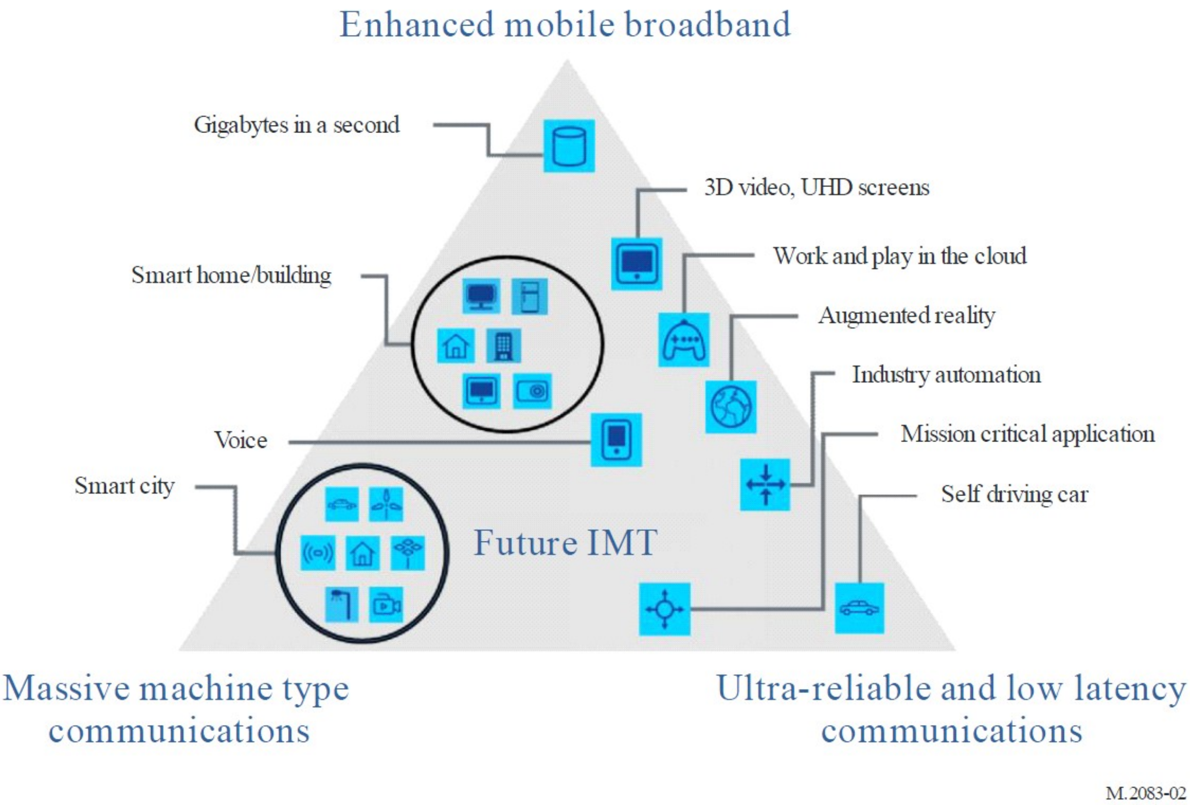

Figure 31: General design objectives of ITU-R when defining the IMT-2020 and beyond

In general, IMT-2020 can be construed as a digital cellular radio communication system capable of seamlessly transmitting data and voice. Its actual performance features in any given application are determined by allocating the systems' overall throughput capabilities to different locations within the triangle shown in Figure 31. This triangle is projected by the three mutually competing performance dimensions as specified by ITU as follows:

- '*Enhanced Mobile Broadband:* Mobile Broadband addresses the human-centric use cases for access to multi-media content, services and data. The demand for mobile broadband will continue to increase, leading to enhanced Mobile Broadband. (…) This usage scenario covers a range of cases, including wide-area coverage and hotspot, which have different requirements. For the hotspot case, i.e. for an area with high user density, very high traffic capacity is needed, while the requirement for mobility is low and user data rate is higher than that of wide area coverage. For the wide area coverage case, seamless coverage and medium to high mobility are desired, with much improved user data rate compared to existing data rates. However the data rate requirement may be relaxed compared to hotspot.' ([ITU-REC-M2083], para. 4)
- '*Ultra-reliable and low latency communications:* This use case has stringent requirements for capabilities such as throughput, latency and availability. Some examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc.' ([ITU-REC-M2083], para. 4).
- '*Massive machine type communications:* This use case is characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data.

Devices are required to be low cost, and have a very long battery life.' ([ITU-REC-M2083], paragraph 4)[31]

In order to achieve this, the necessary frequency allocations have been done in several frequency bands in the past years, i.e. IMT-2020 brings along its own frequency setup. Also, depending on the intended application scenario, the cell configuration of the digital cellular system is as flexible as illustrated in Figure 32.

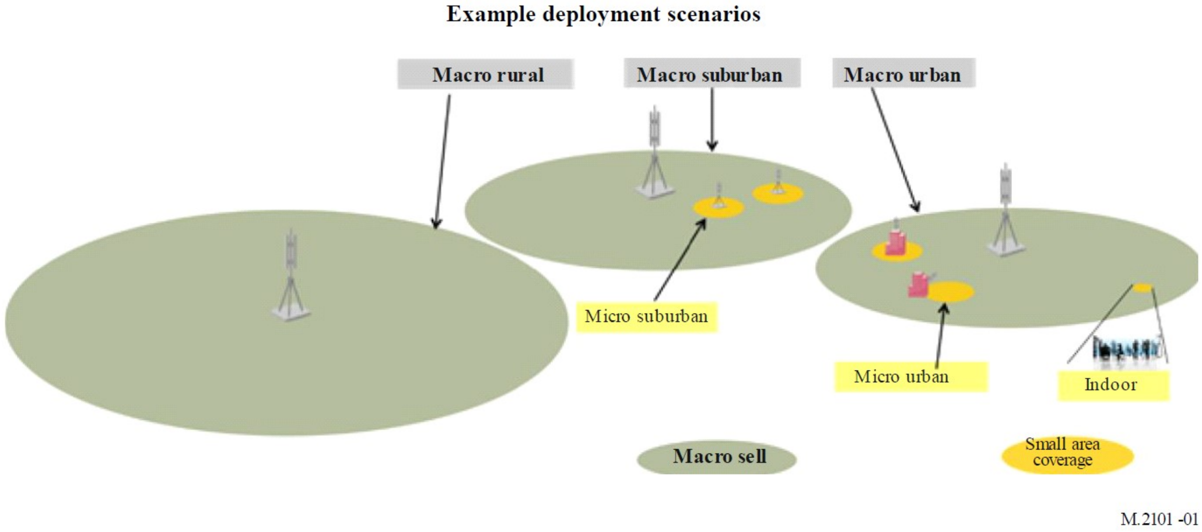

Figure 32: Cell layout adaptability of IMT-2020

It is this versatility inherent to IMT-2020 that has attracted considerable attention in all modes of transport considered here, as follows.

4.2.5.4 Radio communication technologies in the road domain, in particular ITS

As the name Conventional Digital *Land Mobile* Radio Systems (CDLMRS) implies, this technology family originated from the road domain, and its family members are widely used there for in particular voice communication between a transport company's centre and their vehicle fleets.

The digital cellular radio communication system *GSM* is used for automated V2C emergency notifications.

Regarding ITS, at present, there are competing two radio communication technology families for application in the domain of short range data radio communications vehicle to its environment (V2X), namely *an automotive adaptation of WLAN technology called ITS G5* (based on the IEEE 802.11p WLAN standard) on one hand and *an IMT-2020 automotive adaptation called Cellular V2X (C-V2X) or LTE-V2X* (based on relevant 3GPP standardisation) on the other hand. In the EU, the present decision making opts for co-existence of both systems in the frequency band of 5.9 GHz, but 'this Decision shall be reviewed as soon as market developments and evolution of standards and technology justify such a review or at the latest by 30 September 2023' ([EU-2020/1426], Article 4). This EU Commission Implementing Decision offers a detailed account of the developments leading up to that decision.

4.2.5.5 Radio communication technologies in the railway domain

Interesting here are only those technologies used for train operation purposes (as opposed to passenger communication services). The generic umbrella term for these families used by ITU is *Railway Radiocommunication Systems between Track and Trackside (RSTT)*, and RSTT is defined as: 'RSTT carry train control, voice dispatching, command, operational information as well as monitoring data between on-board radio equipment and related radio infrastructure located along trackside' ([ITU-REP-M2418], para. 5). ITU's introduction to many of these technologies is [ITU-REP-M2418], and an overview of RSTT applications has been given in above Figure 17.

[31] For details regarding the absolute figures and the trade-offs between the three dimensions depending on application scenario, compare the key document of the many IMT-2020 related ITU documents, namely [ITU-REC-M2083], para. 5, and in particular Figures 3 and 4 there.

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The rail specific requirements for RSTT are summarised as follows: 'Radiocommunication networks are critical to train operations including stringent requirements for reliability, availability, safety and security for these operations. Different security measures are considered based on the assumption of transmission error or communication blackout in RSTT. In general, radiocommunication for railway operations are considered as <mission critical> for train operations in general and the management of train emergency situations. Furthermore, railway radiocommunication systems require the support of legacy technology and to have a long life cycle. RSTT provide improved railway traffic control, passenger safety and security for train operations' ([ITU-REP-M2418], para. 5).

4.2.5.5.1 Rail purpose-tailored terrestrial digital radio communication technologies

Leaky Coaxial Cable 'are laid at trackside all along the line' to enhance the protection against radio interference of the physical radio links of any analogue or digital train radio communication system using it ([ITU-REP-M2418], para 8.1.5). Because this technology is not expected to be compatible in a 'wet' domain, it is not further considered.

4.2.5.5.2 Rail adaptations of CDLMR system

CDLMR technologies 'are used in some countries for wagon tail communications, shunting operation and intercom communication. Onboard staff, locomotive driver and people involved in maintenance and management are normally participating' ([ITU-REP-M2418], para. 8.1.2). Systems used to that end are TETRA (ETSI) and B-TruncC (China). Due to their apparent limited range of application in RSTT and due to the paramount role of IMT family systems in rail, CDMLR adaptations to rail are not further considered for any potential adaptation to the IWT fairway & navigation domain.

4.2.5.5.3 Rail adaptations of IMT family technologies for train operation purposes

The rail domain has successfully used a rail specific derivative of GSM, named GSM-R, as part of the European Train Control System (ETCS) for safety-critical applications since many decades now. 'GSM-R is a secure platform for voice and data communication between railway operational staff, including drivers, dispatchers, shunting team members, train engineers, and station controllers. It delivers features such as group calls (…), voice broadcast (…), location-based connections, and call pre-emption in case of an emergency' ([ITU-REP-M2418], para. 8.1.3).[32]

The International Union of Railways (UIC) as the organisation responsible for setting global standards for rail operations and rail-specific technologies has recently decided to embark on adapting an successor technology to the rail domain as follows: 'The predicted obsolescence of GSM-R by 2030, combined with the long term life expectancy of ETCS (2050) and the Railway business needs, have led to the European Railway community initiating work to identify a successor for GSM-R. The successor has to be future proof, learn from past experiences / lessons and comply with Railway requirements. (…) [As] one of the first steps in this process (…) the railways' needs are identified and defined in a consistent and technology independent way, the foundation for next steps on defining the *Future Railway Mobile Communications System (FRMCS)*' ([UIC-FRMCS-FU7100], 3.1.3; emphasis added).

The operational requirements for the FRMCS have thus been comprehensively identified and described in a technology-agnostic manner in [UIC-FRMCS-FU7100]. It should be noted here, that this document presents up-front a rail specific version of the system interconnection architecture introduced above: 'The scope of the FRMCS is depicted in Figure 1 from the perspective of the user. Figure 1 shows the complexity of the communication needs in the railway environment, and illustrates only a certain number of relationships between the actors (human users) and equipment (trackside and onboard) or between equipment without human interaction' ([UIC-FRMCS-FU7100], para. 3.3.1; Figure not reproduced here). Thus, *the rail domain is not only supporting the assessments made above regarding the importance and usefulness of having an ISIA, but provides a good example for its development.*

After having established the rail specific requirement base for the FRMCS, UIC agreed on a 'strategic plan for FRCMS introduction' ([UIC brochure], 9) after having identified IMT-2020 of technologies as suitable to support the rail specific requirements not only in principle, but also on the fast track, namely 'seeing the first roll outs in Europe in 2025' ([UIC-FRMCS-Brochure], 9). The strategic plan consists of 'three pillars' which can be briefly summarised as follows ([UIC-FRMCS-Brochure], 9):

[32] Also, LTE has been adapted to train, but it appears that this is limited to passenger services ([ITU-REP-M2418], para. 8.1.4), only.

- *'FRMCS V1 Specification':* In this phase, starting from established user requirements and use cases being described and originally planned to be completed by the end of 2021, all relevant specification parts were supposed to be developed and published. So far, as of end of 2020, it is claimed to be on time 'despite the pandemic and related consequences we are still enduring'.
- *'FRMCS Demonstrator -> V2 Spec':* This phase would use the stabilised FRMCS specification of the first phase and industry would build a FRCMS demonstrator until autumn 2023 as a planned date.
- *'FRMCS European Trail - > Readiness':* This phase aims at deploying first FRMCS solutions by summer 2025.

Of particular strategic importance for that ambitious strategic plan was the recognition of rail-specific adaptation of IMT-2020 by one of the major standardisation organisations globally, namely of the agreement of 3GPP to develop that rail-specific adaptation as part of one of their upcoming IMT standardisation releases (R18 latest) ([UIC-FRMCS-Brochure], 9ff).

4.2.5.6 Radio communication technologies in the maritime domain

4.2.5.6.1 Introduction and overview

Terrestrial and satellite radio communication technologies play a major role in the maritime domain for obvious range reasons. Without going into too much detail here, Figure 33 arranges the different radio communication technologies in accordance with two fundamental distinctions, by which the present situation in the maritime domain can be characterised as follows:

- *Terrestrial radio communication systems vs. satellite radio communication systems:* While satellite radio communication systems have been complementing terrestrial radio communication systems since decades, latest developments in satellite radio communication systems have enabled them to compete with terrestrial radio communication systems in the latter's genuine application domains. Both terrestrial as well as satellite radio communication systems have been introduced as carriage requirements for sea-going ships by IMO, the satellite radio communication systems as part of the GMDSS exclusively so far.
- *Maritime purpose-tailored radio communication technologies vs. general purpose radio communication technologies adapted to the maritime domain:* In particular regarding the terrestrial radio communication technologies, there have been developed over several decades many maritime purpose-tailored technologies, both analogue and digital, several of which have been introduced as carriage requirement for sea-going ships by IMO. While certain terrestrial general purpose radio communication technologies have been adapted to the maritime domain in certain niches without acquiring any carriage requirement status, only recently the discussion on a broad adaptation of general purpose radio communication technologies has started at IMO,

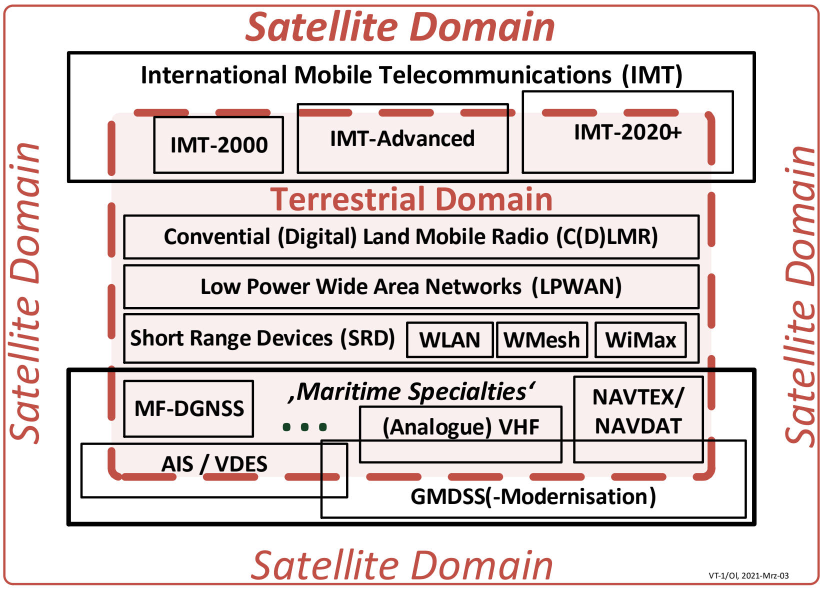

Figure 33: Overview radio communication technologies in the maritime domain

Regarding radio communication technologies and their usage of frequencies, there has been established since long a co-operation between IMO and ITU, and in particular the periodic WRCs of ITU-R have acquired milestone character for the introduction of new radio communication technologies to the maritime domain. This holds true also for the upcoming WRCs due to the following agenda items:

- *WRC-23, agenda item 1.11:* 'to consider possible regulatory actions to support the modernization of the Global Maritime Distress and Safety System and the implementation of e-navigation, in accordance with Resolution 361 (Rev.WRC-19)' [ITU-Council-Res 1399]+[ITU-WRC2019-Res-361];
- *WRC-27 preliminary agenda item 2.10:* 'to consider improving the utilization of the VHF maritime frequencies in Appendix 18, in accordance with Resolution 363 (WRC-19)' [ITU-WRC2019-Res-812] the latter having requested WRC-27 'to consider possible changes to Appendix 18 in order to enable use in the MMS for future implementation of new technologies, for improving efficient use of the maritime frequency bands ([ITU-WRC2019-Res-363], Resolves #1).

To re-iterate: What is going on in the maritime domain is relevant to the IWT fairway & navigation domain at mixed traffic situations, by creep-in effects, and by the general usefulness by adaptation. Since the radio communication technologies' adaptations to maritime are dependent on the WRCs, their proceedings are relevant for assessing the time frames needed *for any and all such radio communication technology adaptations where new or amended frequency allocations are necessary,* hence for the Technology Radar assessments of the present study and report. Accordingly, a selection of particularly relevant developments is presented in the following sections.

4.2.5.6.2 Maritime purpose-tailored terrestrial digital radio communication technologies

There are several maritime purpose-tailored terrestrial digital radio communication technologies. Overviews of these technologies can be found in [Carson-Jackson + Pokorny 2021], the IALA Navguide ([IALA Navguide2018], section 4.7), the IALA Maritime Radio Communications Plan (MRCP) [IALA MRCP], and in the IALA guideline on the CSSA [IALA-G1114], where these technologies are all part of Data Collection & Data Transfer domain of technical services (as introduced in Figure 20). Some of these technologies have already been made available to the IWT fairway & navigation domain and can thus be considered well-known and established. Others do not have any likely adaptation potential to the IWT fairway & navigation domain, such as the GMDSS related services like dedicated DSC, NAVTEX or even NAVDAT services. Yet other technologies, such as the AIS technology derivative AMRD [ITU-R-REC-M2135] will likely creep into the IWT fairway & navigation domain and thus need to be addressed in due course while not adding anything to the digitalisation question at hand. Hence, only one recent development not yet endorsed by the IWT fairway & navigation domain is to be introduced and assessed.

4.2.5.6.2.1 VHF Data Exchange System (VDES)

An overview of VDES is provided in [IALA-G1117]. The overarching goal for the VDES development was to protect the 'traditional' AIS functionality ([ITU-REC-M1371] refers) while considerably increasing the capacity of ASM throughput for maritime safety purposes and supporting detection and bi-directional data exchange by and with satellites – all by *exclusively* using frequencies within the VHF maritime mobile frequency band as defined in [ITU-RR], Appendix 18: 'The VDES provides a variety of means for the exchange of data between maritime stations, ship-to-ship, ship-to-shore, shore-to ship, ship-to-satellite and satellite-to-ship. The VDES is a multi-component system comprising of VDE, ASM and the AIS in the VHF maritime mobile band (…). The VDES has a terrestrial component VDE-TER and a satellite component VDE-SAT' ([ITU-REC-M2092], para. 1). Necessary frequency allocation have been available in principle for all terrestrial needs, but additional frequency allocations are being requested within the VHF maritime mobile band (see above at WRC).

It is important to note, that while sharing certain functional commonalities, the physical links provided by the newly defined VDE and by the traditional AIS carriers are different and not compatible, the VDE carrier being highly optimised for data throughput, in particular for the throughput of ASM, both for terrestrial and satellite receptions: In a recent communication of IMO to ITU, IMO has expressed its intention to use VDES for digital file transfer in the context of e-navigation.[33]

[33] 'Issue 2 (implementation of e-navigation): NCSR 9 would like to inform ITU-R WP 5B that various existing satellite networks already support the e-navigation concept, and usability studies have been conducted. The VDES and NAVDAT systems, for *which IMO has agreed to develop performance standards,* would also support e-navigation by means of enabling broadcasting (by NAVDAT) and *ex-*

IALA has created and is in the process to further develop relevant documentation for shore-based VDES service, including application use case descriptions [IALA-G1117]. There are under way several test beds for VDES, also in the ITW fairway & navigation domain. IALA also has informed IMO, that R-Mode is feasible in VDES [IMO-NCSR9-INF13].

Thus, it can be concluded, that – by and large – the technical framework of the VDES has been defined on the system level and in considerable detail, including frequency allocations, test bed installations are implemented, and *it can thus be safely assumed that the VDES will work*.

However, as far as maritime domain is concerned, two important aspects are still missing, namely performance standards for the VDES by IMO which would describe the operational usage and resulting requirements; but this has been promised by IMO (see footnote). But even more importantly, IMO has not yet committed itself to the introduction of VDES alongside of AIS, and therefore a phasing in process has not been determined.

The assessment for adapting the use of VDES to IWT fairway & navigation domain is given in the following Table 20.

DIWA assessment metrics	Assessment results
DIWA-TRL	5 (Prototyping & Incubation – testing prototype in user environment)
DIWA-Adaptability	+ (Adaptability with minor modifications) (optimistic) 0 (Adaptable with substantial modifications) (conservative)
DIWA-Adaptation Demands	+ (Intermediate adaptation resource/time demands) (optimistic) 0 (Substantial adaptation resource/time demands) (conservative)
DIWA-Technology Radar	2027-2032 (optimistic; requiring being ahead of IMO) 'Future Box' (conservative)
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain)

Table 20: Assessment of the adaptability of the VDES to the IWT Fairway & Navigation domain

While this assessment indicates potential to an adaptation of the VDES to the IWT fairway & navigation domain, there are some critical questions to be answered to that end first:

- Considering the fact that IMO has not yet committed itself to introduce VDES in the maritime domain - which would require at least performance standards formally adopted by IMO and the legal statement that VDES may be used for certain purposes from a certain date onwards -, the question is, *whether the IWT fairway & navigation domain would commit itself to introduce VDES ahead of IMO?* And if so, for which purposes specifically?
- While recognising the clear benefits of VDES compared to AIS in particular for transmission of the ASM and potentially other bulk data, it still needs to be demonstrated that a potential added-value by the introduction of VDES to the IWT fairway & navigation domain could match the benefits to be gained by the introduction of a general purpose digital radio communication technology *in addition to* further consolidating and potentially progressing the existing AIS as such?[34]

Recommendations from the above discussion are derived as given in the Annex under *REC-VDES*.

4.2.5.6.3 Use of general purpose digital radio communication technologies for maritime safety

General purpose digital radio communication technologies are under consideration at the maritime domain for those fields of application where performance due to their versatility cannot be matched easily or at all by maritime purpose-tailored (terrestrial) digital radio communication technologies ***wherever coverage can be achieved.*** This is the case namely for

- *digital voice communication:* The maritime domain has no digital voice radio communication technology in place.

change of digital files (by VDES). From a spectrum regulatory point of view, the requirements for e-navigation are thus covered' ([IMO-NCSR 9/24-Add.1], Annex 19, para 2.2; emphasis added).

[34] 'A consolidated view should be developed by IMO on the future capability and requirements of AIS' ([IMO-NCSR9/12/7], para. 4.3).

- *broadband data transmissions, e.g. for small amounts of data transmitted with very low latency or for bulk data transmissions (files),* as required in the context of e-navigation for internet-protocol based technologies and for ROVs/AVs respectively.[35]

Hence, IMO has recognised this in principle by arriving at a tentative conclusion in 2021 to use 'public broadband communication and technical standardisation in the context of maritime safety' ([IMO-NCSR8/14/1], paras 7.6/7.8). However, any definitive decision for one of the general purpose digital radio communication candidate technologies, amendments of the relevant IMO performance standards and carriage requirements affected potentially accordingly, and establishment of a transition path are still outstanding. Views expressed during recent IMO discussions reflect the complexity of the topics to be addressed, too:

- 'Analogue voice channels for VHF were heavily congested, and yet further reductions in the number of these channels were expected at WRC-23 and WRC-27' ([IMO-NCSR 9/24], para. 12.6.1)
- 'Digitization of voice communications in the VHF band could assist in solving some of the congestion issues' ([IMO-NCSR 9/24], para. 12.6.2);
- 'IMO should be proactive in the inevitable transition of VHF voice communication into digital format and be able to anticipate future developments at ITU' ([IMO-NCSR 9/24], para. 12.6.3); and
- 'All technical, operational and cost implications of a transition to digital voice communication on VHF, including requirements for a long transition period, should be carefully considered' ([IMO-NCSR 9/24], para. 12.6.4).

The fundamental aspects of this apply to the general purpose digital radio communication technologies at large equally. A critical factor for any 'fast' introduction would be the need to acquire frequency allocations in the VHF maritime mobile band which will need to await decision making at WRC-23 and WRC-27 (see above). Conversely, should a general purpose digital radio communication technology ***not*** require a RR App. 18 VHF frequency allocation by using different already internationally allocated frequencies, this may alleviate the concern expressed above regarding congestion of analogue voice channels ([IMO-NCSR 9/24], para. 12.6.1) ***and*** *may even prove to be the* ***only*** *option for a* ***viable*** *migration path from analogue to digital voice communication, because* ***sufficient*** *analogue voice communications in the VHF maritime mobile service band* ***must*** *be maintained for a* ***long*** *transition period* ***even after*** *the introduction of the then selected general purpose digital radio communication technology.*

4.2.5.6.3.1 CDLMR family usage considerations in the maritime domain

The CDLMR family was generally introduced in a section above. Out of this family of technologies, the *dPMR technology* was introduced for consideration in the maritime domain recently: Trials on the dPMR technology usage performed in the port of Rotterdam were brought to the attention of IMO NCSR by IALA [IMO-NCSR9-INF.12]. Also, both the capability to operate in the VHF maritime mobile service band as well as the need of the dPMR technology for such frequency allocations were recognised by IMO-NCSR9, being informed by their *Joint IMO/ITU Experts Group on Maritime Radiocommunication Matters* in this regards.[36] However, *IMO did not arrive at any conclusion regarding usage of CDLMR family, yet.*

4.2.5.6.3.2 IMT-2020 usage considerations in the maritime domain

Already earlier than CDLMR, the adaptation of IMT family technologies was introduced to IMO similarly: IALA informed IMO NCSR about the role, standardisation activities regarding the adaptation of IMT family systems to the maritime domain by 3GPP and about trials being conducted in several parts of the world in 2019 [IMO NCSR 7/INF.6]. The Republic of Korea informed IMO NCSR in 2022 about the 'ongoing status of using IMT technology for providing e-navigation services in the near coast of the country' [IMO NCSR 9/INF.15]. Also, the Joint IMO/ITU Experts Group indicated their initial consideration of 'Developments on

[35] In addition, it may be expected, that general purpose digital radio communication technologies may be proliferated to additional application domains, once introduced.

[36] 'The Group noted the comments made by some delegations concerning the digitalization of voice communication in the VHF maritime band, which was included in the preliminary agenda of WRC-27, expressing the view that IMO would need to give careful consideration to this subject taking into account all implications for its use in the maritime domain. In this connection, the Group noted that CEPT had published ECC Report 329 on "Implementation of digital voice radio telephony in the VHF maritime mobile band" in October 2021' ([IMO-NCSR 9/12], para. 9.3).

International Mobile Telecommunication (IMT).[37] While it is recognised that the IMT family technologies operate on their own frequency band allocations and thus would not require the allocation of any in the VHF maritime mobile frequency band, similarly to the CDLMR considerations above, *IMO did not arrive at any conclusion regarding usage of IMT-2020 (or any other system of the IMT family), yet*

4.2.5.7 Potential adaptation of general purpose digital radio communication technologies towards the IWT fairway & navigation domain

Table 21 shows a summary of the above introductions. From that overview, the conclusion can be drawn that all modes of transport at least started to consider the introduction of general purpose digital radio communication technologies to their domain. It is reiterated that the focus here is on vehicle navigation (safety) or for vehicle traffic management, not on e.g. passenger services or field infrastructure monitoring.

Technology	Road / ITS	Rail	Maritime
GSM	**X (GSM for emergency notifications)**	**X (GSM-R)**	**-**
IMT-2020	**D / X**	**D (FRCMS)**	**C**
CDLMR family	**X (several)**	**X (TETRA)**	**C (dPMR)**
Legend: (X) Existing implementation, (D) decision for implementation taken, (C) Consideration of introduction hast started.			

Table 21: Comparison of the status of the general-purpose digital radio communication technologies

When considering a potential adaptation to the IWT fairway & navigation, the question would be, whether any of the mode specific derivatives may be used for further adaptation to the IWT fairway & navigation domain, or whether the latter would need to be derived from the generic definitions of the general-purpose digital radio communication technology families. This question is discussed as follows.

4.2.5.7.1 Cellular general-purpose digital radio communication technologies – IMT-2020

All modes of transport at least have started to consider the potential introduction of a mode-specific derivative of the terrestrial component of IMT-2020 to their respective mode (compare Figure 34). There are certain specific differences between the wet domains to be considered when assessing the wet-to-wet adaptability: As opposed to the maritime domain, the IWT fairway & navigation domain does *not* have a sea area coverage issue, since all waterways are 'under land' and also in very close proximity. This advantage is replaced by a coverage issue due to the linear structure of inland waterways: How many stations dedicated to the inland waterway coverage and therefore in addition to the already existing IMT-2020 network for land users would be required to cover the relevant parts of the inland waterway network? As land coverage will improve in the near future as announced in some countries, potentially not that many. But this is a deployment planning issue, anyway (not a technology-capability issue).

[37] 'The Group noted the information provided by IALA (…), containing an update on IALA's considerations with respect to the developments on IMT systems, previously updated as 3GPP, in the maritime domains. While recognizing the increasing use of 5G in all aspects of life, some delegations raised questions concerning the capabilities of 5G technology for maritime use, including its range, safety measures and potential applications, indicating also that caution was necessary when considering the potential use of IMT systems in the maritime domain. The Group noted that Member States conducting tests and experiments for use of IMT systems in the maritime domain could share their findings in due course' ([IMO-NCSR 9/12], paragraphs 9.1+9.2).

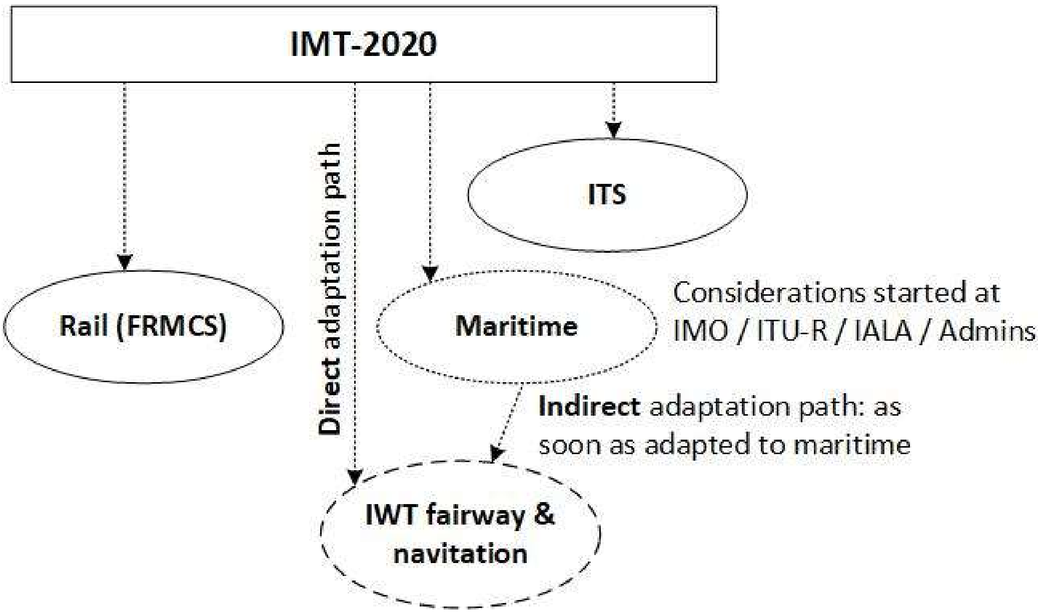

Figure 34: Transport mode derivatives of IMT-2020 and potential adaptation routes

The assessment results are given Table 22.

DIWA assessment metrics	Assessment results
DIWA-TRL	**8** (Initial market introduction) **7** (Pilot production demonstrated) **Note:** Considering present maritime developments, including imminent 3GPP standardisation release R17 and maritime trials are under way using commercial Off-the-Shelf (land mobile) products.
DIWA-Adaptability	**++** (Seamless adaptability when wet-to-wet adaptation route with Off-the-Shelf products.)
DIWA-Adaptation Demands	**++** (Little adaptation resource/time demands wet-to-wet)
DIWA-Technology Radar	**2027-2032**, taking into account that all frequency allocations are already in place, the imminent 3GPP standardisation release R17 (incl. 'wet application' of IMT-2020), pilots in IWT, and planning for deployment in DIWA area only (as opposed to world fleet at IMO.), i.e. ahead of maritime. '**Future Box**', if IMO introduction to be awaited prior to introduction to IWT fairway & navigation.
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain) Note: The specific adaptation avenue is irrelevant in this regard.

Table 22: Assessment results for a wet-to-wet adaptation of IMT-2020

Recommendations from the above are derived as given in the Annex under *REC-IMT-2020.*

4.2.5.7.2 Conventional Digital Land Mobile Radio communication technologies

At least two modes of transport have started to consider or use the potential of a CDLMR technology family member. This is illustrated in Figure 35. This figure introduces two different adaptation routes:

- *Dry-to-wet(IWT) avenue with ATIS identification:* Direct adaptation of a CDMLR family system to the European IWT fairway & navigation domain would first require the region-wide allocation of RR App. 18 VHF frequencies for use by that system in the European IWT fairway & navigation region (ahead or independent of maritime and/or the ITU WRC decision). This appears to be possible in theory but unlikely to happen. Secondly, the IWT-CDMLR-derivative would need to undergo successful pilot demonstration in the IWT fairway & navigation domain.
- *Dry-to-wet(maritime)-to-wet(IWT):* This indirect adaptation of a CDMLR family system via the maritime domain would require the global allocation of RR App. 18 VHF frequencies by ITU WRC27, development of a maritime CDMLR-derivative to be adopted by IMO for use as an alternative to analogue VHF voice communications only after successful maritime pilot demonstra-

tion, consecutive adaptation of the maritime CDMLR-derivative to the IWT fairway & navigation domain and including successful IWT pilot demonstration.

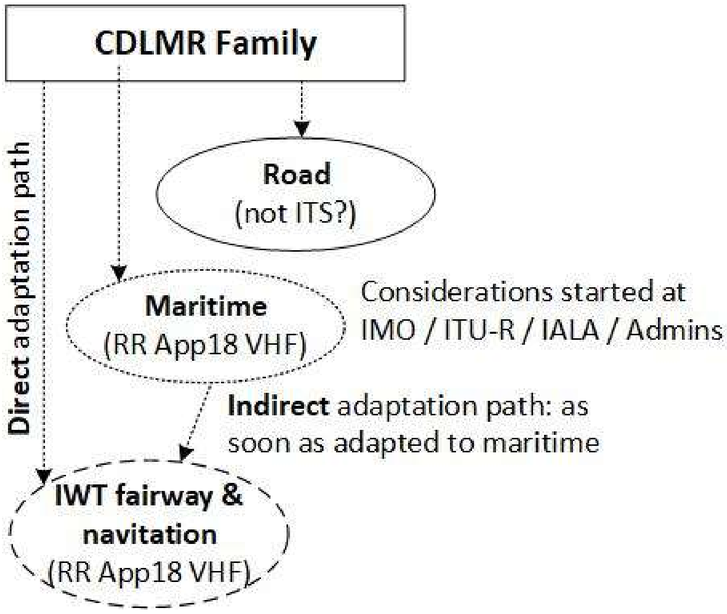

Figure 35: Transport mode derivatives of CDMLR family and potential adaptation routes

For any IWT CDLMR derivative, the integration of an ATIS identification into the CDMLR radio protocol would be required as long as this is maintained by RAINWAT [RAINWAT 2016]. Coverage of the whole extent of inland waterway by CDLMR base station network would be required, if no CDLMR public base station network can be used (which does not seem to be the case). But this is a deployment planning issue, again, not a technology-capability issue.

Assessment of CDLMR family adapted to the IWT fairway & navigation domain on the two different avenues are given in Table 23.

DIWA assessment metrics	Assessment results
DIWA-TRL	**7** (Pilot production demonstrated) for Dry-to-Wet adaptation avenue + **5-7** for Dry-to-Wet(Maritime)-to-Wet(IWT) adaptation avenue.
DIWA-Adaptability	+ (Adaptability with minor modifications) for both adaptation avenues likewise (optimistic)
DIWA-Adaptation Demands	+ (Intermediate adaptation resource/time demands) for both adaptation avenues likewise (optimistic)
DIWA-Technology Radar	**2027-2032** (Dry-to-Wet adaptation avenue; optimistic assessment) **'Future Box'** (Dry-to-Wet(Maritime)-to-Wet(IWT) adaptation avenue)
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain). Note: The specific adaptation avenue is irrelevant in this regard.

Table 23: Assessment results for the adaptation of a CDLMR family system

Recommendations from the above discussion are given in the Annex under *REC-CDLMR*.

4.2.5.7.3 Need to determine the optimum future digital technology setup for voice and data

From the above considerations of physical link technologies it became clear that it is not possible within the scope of the present study and report, to recommend in any definitive way one or another of the CTs for introduction to the IWT fairway & navigation domain immediately. Rather substantial further studies are needed. This is due to the following reasons:

- Due to the advent of general purpose digital radio communication technologies in the wet domain, this implies that there is *an increasing need to justify mode's specialties as such and a large variety of those even more so;* but there are or may be good justifications which need to be clearly indicated, i.e. no single technology can satisfy all requirements.

- While it appears to be certain, that a consolidated AIS would be required also for the long run in the IWT fairway & navigation domain, the above caveat applies in particular to the potential adaptation of the VDES and its consecutive introduction to the IWT fairway & navigation domain.
- But even amongst the two general purpose digital radio communication technology families, there has emerged *a competition in the maritime domain, namely between IMT-2020 and the CDLMR family, while 'dry' modes of transport apparently have opted for building their future needs on a mode-specific adaption of IMT-2020 each*.
- The versatility by design of IMT-2020 for seamless integration of a diverse range of use cases in combination with unprecedented core net functionality *appears to tentatively render IMT-2020 superior to the CDMLR family*, however.

It is therefore required to consider a 'useful combination' of digital radio communication technologies. This is done to some extent in the following chapter on useful combinations when considering *the future optimum IWT Fairway & Navigation HetNet*.

4.2.6 Physical links using light – High bandwidth Visual Light Communications

Recently, ITU has conducted a survey on the emerging technology enabling 'short distance broadband communication via visible light' ([ITU-R REP SM2422-1], para. 5), which precisely expresses the idea. This is labelled '(near) visible light communication (VLC)' or alternatively 'Optical Wireless Communication' ([ITU-R REP SM2422-1], para. 1). After a short history section,[38] the latest developments regarding modulation of light for establishing high-bandwidth physical links are introduced there: 'Visible light optical wireless access data rates ranging from a few b/s to excess of 10 Gbit/s are possible at standard indoor illumination levels. VLC has the potential capability to ease congestion with low radio frequency (RF) spectrum bands since light spectrum can be used as an additional spectrum resource for broadband communications.' ([ITU-R REP SM2422-1], para. 3.1). Use cases of relevance here are identified as follows ([ITU-R REP SM2422-1], para. 3.4), most of which are self-explanatory:

- *'Location-based services / indoor positioning and navigation'* - VLC would be an option to support PNT.
- *'Vehicular communications'* and *'Point-to-(multi)point/relay/communications'* – this implies both V2V as V2I options.
- *'LED based tag applications'* – when either a vessel carries such a tag it can be detected as 'being there' (by another vessel or by an infrastructure sensor) or vice versa when an infrastructure position can be detected as 'being there' by a vessel, this may offer interesting options for in particular the automation of inland waterways. Slightly more specifically but still relevant would be the use case: *'Digital signage and location based content delivery'*.
- *'In-Vehicle data services (flight, train, ship, bus, etc.)'* – there may be options for local VLC link e.g. in the wheelhouse.
- *''Connected-cars and Autonomous Vehicles'*
- *''Underwater/Seaside Communications'*
- *'Internet of Things (IoT)'*.

Hence, wherever data must be exchanged in short distances in spot-like situations between a fixed and a moving position, which is often the case in the IWT fairway & navigation domain, VLC may offer an emerging solution, even it is only 'one bit' – namely the detection of presence of an (expected) object. It would thus support the notion of the IWT Infrastructure Site Architecture.[39] But also, vessel to vessel data exchange at short distances might be an option specifically in the IWT fairway & navigation domain with its regularly close encounters. Finally, the motivation to shift communications from a radio link to a visual link may be helpful also for IWT fairway & navigation domain in the light of the congestion of the VHF Maritime Mobile Service frequency band (RR App. 18) as discussed above. For the application in the outdoor domain, the requirements to be met by any VLC application are given as 'coexistence with ambient light [and] coexistence with other lighting systems' ([ITU-R REP SM2422-1], para. 3.4).

[38] That rightly recognises that communication by (digital) light signals with the human eye as recipient has a very long history, which is true also in the Aids-to-Navigation domain.

[39] Compare the following chapter where a sketch of an integration of VLC is presented.

Co-funded by the European Union

Since a number of products and application domain projects employing VLC are given world-wide ([ITU-R REP SM2422-1], para. 5.4), including EU-partly funded research projects, and standardisation is under way already, it may be assumed that the VLC technology as such reaches the 'Testing prototype in user environment' stage when considering a potential adaptation to the IWT fairway & navigation domain. This implies also, that existing VLC modules may be applied to the IWT fairway & navigation domain readily. The assessment for adapting the use of VLC to IWT fairway & navigation domain is given in Table 24.

DIWA assessment metrics	Assessment results
DIWA-TRL	5 (Prototyping & Incubation – testing prototype in user environment)
DIWA-Adaptability	+ (Adaptable with minor modifications)
DIWA-Adaptation Demands	+ (Intermediate adaptation resource/time demands)
DIWA-Technology Radar	2027-2032 (optimistic) 'Future Box' (conservative)
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain)

Table 24: Assessment of the adaptability of Visual Light Communication to the IWT Fairway & Navigation domain

Recommendations from the above discussion are given in the Annex under *REC-VLC.*

4.3 Sensor technologies (other than radio navigation)

The place of the sensor technologies in the context of the overarching IWT fairway & navigation architecture is indicated in Figure 36 overleaf.[40] In addition, the sensor technologies populate

- the *Sensor / Source Layer* of the Inland-SSSA for the shipboard side, and
- the various *Data Collection and Data Transfer services* of the Inland-CSSA.

This functional technology family can be further subdivided as follows:

- co-operative position determination sensors, including radio navigation and the balise architecture (both covered already above);
- non-cooperative sensor technologies for position determination[41] and for other sensor data; and
- co-operative sensor technologies other than position determination sensors.

Co-operative sensor technologies other than position determination sensors are employed in the different modes of transport for a large variety of relevant sensor data objects. Co-operative sensor technologies all use *functional links* (which in turn use physical links) as their functional basis.

'Sensor' also has acquired *a broader sense* of the term in other modes, when not being confined to a single device. For example, co-operative 'collision detection sensors' determine the imminent risk of a collision *by automatically creating an alert or even a command to the superior technical functionality or to a human user* (as opposed to just non-cooperatively determine the position(s) of other vehicles). These co-operative collision detection sensors thus support the navigational task of collision avoidance *directly* (as opposed to run-time post-processing of determined position data of potentially conflicting vehicles by a superior technical functionality or the human user even).

[40] This context designation holds true for all sensor technologies, including radio navigation technologies.

[41] The common feature of non-cooperative position determination sensors is, that they don't rely on a technical system external to the own vessel or external to the own shore infrastructure. This, by very definition, excludes all radio navigation sensors. There is a substantial body of position determination technologies in different modes of transport described at ITU, most of which employ radar principle.

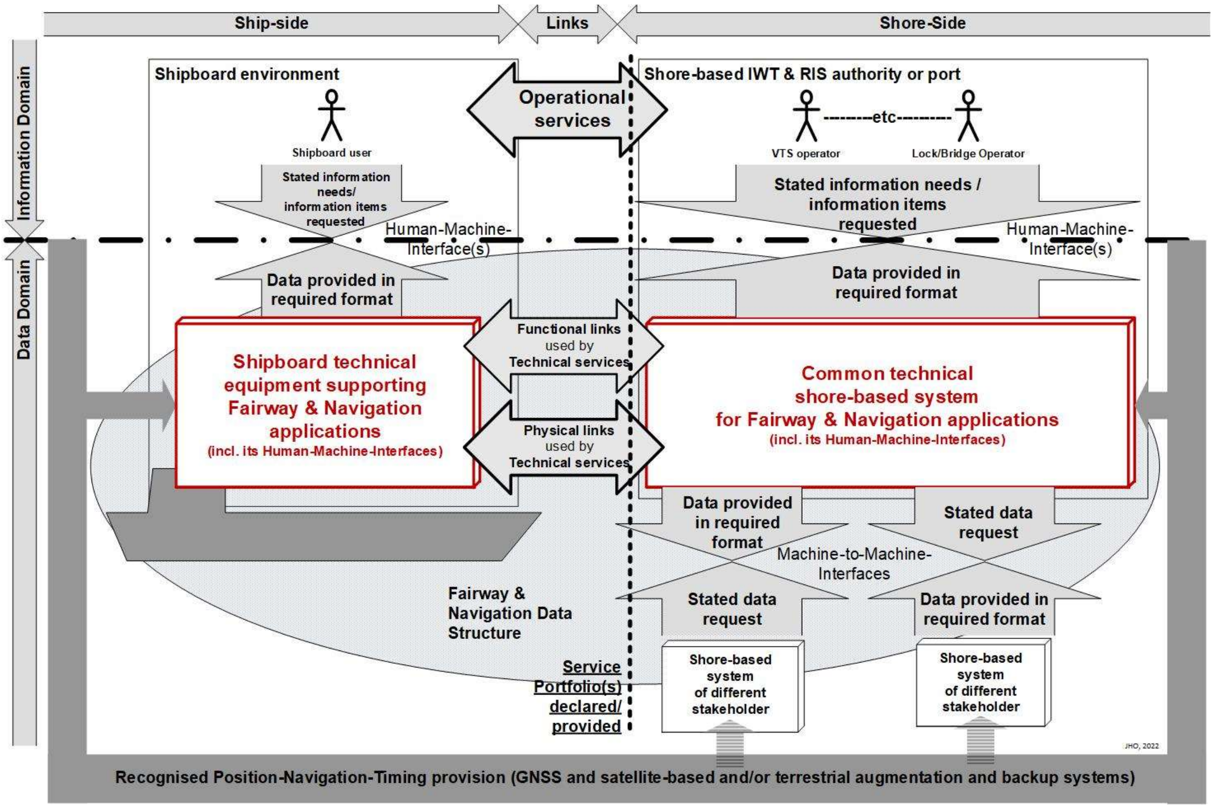

Figure 36: Overarching IWT Fairway & Navigation Architecture with entities highlighted that employ sensor technologies

Also, similar to the position determination using the various (recognised) external radio navigation systems, *external systems as a whole* can be construed as a co-operative sensor. For example, swarms of sensor-equipped vehicles or space-based sensor technologies may collect and provide relevant environmental or infrastructure-related data.[42]

Due to the reasons indicated in the introductory section to this chapter, the above aspects could only be indicated, and therefore no assessments were made. However, recommendations for further study of emerging sensor technologies are given in the Annex under *REC-Vessel-Swarm-Collection-Of-Data, REC-Earth-Exploration-Satellite-Technologies, REC-Space-Weather-Sensors,* and *REC-Plan-For-Emerging-Sensor-Technologies.*

Since the IWT Infrastructure Site Architecture introduced in Chapter 3 will certainly be a place for integration of some of the sensor technologies as part of a 'useful combination', additional recommendations will be given in Chapter 5.

4.4 Data modelling methods and technologies

4.4.1 Introduction

So far, CTs for establishing and exchanging relevant data have been considered. This section now turns towards methods and technologies of integrating that data into a consistent data model of the physical and operational environment of the other mode of traffic at hand.

In the Overarching IWT fairway & navigation architecture introduced above (Figure 18), this has been labelled quite generally as 'IWT Fairway & Navigation Data Structure', thus indicating that its scope content-wise may be as wide as all aspects related to the functional entities introduced in Figure 2.

[42] An application of Earth Exploration Satellite technologies is Space-Based Bathymetry, for example. Space Weather Sensors will be on the agenda of WRC27 ([ITU-WRC2019-Res-812], Agenda item 2.6).

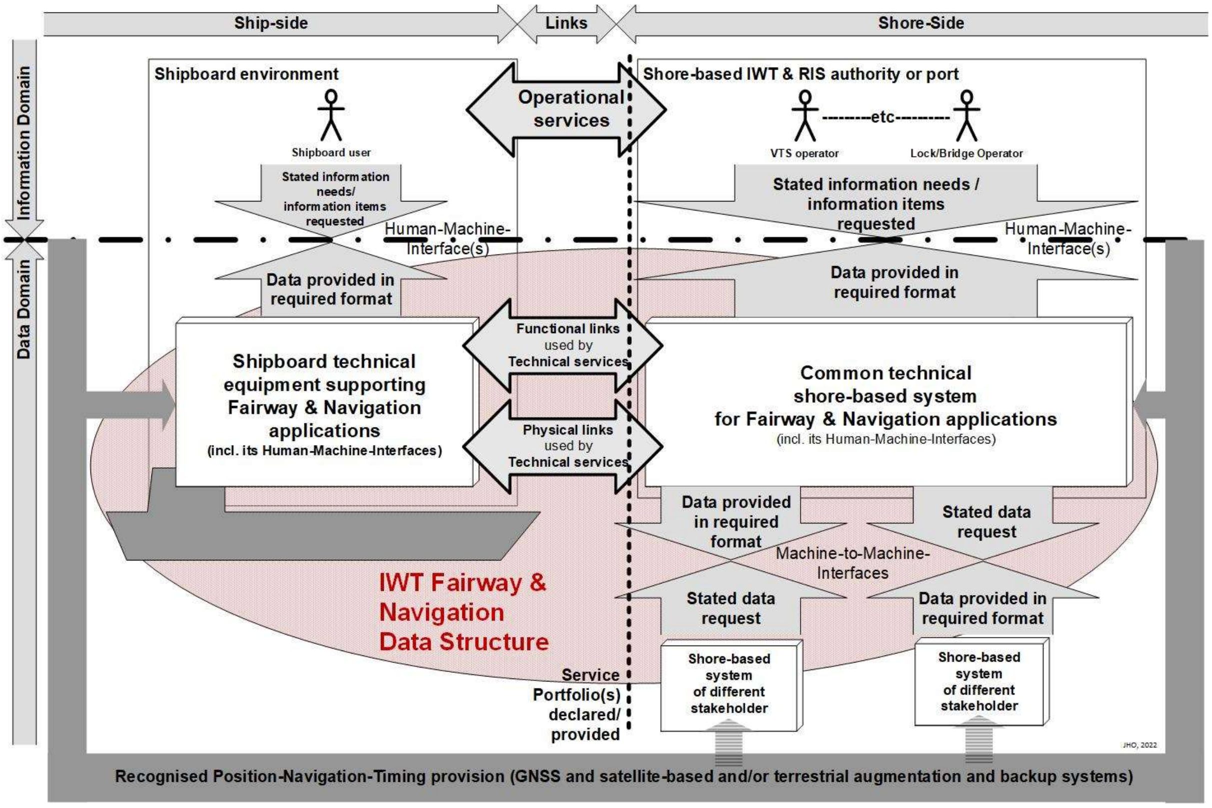

Figure 37: Overarching IWT Fairway & Navigation Architecture with IWT Fairway & Navigation Data Structure highlighted as affecting all data domain entities

Figure 37 highlighted the IWT Fairway & Navigation Data Structure and illustrates its context: *Ideally, all functional entities tap into the same, comprehensively and unambiguously defined data structure* – hence the extension of the highlighted oval from shipboard via the links to the shore side, including data interfaces to various other shore-based stakeholders and also the PNT bracket.

While all different modes of transport have used – presumably latest – generic data modelling methods and technologies to perform that task for their mode, an inventory of these generic concepts as such would be beyond the scope of the present Sub-Activity. When looking at results of data modelling methods and technologies employed by different modes, however, it is again both possible and necessary to confine the description in this section to the mode with the closest proximity to the IWT fairway & navigation domain, i.e. to the maritime domain.

4.4.2 Data modelling and use case definitions at IMO SN.1/Circ.289

The prime CT to be considered are the *International Application Specific Messages* as defined by IMO originally for transmission by the AIS as a physical link and to be legally used since 2013 [IMO-SN.1/Circ.289]. They essentially are topical data containers for vessel navigation. *Using any of those topical data container within even only one application renders this application a use case of that topical data container; hence, the IMO defined international ASM constitute internationally harmonised use cases 'in disguise'.*

In addition, as demonstrated in a previous section, ASM can be used carrier-agnostically; this holds true even if AIS would become the carrier as originally intended. Here, the international ASM definitions are considered when used carrier agnostically, and also the discussion of potential applications to the IWT fairway & navigation domain will only focus *on their characteristics as topical data containers.*

IMO has internationally defined the following topical ASM (order of appearance by topical domains):[43]

[43] Summaries are given for those topical data sets that are not quite self-explanatory by their names. Neither apparently self-explanatory names nor summaries given should prevent the reader from the consulting [IMO-SN.1/Circ.289] directly, because there has been defined data objects relevant for a surprisingly large number of potential use cases.

- *'Meteorological and Hydrographic data'*
- *'Environmental':* This versatile message allows for transmission of the following different sensor data sets on sensor site and ID itself, wind, water level, current flow (2D), current flow (3D), horizontal current flow, sea state, salinity, weather, and air gap/air draft. The different sensor data sets can be transmitted in any order, selection, and frequency as deemed appropriate.
- *'Weather observation report from ship'*
- *'Extended ship static and voyage-related data'*
- *'Dangerous cargo indication'*
- *'Number of persons on board'*
- *'VTS-generated/synthetic targets':* This data container allows for the transmission of navigation data on behalf of traffic objects not transmitting this data by themselves,
- *'Clearance time to enter port'*
- *'Marine traffic signal':* Provide traffic signal data set in accordance with the respective IALA traffic signal definitions.
- *'Berthing data'*
- *'Area notice – broadcast / addressed':* This data container allows to exchange 'dynamic information concerning a specified geographic area, polyline or positions. It should be only used to convey pertinent time-critical navigation safety information'([IMO-SN.1/Circ.289), para. 11.1).
- *'Route information – broadcast / addressed'*
- *'Text description – broadcast / addressed':* data container allows transmission of free text.

Within [IMO-SN.1/Circ.289] substantial definition work on various topical data containers has thus been provided by IMO and other participating international organisations – *ready to use: in maritime and in the IWT fairway & navigation domain*. When considering the potential adaptation of the above topical data containers to the IWT fairway & navigation domain the following options can be identified:

- The above topical data containers appear to be relevant for the IWT fairway & navigation domain, too, except some very few such as ocean weather conditions. This holds true in particular for those addressing also the logistics interface. Hence, wet-to-wet adaptation appears to be not only feasible but also attractive to salvage the definition work done.
- Usage stipulations given by IMO for the maritime domain in addition to the definition of the topical data containers may *not* be relevant for the IWT fairway & navigation domain, however. They can be replaced by IWT tailored ones. This applies in particular to the direction of transmission – all topical data containers can be transmitted bi-directionally in principle.

The assessment for adapting IMO-defined ASM for carrier agnostic use to IWT fairway & navigation domain is given in Table 25.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion)
DIWA-Adaptability	++ (Seamless Adaptability)
DIWA-Adaptation Demands	++ (Little adaptation resource/time demands)
DIWA-Technology Radar	2022-2026 (optimistic) 2027-2032 (conservative)
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain) Note: IDL III would consider this as a given.

Table 25: Assessment of the adaptability of the IMO-ASM for carrier agnostic use

It should be noted, that the existing IMO ASM circular covers topics also included in the younger S-421 standard for data transmission on route exchange (see discussion below), but has a wider topical scope

Recommendations are given in the Annex under *REC-Carrier-Agnostic-Use-Of-ASM*.

4.4.3 Data model for voicelesser communication using NDLC

The NDLC architecture was introduced in Chapter 3 indicating its potential to move operational communication safely from the voice domain to datalink domain, thus rendering a voiceless<u>er</u> IWT fairway & navigation domain; in a previous section the understanding of the NDLC as a functional link technology was introduced. Turning now to the contents of that NDLC based communication, it may be safely assumed, that there are today many operational phrases routinely used in day-to-day voice communications in operational relationships in the IWT fairway & navigation domain, in particular between a centre and vessels, even if they have never been collected systematically. Should there be no such *collection* in the IWT fairway & navigation domain, its establishment would be required as a **first step**.[44] As a **second step**, the *operational contexts* of the phrases identified need to be established, i.e. which functional entities are involved in what operational relationships.[45] In a **third step** the *operational concepts* expressed by the operational phrases in them are described in a *structured data model* which conforms to the demands of consecutive encoding. In a **final step**, based on the structured data model, the relevant operational phrases need to be *encoded in messages for NDLC functional link transmission*. The development of a data model for voicelesser communication in the IWT fairway & navigation domain using NDLC following these example of other modes is assessed in Table 26.

<u>DIWA assessment metrics</u>	<u>Assessment results</u>
DIWA-TRL	3 (Concept Validation – first assessment feasibility)
DIWA-Adaptability	- (Adaptable by redesign in analogy)
DIWA-Adaptation Demands	- (High adaptation resource demand)
DIWA-Technology Radar	'Future Box' (due to low DIWA-TRL)
DIWA-IDL Impact	III (Intelligent IWT fairway & navigation domain: Automated response to standard situations; maybe even only by this approach as far as communication is involved)

Table 26: Assessment of the data model for voicelesser communication using NDLC

Rrecommendations from the above discussion are given in the Annex under *REC-Data-Model-For-Voicelesser-IWT.*

4.4.4 The impact of a transition to the 'S-100 World'

The IHO-lead development of the 'S-100 World' can be construed as the maritime application of the philosophy of the ISO 19100 series – being the generic data modelling method and technology - to the maritime domain. ***It is important to note,*** *that the 'S-100' is not confined to 'another version of an electronic navigational chart',* and thus consequently any adaptation of the 'S-100' to the IWT fairway & navigation domain would also not be confined to the import of just 'another version of an Inland-ENC or Inland-ECDIS'. While it is true, that 'S-100' contains *as its functional core* indeed 'another version of an electronic navigational chart', *'S-100' in fact identifies itself as 'Universal Hydrographic Data Model' (i.e. the very title of [IHO S-100]) and thus as a framework capable of incorporation of all data entities associated with the wet domain. It thus represents a paradigm.*[46] *It is thus important to note, that the introduction of 'S-100' into any of the wet modes of transport would constitute a* ***paradigm shift.*** DIWA Sub-Activity 2.5 has already recognised this, when recommending as a result of their study in particular: 'Investigate the principles and *governance* of the S-100 world as a *baseline* within the overarching architecture of RIS.' (REC11; compare introduction above; emphasis added). The present study and report complements the study of Sub-Activity 2.5 by highlighting some relevant technological developments in the context of 'S-

[44] *Potentially learning from maritime:* In the maritime domain, IMO has collected and published the 'Standard Marine Communication Phrases (SMCP)' [IMO-A918(22)]. There are available translations into other languages than English, e.g. a German translation.

[45] *Potentially learning from rail:* As a preparation to their adaptation of a general purpose digital radio communication system and as a starting point for determining their user requirements, the operational contexts of any and all communication was established (compare [UIC-FRMCS-FU7100], Figure 1 *'Application Layer Relationship Diagram'* in just one page).

[46] An illustration of the IHO envisaged 'S-100 World' is accessible at http://s100.iho.int/home/s100-introduction, which has no aspiration to represent the complete 'S-100 World' presently under development by a variety of international organisations in the maritime domain. A recent introduction from a hydrographic office's point of view to the envisaged 'S-100 World' in the context of e-navigation is [Schröder-Fürstenberg 2021].

100' and also inform about the latest developments. This is done by introducing and assessing two CTs at the maritime domain, namely the maritime transition to S-100 paradigm at large and the new S-421 standard on route related data exchange vessel-shore/shore-vessel *as a mature example* of emerging standards populating the 'S-100 World'.

4.4.5 Transition to the 'S-100 World'

4.4.5.1 Recent IMO decision making regarding a S-100 based ECDIS

The global maritime domain seems to be gradually accepting that *imminent paradigm shift:* During the study period of the present Sub-Activity, IMO NCSR discussed the transition to an S-100 based ECDIS [IMO-NCSR-9/24] under the agenda item of the revision of the IMO Performance Standards for ECDIS [IMO-MSC-Res 232]. This would be the first revision of the ECDIS PS since almost 20 years. As invited by the agenda item, the IHO, the shipping industry organisation INTERTANKO, and the international maritime shipping navigational equipment manufacturer organisation CIRM jointly submitted a draft revision of ECDIS that addresses the intended transition to the S-100 paradigm in no imprecise terms as follows:

> 'IHO's currently most relevant ECDIS-related standard is the transfer standard for digital hydrographic content S-57. This standard has been used for the production of official ENCs *since November 2000 and has not been technically updated since then*. This period of consolidation has facilitated a stable technical environment for data production and dissemination services to reliably feed ECDIS installations delivered by a variety of Original Equipment Manufacturers (OEM) in compliance with the applicable IMO regulations on ECDIS. However, *in the context of e-navigation and digitalization, there is now a need for upgraded technology.*
>
> *In support of improving digitization on board, the exchange of nautical information and the provision of maritime services in the context of e-navigation,* IHO's S-100 Universal Hydrographic Data Model was adopted by IMO in 2011 as the basis for technical harmonization of data services providing navigation related information exchange. S-100 is a contemporary, more versatile standard – it also incorporates the required elements of S-57 and is aligned with the ISO 19100 series of geographic information standards.
>
> *S-100 is the basis upon which a wider range of digital products and transfer standards for hydrographic and maritime services related applications are based.* The e-navigation Strategy Implementation Plan (SIP) (MSC.1/Circ.1595) requires that Maritime Services should be S-100 conformant as a baseline. Several of the Maritime Services proposed in the SIP[47] will be dependent on product specifications being developed by IHO within the S-100 standard. Under the IHO domain *high-density depth information in a 3D format, real time hydrographical information such as water level and surface currents, maritime safety information (MSI) in ECDIS and sailing direction information could together contribute to high precision Under Keel Clearance (UKC) calculations for improved safety, maximized loading and route optimization*. S-100 is also an important step towards *usage of machine-readable data for future MASS applications.*[48] These additional services and others, actually at the implementation stage, must be able to function in interoperability with a modernized version of the current ENCs.
>
> *The S-100 framework has matured to an extent that the regular production and dissemination of official ENCs in a new transfer standard, named IHO S-101, can now be envisioned.* This new transfer standard is not substantially different from IHO S-57 in terms of cartographic content and maintains the same level in support for safe navigation, but it offers additional, substantial advantages:
>
> > (1) the operational elements of ECDIS software to process cartographic content can be more easily maintained since the display instructions are embedded in the dataset as part of the S-101 ENC delivery;
> >
> > (2) S-101 ENCs enjoy a modernized method of encryption to improve robustness against cyber threats;

[47] Compare [IMO-MSC-Res-467] and [IMO-MSC.1/Circ.1610] (Note by the present author).

[48] Maritime Autonomous Surface Ships (MASS) is IMO's designation for AVs. For an introduction to the status of IMO's work on AVs compare [DIWA Sub-Activity3.5 2022a] (Note by the present author).

> (3) the implementation of the capability to read and process S-101 ENCs, including the new encryption mechanism, offers the technical basis for future implementation of e-navigation services relevant to ECDIS; and
>
> (4) interoperability with other additional S-100 products, to meet future Maritime Services in accordance with the e-navigation SIP.
>
> IHO has collaborated closely with the industry in the development of data production and encryption software ready to support safe and continuous production and dissemination of S-101 ENCs. IHO Member States have started work on a harmonized approach to enable ENC producing hydrographic offices to provide S-101 ENCs for their respective areas of responsibility, in parallel to the established production of S-57 ENCs. S-101 ENC distribution will happen via the established dissemination network in partnership with commercial chart suppliers. *The enhancement of ECDIS functionality to include S-101 ENCs as a mandated transfer standard is a logical and necessary step towards the implementation of the e-navigation concept of harmonized Maritime Services.'* ([IMO-NCSR9/16/1], paragraphs 3-7, emphasis added).

Based on that rationale, the submission states as a goal *'to make S-101 ENC compatibility legally binding for new ECDIS* (…) [by including] references to the Product Specification for S-101 ENCs and the underlying S-100 framework' ([IMO-NCSR9/16/1], paragraph 1, emphasis added) and continues to consider the necessary migration path as follows: 'In order to maintain ECDIS devices already installed on SOLAS ships, which are technically not ready nor required to be upgraded to S-101 ENC compatibility, and to comply with the applicable IMO regulations pertaining to existing navigation equipment, IHO is committed to ensuring that identical geographic coverage will be provided for S-57 ENCs and S- 101 ENCs for a transition period until there is no significant number of legacy (S-57 based) systems in use at sea and all ECDIS in operation have become S-101 ENC compatible. During the transition period, IHO will keep on with the full technical support of both S-57 ENC and S- 101 ENC formats.' ([IMO-NCSR9/16/1], para. 2).

To support this, in the IHO *proposed* revised ECDIS incorporated specific new shipboard entities and references to specific standards as follows:

- Introduction of a new shipboard database, called *'Electronic Navigation Data Service (ENDS)'*, that is ' a special-purpose database *compiled from nautical chart and nautical publication data,* standardized as to content, structure and format, issued for use with ECDIS by or on the authority of a Government, authorized hydrographic office or other relevant government institution, and conforming to IHO standards; and, which is designed to meet the requirement of marine navigation and the nautical charts and nautical publications carriage requirements (…). The navigational base layer of ENDS is the electronic navigational chart (ENC)' (quoted from NCSR accepted version ([IMO-NCSR9/24], Annex 24, para. 3.3) which is identical to the proposal).
- Specific *new capabilities regarding route plans*: 'It should be possible to exchange, send and receive, both selected and alternative route plans with actors outside of the own ship. The exchange should be in accordance with *standard formats for route plan exchange (IEC 61174 / IEC 63173-1)* and use standard service interfaces including *information security protection (IEC 63173-2) to allow for secure machine-machine communication.* The use of the received route plans should be controlled by the mariner. The exchanged route plan should include a *route schedule including estimated time of departure and estimated time of arrival* as soon as they can be determined with reasonable accuracy' ([IMO-NCSR9/16/1], Annex, para. 11.3.4 – 11.3.5, emphasis added). Thus the proposal was specifically referencing the *S-421 route exchange* data definitions (to be introduced below) as well as the *SECOM protocol* introduced above as the exclusive[49] means for (secure) ECDIS related data exchange.
- Specific references to BAM throughout as stipulated by [IMO-MSC-Res-302].

There were no opposing submissions. Some supportive submissions went on even further to request incorporation of following items:

- *A mandatory electronic connection between the shipboard AIS equipment and the new ECDIS* which in turn would provide *additional access to the S-100 world* as indicated as follows:

  'Canada believes that the ECDIS must be connected with an Automatic Identification System (AIS) to enable the full capability of the S-100 series of products. AIS Application Specific Mes-

[49] This is the reading implied by a specific standard referenced.

sages (ASM) is an essential conduit for observations and broadcasting of information in real-time that works in collaboration with the S-100 series of products. Without a proper connection, mariners will not be able to benefit fully from the following specifications:

(1) S-101 Electronic Navigational Chart (ENC) which contains information on AIS AtoN for route planning and monitoring;

(2) S-102 Bathymetric Surface and S-104 Water Level Information for Surface Navigation which are expected to provide real-time water level and assist with ascertaining the air gap under bridges and overhead cables;

(3) S-111 Surface Currents which provides surface current pattern situation; and

(4) S-125 Marine Navigational Services which is expected to provide a digital list of aids to navigation.' [NCSR9/16/4]

- China and CIRM suggested an '*internationally harmonized regulatory framework* (...) to enable onboard ECDIS to *demonstrate ongoing compliance* with the applicable standards following hardware and/or software updates' ([IMO-NCSR9-16-2], para. 4; compare [IMO-NCSR9-INF.14]; emphasis added).

During the discussions at IMO NCSR, despite concerns being expressed regarding some of the above items, IMO NCSR approved an amended draft revision ([IMO-NSCR 9/24], Annex 24) for (expected) adoption by IMO MSC (November 2022). While a detailed comparison between the ECDIS PS in force, the proposals and the IMO NCSR agreed version is beyond the scope of the present study and report, it can be concluded, that *the IMO NCSR agreed draft revision allows for the transition to the S-100 world without much advertising it*. It restricted itself rigidly to the functionality requirements while omitting being mandatory on the means (such as SECOM) to achieve them. The potential incorporation of the proposed new features regarding the 'standardized digital exchange of ships' route plans' was deferred depending on further decision making by IMO MSC ([IMO NCSR 9/24], Annex 24, Annex para. 21.4.3). Also, a transition time schedule was agreed tentatively, that would require all maritime ECDIS installations from 2029 onwards to conform to the new ECDIS PS, allowing for a choice between installing the new or the previous version based on [IMO-MSC-Res-232] between 2026 und 2028, while also providing protection for existing installations or installations up until 2026 ([IMO NCSR 9/24], Annex 24, para 2). Consequently, IHO and IEC have developed their plans accordingly to have the necessary documentation and – in the case of IEC – test standards in place before 2026.

4.4.5.2 Fundamental decision to transition to S-100 in the IWT fairway & navigation domain

The fundamental decision of the maritime domain to transition to S-100 as the (future) fundamental paradigm for data modelling with the same scope as the 'S-100 World' is assessed for its adaptability to the IWT fairway & navigation domain, as far as applicable, in Table 27.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (fully developed at IHO and IMO recognition of benefits in place)
DIWA-Adaptability	++ (Seamless Adaptability)
DIWA-Adaptation Demands	++ (Little adaptation resource/time demands)
DIWA-Technology Radar	2022-2026
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain) Note: IDL **III** would consider this as a given.

Table 27: Assessments of the fundamental decision to transition to S-100 'as a baseline' of the IWT fairway & navigation domain (as an agreed plan amongst all relevant stakeholders)

Note, that *this is **not** an assessment of any specific data product or standard of the S-100 world, in regard to their applicability to the IWT fairway & navigation domain.* They need to be individually assessed, which is outside the scope of the present study and report except for the one in the following section. What the above assessment means, is that ***it is considered possible to arrive at a 'baseline' decision as IMO did in 2011 in the IWT fairway & navigation domain very soon.*** Such a decision may – of course – propel also the development of IWT adapted versions of specific data products or standards, if at all necessary.

Recommendations are derived as given in the Annex under *REC-Imminent-Introduction-of-S100-World-Paradigm*, *REC-S101(ECDIS)-Introduction*, and *REC-S100-Metadata-Registry-Impact*.

4.4.6 EN IEC Standard 63173-1 (S-421) on Route Plan based on S-100

As a single example for a specific S-100 based product specification or standard, the S-421 on route and intention exchange will be introduced and assessed here. Major reasons for that are as follows:

- Several features of the S-421 are intended to be used for both strategic *and* tactical exchange of route and intention data exchange, up to real-time data exchange.
- While the IWT fairway & navigation domain may be restricted regarding the lateral tactical route alternatives compared to maritime, it may benefit from the IHO suggestion that, 'the exchanged route plan should include a route schedule including estimated time of departure and estimated time of arrival as soon as they can be determined with reasonable accuracy' ([IMO-NCSR9/16/1], Annex, para. 11.3.5), thus supporting synchromodality by providing the shipboard estimations.
- S-421 has been adopted in 2021 as an international standard by IEC, and *can* thus be used independently of any IMO decision.
- S-421 has even been adopted by CENELEC to the EU harmonised market in 2021 and thus *can* be used in that framework directly (compare IEC 63173-1 at [European Standards]).[50] It can thus *not* be ignored in the EU.

The S-421 essentially is a test standard, i.e. it prescribes in a normative way how tests of the system claimed to be compliant with the S-421 should be established, performed, and what the expected specific results of the system under test are, so that it may achieve type approval. *Since the exchange of route plans and associated features essentially is a 'data product',* the following need to be known in all detail needed for M2M communications prior to designing and/or testing such a system:

- the *technical* descriptions of the data objects involved, i.e. the data model of the route plan exchange functionality needs to be defined down to the feature catalogue level of the S-100 framework;
- the *technical* descriptions of the formats and mechanisms of the route plan data exchange; and
- the *operational* use cases describing the expected interactions between a shipboard system and a shore system when engaged in route plan exchange.

Since these relevant details have not been described in some other international document in a normative way, the S-421 has incorporated and thus defined all of these parts before even arriving at the test methods and expected results (as opposed to referencing other relevant documents). While this approach facilitates testing for type approval and also may contribute to the integrity of the intended data product, ***the operational use cases are also made normative*** *as a matter-of-fact, if and when the S-421 defined data product is employed in any M2M interaction between any S-421 compliant shipboard system and the peer shore system(s).*

Hence, *operational stipulations may be introduced in no imprecise terms by the 'back door' via a test standard* (as opposed to via a recognised and normative operational requirements document, for example). In order to assess whether this approach would be acceptable to stakeholders and regulators affected and the S-421 thus be employed consequentially, ***it is essential that they know the use cases and study their potential impact.*** The use case scenarios are given in the normative Annex A of S-421 as 'examples of use cases' as

- *'route cross check'* (between a vessel and 'a shore-based service provider (for example VTS center)' ([IEC 63173-1], A.2),
- traffic *'flow management'* ([IEC 63173-1], A.3),
- *'enhanced monitoring'* of a vessel's route by 'all interested parties which are allowed to have access [to] the ship's route plan' including 'VTS, fleet manager, insurance company, coastal surveillance, etc.' ([IEC 63173-1], A.4),
- *'ice navigation'* ([IEC 63173-1], A.5),
- *'under keel clearance management'* ([IEC 63173-1], A.6),

[50] It has even been translated into some European languages other than English, thus becoming DIN EN IEC 63173-1 in the case of German.

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- *'fleet route planning'* ([IEC 63173-1], A.7),
- *'chart management'* ([IEC 63173-1], A.8),
- *'route optimization'* ([IEC 63173-1], A.9),
- *'port call synchronization'* ([IEC 63173-1], A.10),
- *'offering reference routes'* ([IEC 63173-1], A.11), and
- *'search and rescue'* ([IEC 63173-1], A.12).

As part of the discussions at IMO NCSR9 on the transition to the 'S-100 World' in general as introduced above, it was stated, that the decision regarding the exchange of route plans based on S-100 was deferred until an IMO MSC decision was struck in this regards. In fact, this pending decision making process was initiated by EU member countries (Austria, Belgium, France, Germany, Netherlands et al), the EU Commission, and by the Republic of Korea, referencing specifically the S-421 under consideration here. It is specifically requested that 'standardized exchange of route plans' using S-421 should be introduced by IMO, either as part of the above revision of the ECDIS Performance Standards or as a standalone stipulation.

The rationale is summarised as follows: 'Several e-navigation projects have studied exchange of route plans. Its positive effects, namely increased safety, reduced administrative burden and more efficient operations, combined with reduced environmental impact, have been validated. An international standard format for route plan exchange has been developed and it is considered an appropriate next phase to also adapt the regulatory aspects to facilitate standardized exchange of route plans' [IMO-MSC-104/15/7].

It should be noted, that an IMO MSC decision to introduce the S-100 based ECDIS and the standardised exchange of route plans using S-421 jointly, as suggested by the outcome of NCSR, may accelerate the up-take of both.

While the EU lead initiative at IMO formally applies to the maritime domain, only, it may not be farfetched to suggest that the potential import of a standardised exchange of route plans using S-421 in the context of 'S-100 as a baseline' be considered by the IWT fairway & navigation domain, and potentially even be adopted in due course.

DIWA assessment metrics	Assessment results
DIWA-TRL	**8** (initial market introduction: standardised at IEC and introduced in EU harmonised market, pilot projects performed, and maritime introduction pending)
DIWA-Adaptability	**++** (Seamless Adaptability; for those IWT fairway & navigation applications virtually identical to maritime regarding their vessel's route and intention data exchange requirements); **+** (Adaptability with minor modifications, if 'IWT add-on' standard would be required.)
DIWA-Adaptation Demands	**+** (Intermediate adaptation resource/time demands; for creation of IWT fairway & navigation application)
DIWA-Technology Radar	**2022-2026** (immediate up-take), **2027-2032** (delay in up-take for whatever reason such as persistent reluctance to strike S-100 baseline decision)
DIWA-IDL Impact	**II** (Connected IWT fairway & navigation domain) Note: IDL **III** would consider this as a given.

Table 28: Assessments of the introduction of a standardised route exchange of route plans using S-421 in the context of an S-100-based ECDIS to IWT fairway & navigation

Recommendations are given in the Annex under *REC-Standardised-Route-Plan-Exchange-via-S421.*

4.4.7 Turning towards shore side - IALA's contributions to the 'S-100 World'

IALA – being the international organisation responsible for setting international standards and providing relevant recommendations and guidelines for Aids-to-Navigation and VTS provided to shipping from ashore – has adopted the above S-100 baseline decision of IMO in 2011 early on. Since then, IALA has started to develop its contributions to the 'S-100 World' by populating their S-200 document series, a sub-set of the S-100 data product specifications, as illustrated in Figure 38.

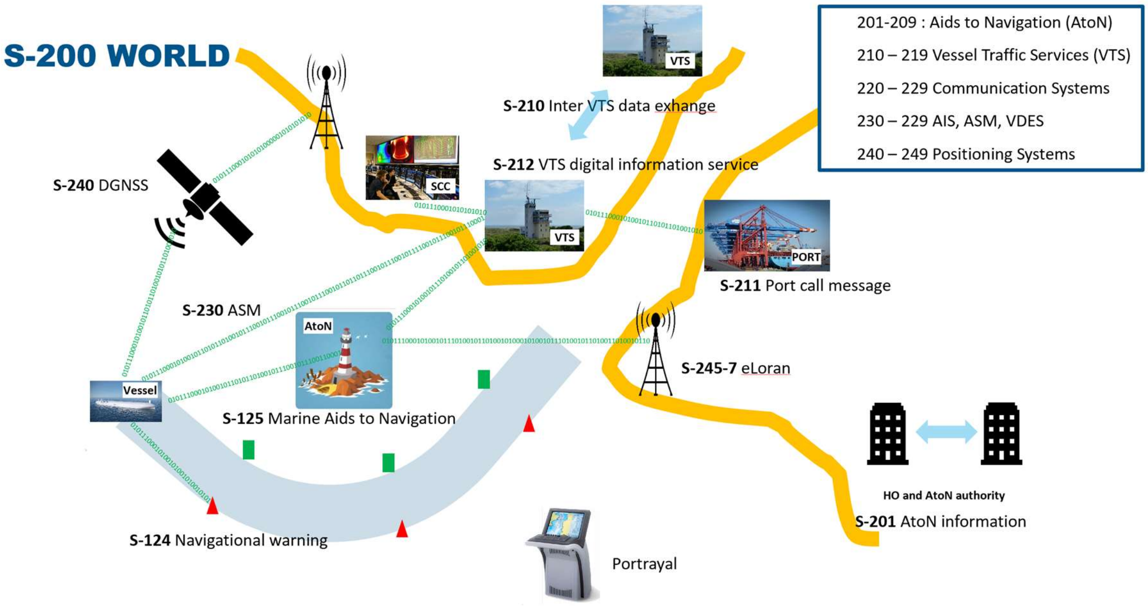

Figure 38: 'S-200 World' - Overview of IALA's contribution to the 'S-100 World'

Of particular relevance for the topics discussed in this study and report would be the following IALA defined data products, once they are finalised which is to be expected within the DIWA scope:

- S-240 on DGNSS;
- S-230 on ASM;
- S-125 on exchange of data on Marine Aids to Navigation with vessels;
- S-201 on exchange of AtoN data between authorities;
- S-211 on port call messages;
- S-212 on VTS digital information services, and
- S-210 on Inter-VTS data exchange.

The present status of those developments can be retrieved at IALA. Obviously, all of these topics are relevant to the IWT fairway & navigation domain and most of them have thus been addressed already as subjects above. Individual data products of the IALA 'S-200 World' were not assessed by the present Sub-Activity, however. Their eventual effective introduction and consequential up-take in the maritime domain will all depend on the above *pending IMO decisions regarding transition to S-100*. Hence, as a summary statement, it can be concluded that all of those S-200 data product definitions would need to be individually studied and assessed for their potential adaptation to the IWT fairway & navigation domain by then.

Recommendations are given in the Annex under *REC-IALA-S200-World-Data-Product-Adoption*. ***As soon as the S-100 transition decision will have been taken by IMO,*** *the studies and assessments for IWT fairway & navigation adaption of S-200 world data products should be done to* ***as a matter of priority, to potentially adopt them early on and thus avoid any redundant developments in the IWT fairway & navigation domain***. It should be noted, that these studies and assessments should specifically also consider the potential or necessity of a planned migration from presently adopted data exchange standards in the IWT fairway & navigation domain towards the S-200 world standards.

4.4.8 Reconciling apparently conflicting data modelling approaches

Above, different approaches for modelling data have been introduced and assessed as relevant to the digitalisation of the IWT fairway & navigation domain, namely the international ASM definitions as carrier agnostic data containers on one hand and the S-100-based data container definitions on the other hand. In addition, there are existing definitions specific to the IWT fairway & navigation domain with overlap in scope, too. There appears to be already a present and even more so in the future a substantial overlap in data object definitions between these approaches. In order to avoid any potentially critical ambiguity of data provided to IWT fairway & navigation applications, *the different approaches need to be reconciled* to arrive at a safe situation in the future for any DIWA desired digitalisation of the IWT fairway & navigation.

Since each of the data modelling approaches have their respective merits and therefore none can be ruled out easily, it is necessary to develop a criteria base for reconciliation of the data modelling approaches which may include the following criteria, amongst others to be developed:

- *Topical scope of data objects defined:* Identify the areas of overlap and the potentially different degrees of data quality in the context of the IWT fairway & navigation application(s) in mind.
- *Application affinity to required communication profile:* Certain IWT fairway & navigation applications would have a specific affinity to one of the data models due to the required communication profile of the functional or physical links needed, while others may allow for any or both.
- *Bandwidth demands on the supporting functional links and physical links when employed:* The ASM are a very bandwidth efficient way to transmit profound topical data sets, even also allowing for frequent (re-)transmission: Even with the advent of internet-geared broadband radio communication technologies, there remain applications where bandwidth efficiency is critical, in particular in infrastructure site applications with low power availability such as waterway sensor sites. S-100 defined data transmissions require higher bandwidth as a rule, in particular as soon as SECOM would be required for transmission.
- *Recognition of co-existence of all methods during a period of time*: Although not at all desirable, it may be required to support all methods concurrently, at least for a migration period to be determined, while making sure by different means, such as metadata qualifiers, that ambiguity is reduced.

Recommendations are given in the Annex under *REC-Reconciliation-of-ASM-with-S100-World-Data-Models*.

4.5 Data evaluation methods and technologies

The place of the data evaluation methods and technologies in the context of the overarching IWT fairway & navigation architecture is indicated would be the same as in the above Figure 36.

It is in particular this functional technology family *that would be required to ultimately achieve the DIWA desired IDL III ('Intelligent')*, which is characterised in particular by AI assisted process optimisation, prediction capabilities, and automated response to standard situations (compare [DIWA-SuAc3.5 2022b]).

While these technologies may be relevant in principle both for the vehicle side and the shore-side alike, for the authorities participating in DIWA it might have been particularly relevant how these technologies under development at other modes of transport support the infrastructure-side task of vehicle traffic management, though: Adapted to the wet domains, this would have introduced technologies supporting the vessel traffic management provided from e. g. a VTS (centre), but not limited to it. This would have been technologies such as VTS decision support technologies, including vessel traffic pattern analytics, which are made possible by the advent of 'new technologies' such as AI and Big Data. Since IALA is the competent body for VTS (and not confined to maritime alone), these topics have been discussed since a while at IALA Conferences and Symposia with increasing intensity.

As indicated above, despite its recognised relevance, this functional technology family as employed in other modes, in particular at maritime, cannot be covered by the present study.

Recommendations are given in the Annex under *REC-Data-Evalution-Methods+Technologies*.

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5 Structured inventory of useful combinations

5.1 Introduction

The major motivation for creating useful combinations is the recognition, that a combination of technology-oriented architecture and/or one or more individual technology/ies can achieve more desirable results than the individual items alone, namely if the *full required functionality* can only be achieved, because the limitations of individual items even *in the regular case* are compensated for by another item; or if a useful combination serves as a *fall-back arrangement* for a failure of an individual item, while taking into account less functionality than the individual item to be replaced.

This chapter introduces some useful combinations composed of technology-oriented architectures and technologies, *that are as such under consideration at another mode of transport directly or that follow from the previous sections of this inventory by – useful combination*. The individual items used here have been assessed in the preceding chapters. The useful combinations introduced here are inventory items themselves and are therefore subject to assessments.

This third part of the inventory is structured in accordance with the Overarching IWT Fairway & Navigation Architecture, introduced in Chapter 3, starting bottom-up again, i.e. beginning with useful combinations of communication technologies.[51]

5.2 Future optimum IWT Fairway & Navigation HetNet

In Chapter 3, the *IWT Fairway & Navigation System Interconnection Architecture (ISIA)* was derived by learning from ITS. In Chapter 4 several *radio communication technologies or even technology families* were introduces and assessed for their potential adaptability to the IWT fairway & navigation domain. As a promising radio communication technology family to that end, *IMT-2020* was identified. It is either already in use in some modes of transport (such as ITS) or is under consideration for future use in other modes of transport (such as at rail or maritime) due to its apparent versatility and to the undisputed progressive capabilities of its so-called Core Network (CN),[52] i.e. that part of the IMT-2020 system's set-up that processes and coordinates the several different technologies for radio access used (Radio Access Technologies - RATs). The combination of the different RATs employed is called Radio Access Network (RAN) at IMT-2020, and the RAN expressively allows for a variety of RATs with entirely different radio communication features each. Thus, conceptually the RAN is a *heterogeneous network of RATs* with largely diverse radio communication capabilities, abbreviated as HetNet (compare Figure 39).

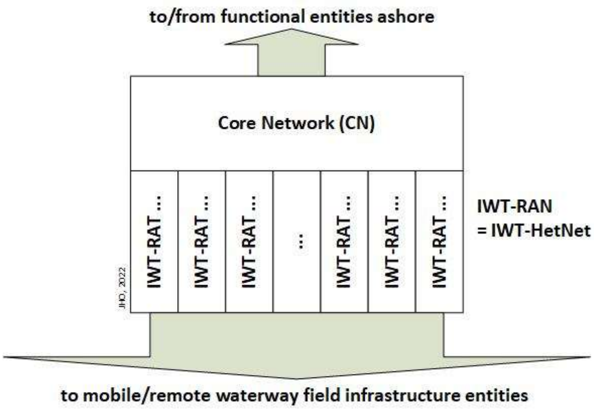

Figure 39: Functional setup of future IWT Fairway & Navigation HetNet as inspired by IIMT-2020 terminology

While setting up and operating an IMT-2020 network for the IWT fairway & navigation domain by IWT authorities may be challenging, it is still within their remit and also part of their responsibility to consider what combination of radio communication technologies should be employed in the future to fulfil the

[51] Useful combinations of PNT, including fall-back arrangements, to render Resilient-PNT are being considered by Sub-Activity 3.3.

[52] Compare for example the ITU-T Y.3100 series of documents for further information.

radio communication requirements stemming from the existing and emerging operational relationships as introduced in Chapter 2.

To take up the IMT-2020 terminology as inspiration, the question at hand for IWT authorities (and also ports albeit on a smaller scale) could be rephrased to read: *What **IWT Fairway & Navigation Radio Access Network (IWT-RAN)**, being composed of several **IWT Fairway & Navigation Radio Access Technologies (IWT-RATs)** and being an **IWT fairway & navigation specific HetNet (IWT-HetNet)**, would be required in the future, and what would be the IWT-RATs specifically?*

One thing is clear from the outset, though: The number of different IWT-RATs to be deployed is limited due to resource constraints, *hence an optimum HetNet for the IWT fairway & navigation domain needs to be defined, i.e. an **optimum IWT-HetNet**.*[53]

This task clearly would require intensive study in the upcoming period. However, some of the technology-oriented architectures adapted from other modes to the IWT fairway & navigation domain by the present Sub-Activity may assist in facilitating this task:

- In a first step, the most fundamental architecture of the *Nautical Datalink Communications* should be used to determine – based on a more detailed analysis of the operational relationships as introduced in Figure 5 – ***all*** of the H2H-NDLCs, the M2H-NDLCs, and the M2M-NDLCs to be expected in the future *besides the then still required voice communication relationships*.
- In a second step, as introduced in Chapter 4, the *communication characteristics* of the above NDLCs and voice communication relationships need to be determined completely.
- In a third step, the *IWT Fairway & Navigation System Interconnection Architecture (ISIA)* as developed in Chapter 3 can be employed to map the NDLC and voice communication relationships determined in the previous steps to one or several of thus 'activated' system interconnection domains (on-board, vessel-to-vessel, vessel-to-field etc. system interconnections). An informative example is given in Table 29 overleaf.
- In a final step, the optimum IWT-HetNet can be determined from the ISIA by determining *the optimum selection of IWT-RATs* from all available RATs assigned to each of the above system interconnection domains. The criteria base for 'optimum IWT-HetNet' needs to be established beforehand, of course.

Note: The population of the ISIA table can start *immediately* (compare the following figure as an *informative* example as being informed by Chapter 4 and solely confined to terrestrial CTs) with the caveat of adapting its content as the CTs under consideration further develop (or disappear) over the time period needed for the above study.

For assessment of this useful combination inventory item, the assessment reference to 'deployment' needs to be interpreted as meaning ***future optimum IWT Fairway & Navigation HetNet established (as an agreed plan amongst all relevant stakeholders)***, but should not be construed as the deployment of the CTs of the future optimum IWT Fairway & Navigation HetNet as such – the latter would need (much) more time. The assessment is given in Table 30 overleaf.

[53] The same logic holds true for the maritime domain, i.e. coastal authorities need to face the same questions in due course. The consideration in the maritime domain has started as introduced when considering the CDLMR family and IMT-2020 in the previous chapter, but the resulting need to determine and regulate for sea-going ships (!) the optimum maritime HetNet has only been introduced recently. Compare e.g. the present author's introduction given to the IALA Symposium 2021 [Oltmann 2021a] and the more detailed strategy considerations for the maritime domain [Oltmann 2021b].

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On-board system inter-connections		*Vessel-to-Vessel (V2V) system interconnec-tions*		*Vessel-to-Field-Infrastructure system interconnections (and vice versa)*		*Wireless-to-Fixed system interconnections (and vice versa)*		*Fixed-to-Fixed system interconnections*		*General Remarks*
CTs	Remarks	CTs	Remarks	CTs	Remarks	CTs	Remarks	CTs	Remarks	
WLAN, Blue-tooth, IMT, …	Wireless	AIS		AIS, VDES		AIS, VDES, DSC,	Bi-directional	WLAN-Technologies		
IEC61162-xxx, Ether-net, RS-232, …	Wired	VDES				NAVDAT, T-Mode DGNSS, …	Broadcast Fixed-to-Wireless	Wired Ether-net/Internet technologies, fibre optics		
		DSC		LPWAN (IoT – technologies)		DAB+		Fixed-link		
		a CDLML family sys-tem (e.g. dPMR)				a CDLML family sys-tem (e.g. dPMR)				RR Appendix 18 VHF fre-quency allocations needed
IMT-2020		IMT-2020		IMT-2020		IMT-2020		IMT-2020		Shore network may be needed for mobile-to-mobile interconnection, but at IWT fairway & navigation shore is always near

Table 29: Informative example population of IWT Fairway & Navigation System Interconnection Architecture (ISIA) with terrestrial Candidate Technologies

Compare Figure 15 as background to this figure.

Additional use cases for this table once fully populated and capability limitations introduced (remarks):

- *Determine and employ versatility of CTs:* Determine future optimum IWT-HetNet with increasing share of versatile CTs as compared with present situation.
- *Determine fall-back- and redundancy-arrangements within the same system interconnection domain*
- *Determine fall-back- and redundancy- arrangements by using different avenues* (through different system interconnection domains) *for the same purpose of communications.*
- *Perform security assessments:* on system interconnection domain and / or radio communications technology level.

DIWA assessment metrics	Assessment results
DIWA-TRL	**5** (Prototyping & Incubation – testing prototype in user environment) (Optimistic: assuming immediate uptake by IWT fairway & navigation community after DIWA.) **4** (Concept Validation – lab prototype) (Conservative: a 'lab prototype' has been created by the results of the discussions of the present Sub-Activity's workshops as shown above.)
DIWA-Adaptability	+ (Adaptability with minor modifications)
DIWA-Adaptation Demands	+ (Intermediate adaptation resource/time demands)
DIWA-Technology Radar	**2027-2032** (optimistic) '**Future Box**' (conservative)
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain) (Note: Cannot exceed the DIWA IDL Impact of the most versatile CT considered, namely that of IMT-2020; compare Chapter 4)

Table 30: Assessments of the future optimum IWT Fairway & Navigation HetNet established (as an agreed plan amongst all relevant stakeholders)

Recommendations from are given in the Annex under *REC-IWT-Future-Optimum-IWT-HetNet*.

5.3 Technology combinations for 'smart' IWT infrastructure sites

Chapter 3 introduced the IWT Infrastructure Site Architecture generically. It lends itself for IWT fairway & navigation domain applications which would be generally labelled 'smart' in the sense of 'bringing together' different technologies thus becoming a 'useful combination'.

Considering a deployment of many instances of the same or similar such 'smart' IWT infrastructure sites along relevant inland waterways would allow for higher IDL applications where implemented, namely when 'smart' IWT infrastructure sites would steadily communicate with 'smart' inland vessels during their (full) voyage along rivers and canals in the IWT fairway & navigation domain. Sites with a high affinity of potentially hosting a 'smart' infrastructure site would be (existing) hectometre stones and/or AtoN positions, thus rendering 'Smart Hectometre Stones' and/or 'Smart AtoNs', and bridges thus rendering 'Smart Bridges'.

An engineering sketch for the functional setup of such 'smart' IWT infrastructure sites is given in Figure 40 overleaf. The functional entities should be self-explanatory or have been described as CTs in the previous chapter. The following notes reflect topics being raised during the expert discussions of the present Sub-Activity which may not be obvious from the functional block diagram:

- The 'smart' IWT infrastructure site would establish *co-operative* functional links (and thereby physical links) with appropriately equipped vessels ('smart' inland waterway vessels), thus substantial consultation between all affected stakeholders would be required, eventually resulting into a strategic implementation plan agreed amongst all relevant stakeholders.
- A 'smart' IWT infrastructure site would lend itself as a contribution to Resilient PNT, if and when its precisely known position is used in combination with a precise time kept and being transmitted by any relevant radio or light communication technology or technologies. The deployment of many 'Smart Hectometre Stones' along relevant waterways may resolve the challenge of providing R-Mode in the IWT fairway & navigation domain indicated above.
- The remoteness of the sites equipped, would require local energy generation and storage, if and when no fixed electricity line would be available. In the maritime domain, there has been gained substantial experience with the integration of solar powered low-power electronics as indicated by the example of the 'Solarkompaktaufsatz' (compare Figure 41 overleaf).
- Integration degree of electronics will likely further increase over time while size and energy consumption of individual components will decrease, thus allowing for more functionality to be integrated and/or the dimensions of the 'Smart Hectometre Stone' being reduced.

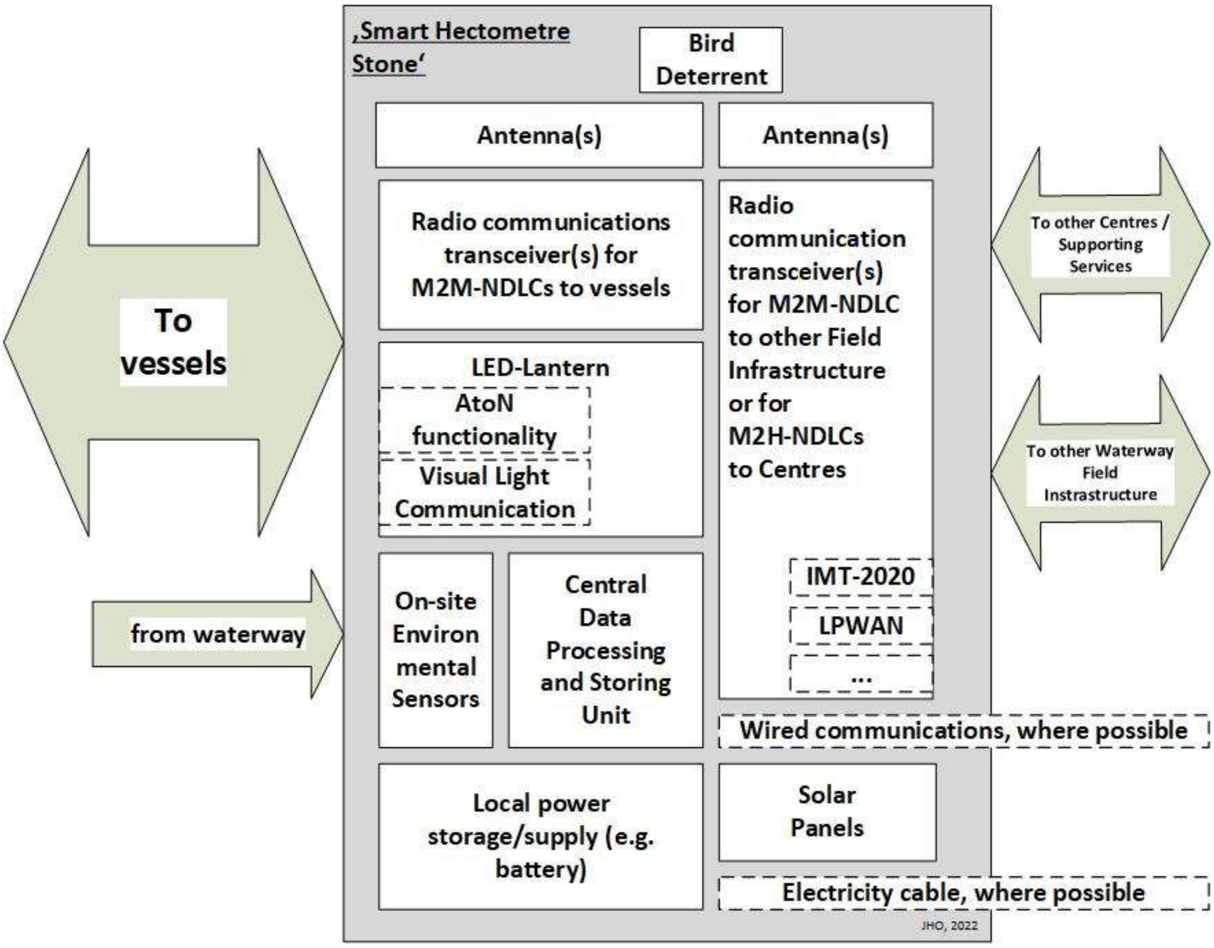

Figure 40: Functional block diagram of a 'Smart Hectometre Stone'

Figure 41: 'Solarkompaktaufsatz' as a maritime example of an existing 'infrastructure site' optimised for remote, self-contained operation in a robust environment

The assessments of the definition of the co-operative system of at least one variety of 'smart' IWT infrastructure site and of the necessary shipboard equipment and functionality (as an agreed plan amongst all relevant stakeholders) is given in Table 31.

DIWA assessment metrics	Assessment results
DIWA-TRL	5 (Prototyping & Incubation – testing prototype in user environment) (Optimistic: assuming immediate uptake by IWT fairway & navigation community after DIWA.) 4 (Concept Validation – lab prototype) (Conservative: a 'lab prototype' has been created by the results of the discussions of the present Sub-Activity's workshops as shown above.)
DIWA-Adaptability	+ (Adaptability with minor modifications)
DIWA-Adaptation Demands	+ (Intermediate adaptation resource/time demands)
DIWA-Technology Radar	2027-2032 (optimistic) 'Future Box' (conservative)
DIWA-IDL Impact	II (Connected IWT fairway & navigation domain) (Note: Cannot exceed the DIWA IDL Impact of the most versatile CT considered, namely that of IMT-2020; compare Chapter 4)

Table 31: Assessments of the definition of the co-operative system of at least one variety of 'smart' infrastructure site and of the necessary shipboard equipment and functionality (as an agreed plan amongst all relevant stakeholders)

Recommendations are given in the Annex under *REC-Smart-IWT-Infrastructure-Site-Deployment.*

5.4 System engineering concept of a future shipboard navigation and communications environment based on Inland-SSSA

In Chapter 3, as informed by relevant developments in the maritime domain, the Inland-SSSA was justified and introduced in general terms as a potential architectural framework for the integration of shipboard navigation and communications functionality and equipment, including a human-centric layout and design of the HMIs at the helmsman's position in the wheelhouse. Chapter 4 introduced certain CTs and assessed their potential for the IWT fairway & navigation domain. The very tasks to be performed at the helmsman's position in the wheelhouse necessitate a 'useful combination' of the HMIs of the relevant shipboard navigation and communications functionalities and equipment. This in turn implies an Inland-SSSA to be also construed as a 'useful combination' of the shipboard parts of relevant CTs.

But why should IWT fairway & navigation authorities should bother about that *(future) shipboard navigation and communications environment?* As an answer, it is re-iterated here, that the DIWA desired increase of IDL prompts more co-operative functionalities and technologies to be used, and that it is therefore necessary also for IWT fairway & navigation authorities to *reliably and accurately* know what the generic (minimum) shipboard navigation and communications environment would be when providing digital services at any given migration step towards higher IDLs.

This rationale may hold true when considering the advent of ROVs/AVs, too, but with two differences: The *still necessary HMIs* would no longer be in the wheelhouse but rather at the Remote Control Centre or at the Autonomous Vessel Control Centre (compare Figure 5), and the portrayal of data will likely be different from the portrayal in the wheelhouse of a traditionally operated vessel.

While the present Sub-Activity is *not* in a position to draft a detailed future shipboard navigation and communications environment here, it is the intent of this section to populate the layers of the Inland-SSSA with the potential future imports from other modes of transport, in particular maritime, thus rendering a system engineering concept of a future shipboard navigation and communications environment as a 'useful combination'. It must be added immediately that this must *in no way* be construed to imply that the IWT fairway & navigation domain does not have useful functionalities and equipment in place today. There is nothing which cannot be improved by learning from – here: other modes of transport – on the other hand, however. The system engineering concept of a future shipboard navigation and communication environment is therefore *to be construed as an input into a gap analyses of the IWT fairway & navigation domain, comparing the present state of shipboard navigation and communications environment of inland waterway vessels with the states required by certain DIWA desired IDLs respectively.*

Table 32 shows this system engineering concept, being informed by the relevant analogous developments at IMO and at international standardisation organisations as introduced in Chapters 3 and 4.

Overarching functionalities (to be operative in all layers to some degree)	Operational Layer (including HMI to human(s) at helmsman's position)
Fairway & Navigation Data Structure, part shipboard use (1), (2) S-100-Transition as a framework throughout (3) Modular Concept employed throughout Maintaining software quality and implementing update procedures for shipboard equipment	Human-centric harmonised wheelhouse layout, in particular regarding harmonised shipboard HMIs for navigation and communications 'Wheelhouse Alert Management' (4) S-100 informed HMIs and data layers S-421 -based intention / route exchange V2V, V2C (and vice versa) Comprehensive PNT status awareness indication Support for Augmented Reality applications Assistance functionality such as 'Inland-MTCAS' (4)
	Data Processing Layer (including M2M-interfaces to other electronic inland waterway vessel systems)
	Consistent Common Reference System PNT-Data Processing BAM data input processing 'S-100 based database' (4) 'Inland-IRCS' (4) for Communications processing and optimal routing (5) Data content interaction with appropriate shore infrastructure sites (6)
	Sensor / Source Layer (including M2M-interfaces to the physical links)
	PNT sensor layer (7) Radio front ends to all physical links as required by the future optimum IWT Fairway & Navigation HetNet, but also by legacy systems. (8)

Table 32: System engineering sketch of Inland-SSSA populated with potential CTs

When considering Table 32, the following should be noted:

(1) The Fairway & Navigation Data Structure may be more comprehensive than what will be needed on the shipboard side.
(2) The shipboard part of the Fairway & Navigation Data Structure may need to be developed step-by-step in accordance with the DIWA desired IDL increase migration path(s).
(3) Expressively ***not*** confined to the (future) introduction of S-401 (Inland-ENC based on S-100) or even only all of the S-4xx data products to be eventually developed by the IWT Fairway & Navigation domain. It is rather expected, that maritime defined data products of the S-100 framework can be applied directly (in part or even in full).
(4) Appropriate name to be determined for IWT fairway & navigation domain in due course.
(5) For functional links operative (in particular NDLC) and for all physical links operative; IP-based and non-IP-based.
(6) Such as 'Smart Hectometre Stones'. Comprises data collection, initial evaluation/validation, temporary storage, and containerisation for upload to shore infrastructure sites as well as de-containerisation, evaluation and storage in shipboard database of downloads from shore infrastructure sites.
(7) As comprehensive as indicated by e.g. [IMO-MSC.1/Circ.1575], Figure 4.
(8) Based on and in accordance with the ISIA.

The following assessment is one regarding the system engineering concept as given Table 32, only, ***not*** the individual contributing technologies or the Inland-SSSA as such (although the time frame of the development and introduction of the other relevant architectures need to be taken into account). For the following assessment, it needs to be determined what international remit may be expected to be the one defining the future shipboard navigation and communications environment based on Inland-SSSA in their respective documentation as a lead:

- *UNECE-wide remit:* UNECE Inland Transport Committee (ITC) defines itself in its 'ITC Strategy until 2030', 'as a UN platform (…) that provides a comprehensive regulatory framework for inland transport, comparable to the role of the International Maritime Organization (IMO) and International Civil Aviation Organization (ICAO)' ([UNECE ITC 2022], 3). Accordingly, a future revision of the UNECE Res. 61 on 'harmonized Europe-wide Technical Requirements for Inland Navigation Vessels' [UNECE-Res61], in particular the chapter on the wheelhouse and its electronic equipment, would lend itself as a recognised repository for all necessary stipulations on that level.
- *CESNI-wide remit:* A more limited remit, namely of the EU and the countries adjacent to the Rhine and potentially the Danube river systems, would be addressed, if CESNI would host the recognised repository for all necessary stipulations on that level in appropriate documentation.

The benefit of a CESNI-wide, more limited remit could be assumed to be a faster process because co-ordination of only a smaller number of affected countries and stakeholders would be required. Since time is of the essence, this leads to an *optimistic scenario* of a CESNI-wide solution and a more *conservative scenario* of a UNECE-wide solution.

There is one weakness of both scenarios, though, namely the fact that neither covers the truly *global* remit of IWT fairway & navigation domain. This is represented by organisations such as PIANC and IEHG. A non-beneficial situation might indeed occur, if and when the global and the regional solutions developed would not be compatible, to say the least. This is not unlikely to happen, since it may be safely assumed that there may be other projects than DIWA looking into the global developments as described and advice their regions accordingly, sparking initiatives there alike. Hence, from a European perspective, this can only be resolved, if a European variety of a future shipboard navigation and communication environment based on Inland-SSSA were developed *on such a fast track that a quite mature solution may be presented to any global forum in relatively short notice*.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (The work at IMO and supporting organisations regarding their shipboard navigation system architecture and its supporting functionalities and equipment as described in Chapter 3 have reached such high a degree of maturity over more than two decades now.)
DIWA-Adaptability	0 (Adaptable with substantial modifications)
DIWA-Adaptation Demands	0 (Substantial adaptation resource/time demands)
DIWA-Technology Radar	2027-2032 (optimistic and fast-tracked) 'Future Box' (optimistic, but not fast-tracked, or conservative)
DIWA-IDL Impact	III (Intelligent IWT fairway & navigation domain)

Table 33: Assessments of system engineering concept of Inland-SSSA being informed by imports from other modes of transport, in particular maritime (as an agreed plan amongst all relevant stakeholders)

Recommendations are given in the Annex under *REC-Inland-SSSA* and *REC-Inland-SSSA-Introduction.*

5.5 System engineering concept of integration of shore-based services using Inland-CSSA

In this chapter some useful combinations were introduced and assessed, such as the optimum future HetNet and the 'smart' infrastructure site. *It is not only possible but also required to introduce these into an generic instance of the Inland-CSSA*, thus rendering the latter a 'useful combination' also in the precise terms of technical services and improved functionalities on one hand and shore-based peer to the generic instance of Inland-SSSA of the previous section. A system engineering concept is given in Figure 42 accordingly. It is not intended to be complete in any way.

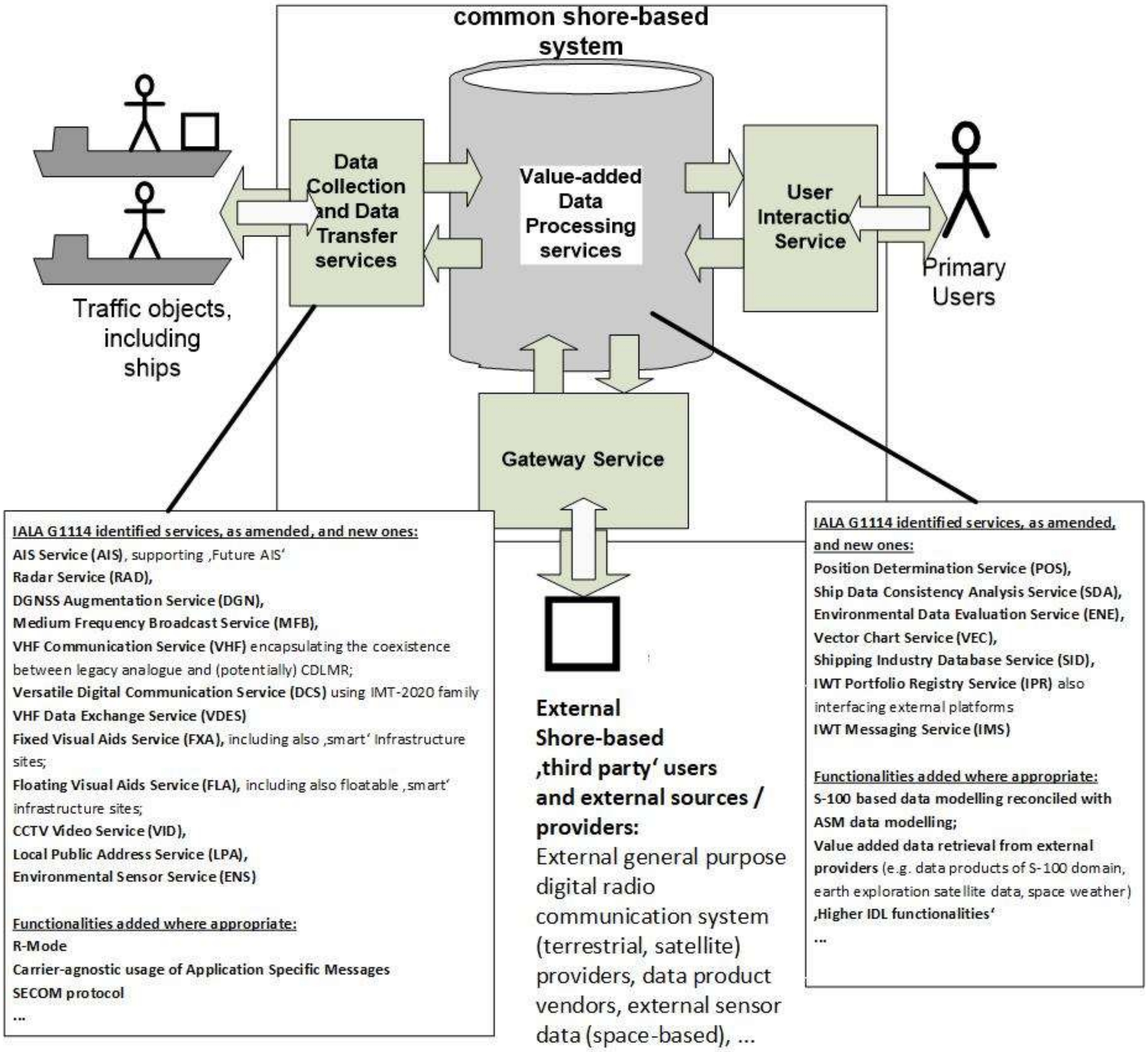

Figure 42: Example of integration of shore-based services using Inland-CSSA and being populated with relevant CTs and higher IDL-functionality

When considering Figure 42, it should be noted:

- The point of the figure is to show – by means of meaningful examples - the potential 'landing pads' for new functionality for the IWT domain due to higher IDL aspirations.
- The IWT fairway & navigation domain may chose names deviating from the maritime if required to indicate a major difference in functionality; otherwise, in the spirit of harmonisation with maritime the original names should be retained to the maximum extent possible.
- This applies to the in the *Value-added Data Processing services group* for example as follows:
  - In general, they would maintain the S-100 based digital-twins of diverse functional entities.

- The *Position Determination Service (POS)* would contain all data related to the positions of traffic objects envisaged by higher IDL levels, such as the data representation ('data floor') of the common operational picture.
- The *Ship Data Consistency Analysis Service (SDA)* would contain all data related to traffic objects (other than positions and generally less time-dynamic) envisaged by higher IDL levels, potentially to be exchanged with the EuRIS.
- The *Environmental Data Evaluation Service (ENE)* would keep environmental data collected by vessel swarms (which are received e.g. via 'smart' infrastructure sites (fixed or even floatable)), but also data acquired (via the Gateway service) from space-based sensors such as earth exploration satellite or space weather services.
- The *Vector Chart Service (VEC)* would keep all (S-100-based) chart data, together with domestic overlays.
- The *Shipping Industry Database Service (SID)* would keep data regarding stakeholders, potentially to be exchanged with the EuRIS.
- The *IWT Portfolio Registry Service (IPR)* would keep the machine-readable IWT fairway & navigation service declarations.
- The *IWT Messaging Service (IMS)* would deal with all kinds of data container messaging stuff, i.e. the one service destined to handle all the NDLC data containers, ASM data containers, SECOM data containers, but also data containers exchanged with external parties.

- Internal communication links by fixed or wireless technologies are not shown because they are encapsulated at this scale. Thus, LPWAN technologies used for infrastructure connections to some central processing sites of the same instance of the Inland-CSSA would thus be construed an internal communication link (not shown in Figure 42); LPWAN would only become a technical service in the Data Collection and Data Transfer services group, if used for connecting to traffic objects.

The following assessment can be given for this generic integration of shore-based services using Inland-CSSA and being populated with relevant CTs and higher IDL-functionality.

DIWA assessment metrics	Assessment results
DIWA-TRL	9 (The work at in particular IALA has reached high maturity.)
DIWA-Adaptability	0 (Adaptable with substantial modifications)
DIWA-Adaptation Demands	0 (Substantial adaptation resource/time demands)
DIWA-Technology Radar	2022-2026 (optimistic and fast-tracked) 2027-2032 (optimistic, but not fast-tracked, or conservative)
DIWA-IDL Impact	III (Intelligent IWT fairway & navigation domain)

Table 34: Assessments of system engineering concept of Integration of shore-based services using Inland-CSSA and being populated with relevant CTs and higher-IDL-functionality

Recommendations are given in the Annex under *REC-Inland-CSSA-Introduction.*

6 Final conclusions, recommendations and suggestions

Throughout this report, intermediate conclusions have been identified in their respective contexts. Recommendations following from those are compiled in an Annex for overview and ease of reference. Therefore, there is no need to re-iterate those here. This chapter wants to go a step further by

- bringing together all the architectures introduced and applied to the IWT fairway & navigation domain into a composite picture showing their mutual support;
- compiling their respective contributions regarding DIWA IDL Impact and their respective DIWA Adaptation Demands into the overarching 4-Quadrant-Matrix, thus rendering final conclusions and recommendations for DIWA's roadmapping;
- compiling the assessments of imminence of technological developments into a composite DIWA Technology Radar representation;
- advocating the harmonisation across the European IWT fairway & navigation domain as the one critical pre-requisite for *any* future increased digitalisation maturity; and
- considering where there might be the IWT fairway & navigation domain ahead of the maritime domain, which has loomed as an example to following in several regards throughout this study and report, *when due diligence is applied.*

6.1 Usage of mutually supportive combination of architecture models

In Chapter 3 a variety of architectures have been introduced, adapted to the IWT fairway & navigation domain in principle and assessed. These architectures were:

- the *Overarching IWT Fairway & Navigation Architecture*, which presented the architectural framework when considering the IWT fairway & navigation domain (alone);
- the *Nautical Datalink Communications (NDLC) Architecture*, which governs the datalink communications between humans, humans and machines, and machines and machines;
- the *IWT Fairway & Navigation System Interconnection Architecture (ISIA),* which governs the physical links involved;
- the *IWT Fairway & Navigation Standardised Shipboard System Architecture (Inland-SSSA)*, which governs the integration and interaction of shipboard equipment;
- the *IWT Fairway & Navigation Common Shore System Architecture (Inland-CSSA),* which governs the integration and interaction of shore-based technical services of an administration or of a stakeholder; and
- the *IWT Fairway & Navigation Infrastructure Site Architecture*, which would govern the integration and interaction of infrastructure components at sites being deployed along the inland waterways throughout ideally and thus may be construed as a remote service delivery point for the (declared) service portfolio of an shore-based stakeholder organisation.

All those architectures mutually support each other as is demonstrated in Figure 43.

Recommendations following from this are given in the Annex under *REC-Mutually-Supportive-Architectures.*

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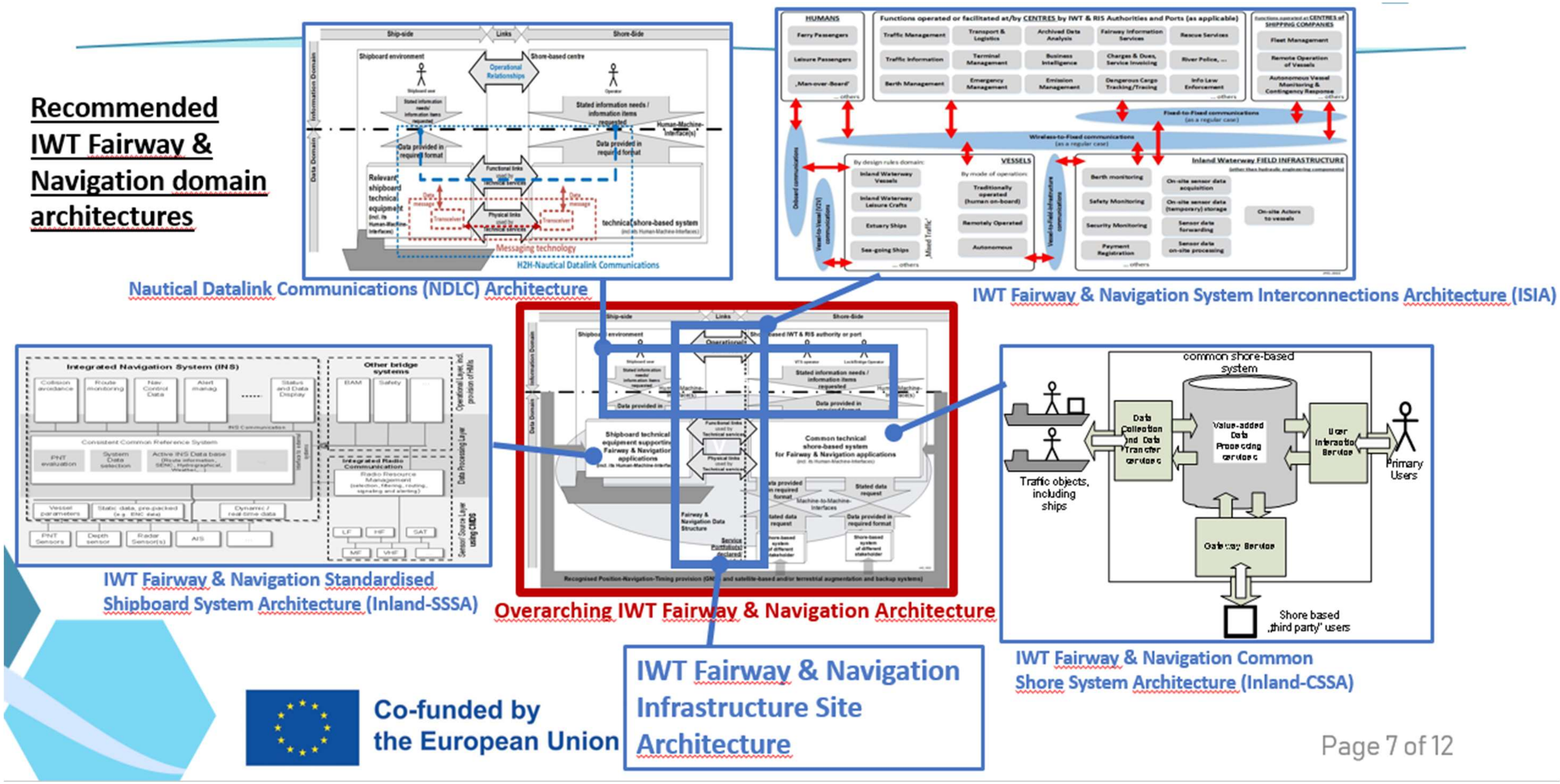

Figure 43: Mutually supportive combination of architectural models adapted to the IWT fairway & navigation domain

6.2 The DIWA 4-Quadrants-Matrix: IDL impacts vs. adaptation demands

As introduced in Chapter 3 and the 'Manual' ([DIWA-SuAc3.5 2022b]), the 4-Quadrant-Matrix allows for the direct derivation of action recommendations based on the quadrants A, B, C, and D's meaning for action. In Figure 44 the DIWA IDL Impact vs. the DIWA Adaptation Demand Assessments of inventory items are shown synoptically. Interestingly, ***all** architectures, CTs and useful combinations assessment results regarding their IDL impact fall into IDL **I** to IDL **III**,* hence rendering quadrants C and D empty (which are therefore not drawn in Figure 44). The reason for this lies in the fact, that only those architectures, CTs and useful combinations were selected for becoming an inventory item that *are under current or recent consideration* in another mode of transport and are thus *always* looking into the future – with the associated IDL impact as opposed to the present situation, i.e. at least IDL I.

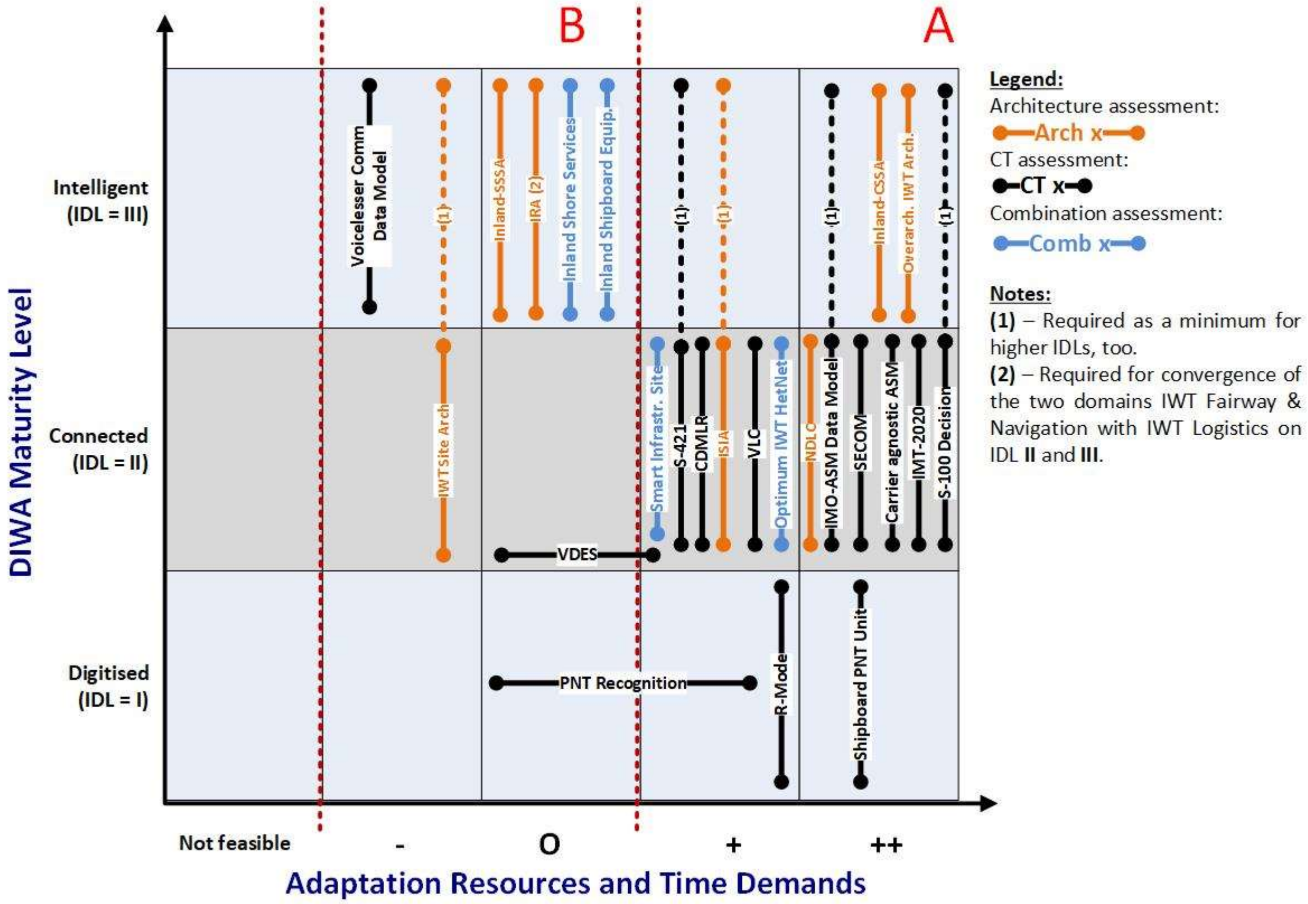

Figure 44: DIWA-tailored 4-Quadrants-Matrix with assessment results

Hence, *only the quadrants A and B remain for any recommendation.* To re-iterate, there are the following meanings for those quadrants:

- A – *Inventory items entered here reach desired high DIWA IDL Impact at low effort.*

  Resulting recommendation: Apply that relevant selection of these inventory items that covers all of the required functionality as soon as possible. Compare Annex under *REC-Very-High-IDL-Impact-Low-Effort-Inventory-Items.*

- B – *Inventory items entered here reach desired high DIWA IDL Impact at a higher effort.*

  Resulting recommendation: Start all preparations for applying all inventory items needed to cover the required functionality fully as soon as possible, with the goal to introduce these inventory items in the long term, i.e. even if beyond DIWA. Compare Annex under *REC- Very-High-IDL-Impact-But-Long-Term-Development-Inventory-Items.*

The different IDLs within each of the quadrants *may assist prioritising **within*** the quadrants' meanings.

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6.3 DIWA Technology Radar – imminence of technological developments

The DIWA Technology Radar allows for the recognition of the imminence of technological developments regarding DIWA's time scope of up to 2032, including a 'Future Box' of potentially interesting technological developments beyond 2032. The assessment results of the inventory items are introduced in Table 35 overleaf. Table 35 largely speaks for itself from the present Sub-Activity's point of view and it is hoped that it thus may be directly useful for the actual roadmapping task of DIWA Activity 5.

6.4 The need for harmonisation across the European IWT fairway & navigation domain as *the one critical* pre-requisite for *any* increased digitalisation maturity

During the present study and report, it was repeatedly recognised that within the IWT fairway & navigation domain in DIWA's area of interest there are operative several recognised international organisations, each with a mandate for one or more aspect(s) relevant for the DIWA desired IDL increase. The following international organisations were recognised as relevant, with no aspiration of a complete list:

- UNECE Inland Transport Committee (ITC) defines itself in its 'ITC Strategy until 2030', 'as a UN platform (…) that provides a comprehensive regulatory framework for inland transport, comparable to the role of the International Maritime Organization (IMO) and International Civil Aviation Organization (ICAO)' ([UNECE ITC 2022], 3).
- Several river commissions, namely in DIWA's area of interest alone the Central Commission for the Navigation of the Rhine (CCNR), the Danube Commission, and the Mosel Commission;
- European Union, represented in particular by the EU Commission;
- CESNI is a committee co-founded by the CCNR and the EU Commission with the goal of acting as a harmonisation body with combined remits of the EU and the Rhine river areas;
- PIANC, in particular their working group on Guidelines for River Information Systems (PIANC-INCOM-WG125). While PIANC has a global remit, their work is largely contributed to by European experts, and their results are applied frequently to the European IWT fairway & navigation domain. Their work on RIS is just one example;
- RAINWAT is a 'regional arrangement' established and revised at intervals by several European countries, that regulates the equipment and use of several analogue and digital radio communication technologies in the European IWT fairway & navigation domain, thus supporting the regulatory body created by CEPT and ITU-R by regional adaptation;
- Several standardisation bodies with a global remit, such as IEC and ISO, are being made relevant to the European IWT fairway & navigation domain by adopting their standards for use in the harmonised European Market by European standardisation bodies, as appropriate;
- Similarly, work of the IHO as applied to the IWT fairway & navigation domain by IEHG, both with a global remit, is eventually applied to the European grid, as the example of the Inland-ECDIS shows; it is to be expected that the IHO move towards the S-100-family of data models and data products will follow the same route of implementation.
- Finally, as a matter of fact and due to the wet-to-wet creep-in of devices put into practical use by individual stakeholders in the IWT fairway & navigation domain even in the absence of any regulation, the decisions and regulatory documents created by organisations with a (predominantly) global maritime scope like IMO or IALA, which also result in ITU-R standardisation respectively, need to be taken into account as source of relevant rulemaking.

Time for deployment	Assessment results for inventory items when adapted to IWT fairway & navigation	
'Future Box': from 2033 onwards	Architectures	- IWT Reference Architecture (IRA) -
	Candidate Technologies	- Formal recognition process of PNT components (conservative) – - Shipboard PNT processing entity(conservative) - - R-Mode for resilient PNT (conservative) – - SECOM (full functionality option) – - VDES (conservative) - - CDLMR-Family (Dry-to-Wet(Maritime)-to-Wet(IWT) adaptation avenue) - - IMT-2020 (Dry-to-Wet(Maritime)-to-Wet(IWT) adaptation avenue) - - Visual Light Communication (conservative) – - IMO ASM Data Model (conservative) – - Data model for voicelesser communication using NDLC -
	Useful combinations	- future optimum IWT Fairway & Navigation HetNet established (as an agreed plan) (conservative assessment) - - 'Smart' Infrastructure Site, e.g. Smart Hectometrestone (conservative) – - Future shipboard navigation and communications environment based on Inland-SSSA (optimistic, but not fast-tracked, or conservative) -
>5 years and <10 years from now = 2027-2032	Architectures	- IWT Infrastructure Site Architecture (conservative assessment) – - IWT Fairway & Navigation Standard Shipboard Navigation System Architecture (Inland-SSSA) -
	Candidate Technologies	- Formal recognition process of PNT components (optimistic) – - Shipboard PNT processing entity(optimistic) - - R-Mode for resilient PNT (optimistic) – - Application Specific Messages for carrier agnostic use (conservative) – - SECOM (Just secure data protocol option) – - VDES (optimistic) - - CDLMR-Family (Dry-to-Wet adaptation avenue; optimistic assessment) – - IMT-2020 (Dry-to-Wet(IWT) adaptation avenue – - Visual Light Communication (optimistic) – - IMO ASM Data Model (optimistic) – - S-421 (EN IEC 63173-1) on Route Plan based on S-100 (delay in up-take for whatever reason such as persistent reluctance to strike S-100 decision) -
	Useful combinations	- future optimum IWT Fairway & Navigation HetNet established (as an agreed plan) (optimistic assessment) - - 'Smart' Infrastructure Site, e.g. Smart Hectometrestone (optimistic) – - Future shipboard navigation and communications environment based on Inland-SSSA (optimistic and fast-tracked) – -Engineering concept of integration of shore- based services using Inland-CSSA (optimistic, but not fast-tracked, or conservative and fast-tracked) –
<5 years from now = 2022-2026	Architectures	- Overarching IWT Fairway& Navigation Architecture - - Nautical Datalink Communications (NDLC) Architecture - - IWT Fairway & Navigation System Interconnection Architecture (ISIA) - - IWT Infrastructure Site Architecture (optimistic assessment) – - IWT Fairway & Navigation Common Shore System Architecture (Inland-CSSA) –
	Candidate Technologies	- Application Specific Messages for carrier agnostic use (optimistic) – - Decision to transition to S-100 in IWT fairway & navigation domain – - S-421 (EN IEC 63173-1) on Route Plan based on S-100 (immediate up-take) -
	Useful combinations	-Engineering concept of integration of shore-based services using Inland-CSSA (optimistic and fast-tracked) –
Here we are today: time of present study and report (2022)		

Table 35: DIWA Technology Radar assessments

During the present study and report, it became clear at several points that the DIWA desired IDL increase will only be possible in the future, if and when there

- will be clear definitions and an ideally non-overlapping distribution of responsibilities of the above international organisations with relevance for the European IWT fairway & navigation domain, taking into account the pre-sets introduced by international organisations with a global (maritime) remit that cannot easily be influenced by the European IWT fairway & navigation stakeholder community alone;
- architectural models will be employed that cover both operational and technical aspects seamlessly;
- will be in place unambiguous and not-contradicting definitions, expressing themselves technology-wise in particular in terminology, data models, interface definitions;
- will be introduced regulatory concepts and frameworks that would avoid IDL mismatch situations during implementation and deployment phases at borders between individual countries, regions, waterways etc.

Concluding, there will be a need for harmonisation across competent bodies in the IWT fairway & navigation domain for *any* increased digitalisation maturity (IDL above level I) – the higher the desired IDL, the more comprehensive and complete the degree of harmonisation would need to be. Recommendations following from that are given in the Annex under *REC-Harmonisation-Need-Awareness-At-Competent-Bodies* and *REC-Intermediate-Harmonisation-Stages.*

By the same token, there would be a need to have one competent body with a remit for the European IWT fairway & navigation domain to *act as 'a spider in the web'*, i.e. bringing together all other relevant bodies at a *'round table'* and thus facilitate their co-ordinated work. Recommendations following from that are given in the Annex under *REC-Need-For-Harmonisation-Governing-Body, REC-IDL-Maturity-Round-Table,* and *REC-Legacy-System-Treatment*

Further, by the same token, it is assessed by the present Sub-Activity that the *one* (and likely also only) architectural framework that would support the concrete harmonisation of existing regulations, architectures, standards, definitions etc. as well as provide indication of future developments in this regards would be the *IWT Reference Architecture (IRA)*: While the above mutually supportive combination of architecture models is confined to the IWT fairway & navigation domain 'only', *the IWT Reference Architecture (IRA) would not be confined to the IWT fairway & navigation domain, but would also allow to capture relevant regulations, architectures, standards, definitions etc. from the IWT Logistics domain – thereby facilitating the convergence between the two domains as ultimately envisioned by DIWA.* This is illustrated by Figure 45.

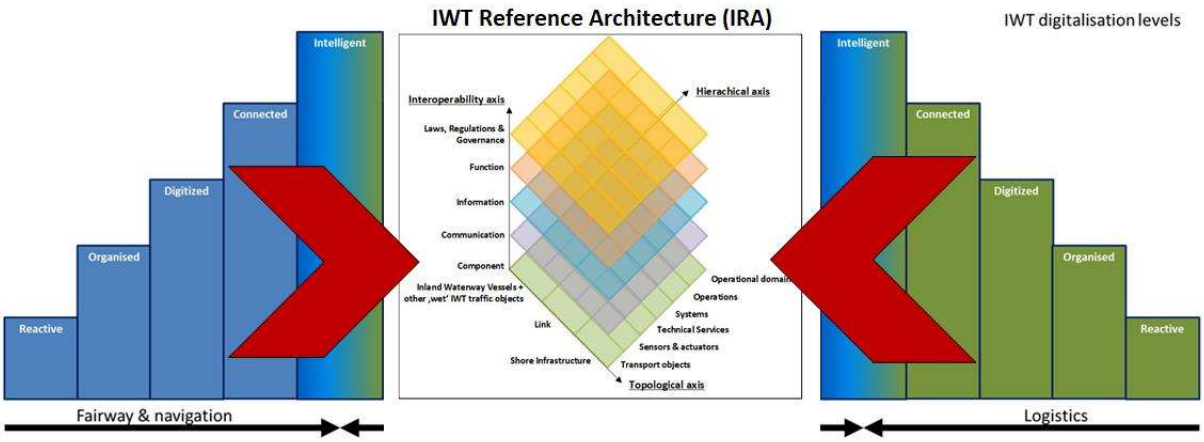

Figure 45: IWT Reference Architecture (IRA) facilitates convergence of IWT fairway & navigation and logistics

From this, a recommendation can be derived as given in the Annex under *REC-IWT-Reference-Architecture(IRA).*

That thus required harmonisation across the IWT fairway & navigation domain for increased digitalisation maturity at large would express itself in harmonised Europe-wide regulations as well as operational and technical requirements (relevant to the desired IDL) for both inland waterway vessels and services provided by authority and port operated waterway field infrastructures (other than hydraulic engineering components) as well as centres of, in particular, shipping companies for remote operation and autonomous vessel monitoring and contingency response.

6.5 IWT fairway & navigation domain ahead of maritime domain?

In this report, the wet-to-wet adaptation route Maritime-to- IWT was mentioned and employed several times. *But what if the (European) IWT fairway & navigation domain would absorb some notions from other modes of transport, not limited to maritime though, readily and fast track some developments so that it would be ahead of maritime in due course?*

Thus putting itself in a position that there may be the need recognised to adapt ***wet(IWT)-to-wet(Maritime)*** by making the maritime domain aware of applicable solutions developed and potentially implemented in the (European) IWT fairway & navigation domain?

One such need might be *to save own investments* by influencing maritime (regulatory) developments in order to avoid diverging developments in e.g. areas of mixed traffic.

Another need might be *capacity building* considerations within the (European) IWT fairway & navigation domain.

Based on the results of this study and report this could be possible for the following subjects:

- Fully develop the *IWT Framework Architecture (IRA)* thereby being in a position to demonstrate harmonisation of the IWT domain at large.
- Fully develop the *Nautical Datalink Communications (NDLC)* into a viable concept for co-existence of NDLC with 'voiceless<u>er</u>' communications with all kinds of generic centres complementing each other, and demonstrate this and the benefits thereof by appropriate test-beds.
- Further develop the *Shipboard PNT processing entity as embedded in Inland-SSSA*: While in particular the requirements and functional layout of the Shipboard PNT Data Processing entity are maturely specified by IMO, its technical development would require work and field trials.
- Fully develop the *IWT Fairway & Navigation System Interconnection Architecture (ISIA)* and develop a well-founded solution for the *future optimum IWT HetNet* with a view to assist the consecutive determinations of future, non-conflicting, optimum HetNets for maritime and IWT fairway & navigation, ideally with a very large overlap between the two.
- Exploiting the beneficial radio coverage circumstances of the IWT fairway & navigation domain ('everything under land') as opposed to maritime, *explore in live test-beds* to start with, the potential of emerging *general-purpose digital radio communication technologies adapted to the IWT fairway & navigation domain*, in particular of *IMT-2020*.
- Fully develop the *Inland-CSSA* in particular in regard to introducing *'smart' functionalities into the Value-Added Data Processing Services* with a view to thereby potentially progress the notion of CSSA at large, including maritime.
- Fully develop the *IWT Infrastructure Site Architecture* with a view to support maritime navigation 'under shore' potentially, thereby potentially rendering new kinds of maritime Aids-to-Navigation.

From this, a final recommendation is given in the Annex under *REC-Influence-Maritime-Domain*.

7 Critical reflections of achievements

This chapter performs a *critical reflection* on how the tasks given to Sub-Activity 3.5 were met by this study and this report. The objectives for this study and report as summarised in Chapter 2 and the achievements of the study as reflected in this report are compared as follows:

- *Summary of the objective stipulation:* Take inventory and study relevant technologies in road, rail, and maritime transport, taking particular interest in those technologies that might potentially be supportive of a 'seamless conversion into multi-modality'.

  Achievements of the study:

  After refining the scope, a tri-partite structured inventory was established. Inventory items were from road, rail, maritime, and – in passing – also aviation. The ITS/Smart Mobility domain was considered with road transport; in fact it was the latest edition of the ITU Handbook on Intelligent Transport Systems (ITS) [ITU-R-ITS-HDB-2021], which informed this to a large degree. Inventory items were technology-oriented architectures, CTs, and useful combinations thereof. Compare Chapters 3, 4, and 5. The inventory was structured in accordance with the Overarching IWT Fairway & Navigation Architecture derived from maritime transport (e-navigation) as adapted by Sub-Activity 2.5 and further adapted by the present study.

- *Summary of the objective stipulation:* Assess the applicability towards IWT including resulting requirements and pre-conditions, in particular alert the project for any such potential applications with an unforeseen and/or high potential.

  Achievements of the study:

  The applicability towards the IWT fairway & navigation domain of the inventory items were assessed by the contributing experts and reflected in this report using an assessment methodology developed beforehand and which was developed into a stand-alone document ('*Manual on Inland Waterway Transport Digitalisation and Assessment Methodology*'). Requirements and pre-conditions for inventory items were discussed to various degrees, including alternative adaptation avenues in some cases due to different pre-condition scenarios. Sometimes optimistic vs. conservative scenario assessments were thus determined. Finally, useful combinations of technology-oriented architectures populated with relevant technologies for illustration were considered and assessed in Chapter 5. By deriving conclusions and recommendations in the Annex on Recommendations and in Chapter 6, DIWA as well as the IWT fairway & navigation community beyond were informed and – in some cases – even alerted to relevant developments and needs.

- *Summary of the objective stipulation*: Assess the effects on digital transitions in the period 2022-2032 (as a minimum time frame for consideration).

  Achievements of the study:

  Firstly, the effects on digital transformation were made *both starting and culmination points* of this study and report by making the DIWA Maturity Model constitutional from the outset (compare above 'Manual'). The assessed potential effects of the inventory items are reflected in a 4-quadrants-matrix where one of the relevant axis the achievable IDL itself! (Compare Chapter 6). This 4-Quadrants-Matrix allowed for derivation of recommendations for further study and actions directly based on the achievable IDL.

  Secondly, the assessments of the inventory items regarding their potential contributions to the DIWA time frame 2022-2032 were reflected by the Technology Radar methodology (for the DIWA project's time frame) in combination with the 'Future Box' (compare 'Manual' for methodology and inventory chapters for the assessment results).

To conclude, this study and report fulfilled all of its stipulated objectives, with certain limitations as to the width and breadth of specific functional technology families surveyed and assessed due to the reasons given. In addition, a large number of relevant recommendations of the preceding Sub-Activity 2.5 were taken up and worked upon by the present Sub-Activity as appropriate. Finally, a generic model for seamless conceptual incorporation of the emerging ROV/AV domain was developed into another stand-alone document (*'Guidelines on capturing Remotely Operated Vessels (ROV) and Autonomous Vessels (AV) for Inland Waterway Transport future planning')* for general usage.

8 Glossary of terms

This Glossary lists definitions of and explanations to important terms used throughout this Report, sometimes including usage information of that term within the context of this Sub-Activity.

Accuracy 'Degree of conformance between estimated parameter at a given time and its true parameter at that time.' ([IMO-MSC.1/Circ.1575], Annex, page 29).

Autonomous Vessel (AV) is a vessel the navigating functions of which are performed autonomously as the regular case by an appropriate machinery of the vessel itself without on-board human interaction. Whether the AV actually is manned or unmanned is irrelevant in regards to its navigating functions as long as they are performed by the ship-board machinery as the intended regular case. It is assumed that it will be required that AVs are subject to a constant *Autonomous Vessel Monitoring & Contingency Response functionality* performed at an *Autonomous Vessel Control Centre (AVCC)* while navigating autonomously. As part of the contingency response, an AV may fall back to become an ROV (or even a traditionally operated vessel, for that matter).

Autonomous Vessel Control Centre (AVCC) is a shore-based centre that monitors and controls an AV and is operated by or on behalf of the shipping company that also operates the AV(s). Since an AV, by its very definition, does not need a human operation or control in regular cases, there is still a requirement that the AV is constantly monitored and contingency response is active in non-regular modes of operation or even malfunction of the AV. Hence, Autonomous Vessel Monitoring & Contingency Response is the main functionality to be performed by the AVCC. Since an AV may fall-back to an ROV as part of the contingency response, the AVCC may also fall-back to an RCC.

Autonomous Vessel Monitoring & Contingency Response is an important functionality supposed to be performed by the Autonomous Vessel Control Centre (AVCC).

Candidate Technology is a technology which is under specific consideration at a different mode of transport and considered falling into the technology scope of Sub-Activity 3.5 and which will be briefly introduced and assessed in particular for its potential applicability to the IWT fairway & navigation domain and, if so, for its contribution to the digital transformation of the IWT fairway & navigation domain.

Centre is a part of a shore-based organisation dedicated to and set apart for the provision of certain functionalities – here: relevant for shipping – and which is staffed to that purpose with adequately trained personnel and equipped with technical entities required to adequately support the functionalities provided at the centre.

Connected Fairway & Navigation means that advanced digital features have been aligned with partners; that the exchange of information is done by default; and that full real-time situational pictures are digitally available for the fairway(s) and the inland waterway vessels' navigation. It may be assumed that 'digital situational pictures' is a paraphrase of what is commonly known as 'digital twin' of the entity under consideration. This IDL is abbreviated with the Roman numeral II. For details refer to [DIWA SuAc3.5 2022b].

Consistent Common Reference System (CCRS) 'A sub-system or functions for acquisition, processing, storage, surveillance and distribution of data and information providing identical and obligatory reference to sub-systems and subsequent functions to other connected equipment or units as available.' ([IMO-MSC.1/Circ.1575], Annex, page 30).

Co-operative technology is a technology where both the vessels and the field infrastructure of fairway or waterway need to be equipped appropriately with corresponding components in order to allow for the desired functionalities. Any kind of radio communication technology is co-operative by definition, for example. With the increase of the operational relationships to be supported by functional and physical links provided by co-operative technologies and with the increase of the digitalisation level, co-operative technologies will be proliferated, which in turn has specific consequences and results in requirements to be met.

Datalink Communications is communications in its most fundamental architectural setup, namely consisting of a mobile side, an infrastructure side, and the links in-between ('three-sides-of-the-coin architecture'), that is covering the full chain of the data flow from its ultimate source – in the case of a human entered by a (dedicated) HMI – to its ultimate destination ('sink' in ITC parlour) – in the case of a human displayed on a (dedicated) HMI again. The interfaces to the ultimate sources or sinks of the data are thus integral parts of the datalink communications.

Data product is a term foundational to the IHO S-100 framework as IHO's adaptation of the ISO 19100 series. There, data product is defined as a 'dataset or dataset series that conforms to a data product specification' ([ISO 19131:2007], paragraph 4.6).[54] 'A data product specification is a precise technical description which defines a geospatial data product. It describes all features, attributes and relationships of a given application and their mapping to a dataset. It includes general information for data identification as well as information for data content and structure, reference system, data quality aspects, data capture, maintenance, delivery and metadata' ([IHO S-100), 11-1). Data products are delivered by Data-as-a-service technologies from data product vendors to data product using machines at user sites, such as shipboard ECDIS.

Digital Transformation 'is the adoption of digital technology by an organization. Common goals for its implementation are to improve efficiency, value or innovation' [Wikipedia-EN 2022a].

Digitised Fairway & Navigation means that an overarching vision (for the digital transformation of fairway & navigation) has been established; that advanced digital features are implemented within confined topical domains ('silos') of the fairway and/or inland waterway vessels' navigation; and that a limited real-time time situational pictures are digitally available for the fairway(s) and the inland waterway vessels' navigation. This IDL is abbreviated with the Roman numeral I . For details refer to [DIWA SuAc3.5 2022b].

DIWA-Adaptability is a metric that reflects the ease (or difficulty) to adapt an item to the IWT fairway & navigation domain. For details refer to [DIWA SuAc3.5 2022b].

DIWA-Adaptation Resource Demand is a metric that reflects the amount of resources needed for the adaptation of an item to the IWT fairway & navigation domain. For details refer to [DIWA SuAc3.5 2022b].

DIWA-IDL Impact of an item under consideration is a metric stating that the item has the potential to contribute to achieving the IDL stated – or, if a range of IDLs is given, to achieve at least the minimum IDL stated and at best the maximum IDL stated. For details refer to [DIWA SuAc3.5 2022b].

DIWA Maturity Model is a maturity model pre-given by the DIWA project framework that is based on the much more elaborate Capability Maturity Model but simplified and adapted to the needs and specifics of IWT. For details refer to [DIWA SuAc3.5 2022b].

DIWA-Technology Radar shows the 'qualitative proximity' or 'relative unavoidability' of many technologies and/or trends compared to the present state of the art of the domain under consideration at a glance. The present state of the domain under consideration is located at the centre spot of the diagram: The closer an item, such as technology or trend, is located to that centre, the higher the 'degree of imminence' to the domain under consideration; the further distant an item is, the more less likely it is that the item will be introduced in the domain under consideration soon or at all (if also far away towards the margins). If an item is

[54] The 2022 edition of the IHO S-100 standard (Ed 5.0.0) uses the 2007 edition of the ISO 19131 standard as a normative reference ([IHO S-100], paragraph 11-2.1).

located on a straight 'collision course', the more likely it is unavoidable for introduction to the domain under consideration. For details refer to [DIWA SuAc3.5 2022b].

DIWA-Technology Readiness Level is a metric for a technology under consideration stating its inherent technological readiness to be deployed to an application domain, which is regularly the one for which the technology was developed for. The readiness metric ranges from 'invention' to 'market expansion'. Hence, 'market expansion' would also imply that a technology has acquired the maturity to also transcend its original application domain. For details refer to [DIWA SuAc3.5 2022b].

Dry-to-Wet designates a general and generic adaptability route of an item, where 'wet' in the context of this report regularly designates the IWT fairway & navigation domain. In some cases, an indirect adaptability route via the maritime domain is discussed, in which case the adaptability route is labelled Dry-to-Wet(Maritime)-to-Wet(IWT).

Entity is a generic designation for any generic object class being an essential functional part of the IWT fairway & navigation domain, such as 'vessel' (and subclasses), 'centres', 'waterway field infrastructure', and 'data objects'. (NB: 'Entity' should not be confused with 'item (under consideration)'.)

Estuary ship is a vessel that has been designed and equipped in accordance with the rules in force at estuaries, if introduced by the competent authority to cater for the specific situations in estuaries.

Field Infrastructure (of fairway or waterway) is a summary term used in the context of DIWA to generically describe all kind of (digital) electronic technical entities and components deploy along or for a fairway or waterway for (digital) electronic interaction with vessels. If vessels need to be equipped specifically for that (digital) electronic interaction with field infrastructure, the technology used for that interaction is called co-operative.

Functional link uses certain technical protocols and encodings in addition to (a) Physical Link(s) to establish data exchange channels with certain relevant characteristics. Relevant characteristics of the data transmission determined by Functional Links are regularly in particular identification of participants, session-orientation, security, and resilience. A Functional link may still be agnostic of the contents and purposes of the data transmitted, depending on the operational purpose it is designed for or tailored too.

'Future Box' is the part of the roadmap developed to describe and determine the migration towards the DIWA desired IDLs of the IWT fairway & navigation domain that is outside of the DIWA time frame, i.e. beyond 2032. As such, the 'Future Box' is the part of any DIWA (Item) Radar that is most remote from present. For details refer to [DIWA SuAc3.5 2022b].

Global Navigation Satellite System(s) (GNSS) is an umbrella term for a group of radio navigation satellite systems, such as – in alphabetical order – BDS (CN), Galileo (EU), Glonass (RU), and GPS (US). While one GNSS alone regularly provides PNT data sufficiently, there were reasons to not solely rely on GNSS for safe navigation. These gave rise to the term Resilient Position, Navigation, Timing (Resilient-PNT).

Human-Machine-Interface (HMI) 'The part of a system an operator interacts with. The interface is the aggregate of means by which the users interact with a machine, device, and system. The interface provides means for input, allowing the users to control the system and output, allowing the system to inform the users.' ([IMO-SN.1/Circ.288], App. 1)

H2H-Nautical Datalink Communications is a Nautical Datalink Communications established between two humans, using a Human-Machine interfaces at the communication terminals on both sides. Abbreviated: H2H-NDLC.

H2M-Nautical Datalink Communications is a Nautical Datalink Communications established between a human and a machine, using a Human-Machine interface at the communication terminal of the human side and a Machine-to-Machine interface at the communication terminal of the machine side. Abbreviated: H2M-NDLC.

IDL-Match-Principle states that that the entities involved in the same operational relationship demonstrate the same IDL. For details refer to [DIWA SuAc3.5 2022b].

IDL-Mismatch occurs if and when the IDL-Match-Principle cannot be met e.g. due to a border situation of whatever kind.

Inland-CSSA see *IWT Fairway & Navigation Common Shore System Architecture*

Inland-SSSA see *IWT Fairway & Navigation Standard Shipboard Navigation System Architecture*

Inland waterway vessel is 'a vessel intended solely or mainly for navigation on inland waterways' ([UNECE-Res61], 1-2.3).

Inland waterway leisure craft is used here as a synonym to the UNECE term 'recreational craft', which is defined as 'a vessel other than a passenger vessel, intended for sport or pleasure' ([UNECE-Res61], 1-2.25),

Integrated navigation system (INS) 'An INS is a composite navigation system which performs at least the following tasks: collision avoidance, route monitoring thus providing <added value> for the operator to plan, monitor and safely navigate the progress of the vessel' ([IMO-SN.1/Circ.288], App. 1).

Integration 'Combining of data, functions and/or operations to accomplish a high-level aim' ([IMO-SN.1/Circ.288], App. 1).

Integrity is 'the ability to provide users with information within a specified time when the system should not be used for navigation including measures and/or indicating of trust.' ([IMO-MSC.1/Circ.1575], Annex, page 30).

Intelligent IWT is achieved when *both* the IWT fairway & navigation and the IWT logistics domains have reached the highest IWT Digitalisation Level 'Intelligent' during the IWT digital transformation process.

Intelligent Fairway & Navigation means that the digital transformation of fairway and navigation would have been completed; that Artificial Intelligence assists in the optimisation of processes related to fairway provision, operation and maintenance as well as in the optimisation of inland waterway vessels' navigation processes proper; that prediction algorithms are in place to support fairway & navigation processes; and that there are implemented standard responses in fairway provision, operation and maintenance processes as well as inland waterway vessels' navigation processes. This IDL is abbreviated with the Roman numeral III. For details refer to [DIWA SuAc3.5 2022b].

Inventory item is an item of either a technology-oriented architecture, or an individual technology, or a useful combination thereof that is part of the inventory of this report.

Item (under consideration) is the subject of introduction and assessment for potential adaptation to the IWT fairway & navigation domain. Different (Sub-)Activities of DIWA cover different classes or families of items, such as business use cases, operational procedures, regulations, technologies, or technological trends. In several (Sub-)Activities there is the task to establish an inventory of items under consideration, thus rendering 'inventory items'. (NB: An item should not be confused with an entity (of the IWT fairway & navigation domain)).

IWT Common Shore System Architecture (Inland-CSSA) is a generic and layered system engineering architecture for the technical services provided by a shore-based stakeholder's shore system adapted to the IWT fairway & navigation domain that would consist most fundamentally of the following service groups: Data Collection and Data Transfer services; Value-added Data Processing services; User Interaction Service, and Gateway Service. The context for the Inland-CSSA is provided by the Overarching IWT Fairway & Navigation Architecture.

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IWT Digitalisation Level (IDL) defines the degree of digital transformation an entity has acquired. This metric is defined for the IWT fairway & navigation domain in ([DIWA 2021b], 5). The different levels are – from least to highest – 'reactive', 'organised', 'digitised', 'connected', and 'intelligent'. For details refer to [DIWA SuAc3.5 2022b].

IWT fairway & navigation domain comprises all aspects related to the navigation of vessels from berth to berth by using the fairways and their infrastructure provided. The complementary term for fairway & navigation domain is the IWT logistics domain. Both terms have been coined within the framework of the DIWA Maturity Model (compare [DIWA 2021b], 4), to allow to conceptually express requirements of the DIWA desired synchromodality precisely.

IWT Fairway & Navigation Standard Shipboard Navigation System Architecture (Inland-SSSA) is a generic and layered system engineering architecture for shipboard navigation equipment adapted to the IWT fairway & navigation domain that would consist most fundamentally top to bottom of an Operational Layer that would include the HMI at 'helmsman's position'; a Data Processing Layer that would include the M2M interfaces to other electronic shipboard systems of the same inland waterway vessel; and an Sensor/Source Layer that would include M2M interfaces to the physical links. The context for the Inland-SSSA is provided by the Overarching IWT Fairway & Navigation Architecture.

IWT Fairway & Navigation System Interconnection Architecture (ISIA) is a generic system engineering architecture aiming at identifying all kinds of interconnections between entities of the IWT fairway & navigation domain as derived from their operational relationships, thereby indicating what functional and physical link communication technologies are being used for what domain of interconnections. The ISIA has identified the Vessel-to-Vessel communications domain, the On-board communications domain, the Vessel-to-Field-Infrastructure communications domain, the Wireless-to-Fixed communications domain, and the Fixed-to-Fixed communications domain. The context for the IWT Fairway & Navigation System Interconnection Architecture is provided by the Overarching IWT Fairway & Navigation Architecture.

IWT Infrastructure Site Architecture is an adaptation of the balise system engineering architecture adapted to the IWT fairway & navigation domain allowing for at least the following use cases: Co-operative position and ID determination of the vessel passing by; upload of data relevant for navigation from IWT infrastructure site to vessel while passing by; download of data gathered and stored at vessel to IWT infrastructure site while passing by. Generic instances of the IWT Infrastructure Site Architecture are the 'Smart Hectometre Stone', the 'Smart AtoN', and the 'Smart Bridge' (useful combinations). The context for the IWT Infrastructure Site Architecture is provided by the Overarching IWT Fairway & Navigation Architecture.

IWT Recognised PNT Provision is a system of one or more recognised GNSS(s), one or more recognised satellite and/or terrestrial GNSS augmentation system(s), and one or more recognised terrestrial backup position fixing system(s) postulated for future use in the IWT fairway & navigation domain for (all) tasks related to Position-Navigation-Timing.

IWT Reference Architecture (IRA) is an architectural framework adapted from the Maritime Architecture Framework (MAF) to IWT that would allow IWT domain business, operational and technical perspectives be brought together within the IWT socio-technical system background for harmonisation and eventual convergence. Via the MAF the IRA is informed by the Smart Grid Architecture Model (SGAM) and thereby by the Reference Architecture Model for Industry 4.0 (RAMI).

M2M-Nautical Datalink Communications is Nautical Datalink Communications established between two machines as sender/recipients, using Machine-to-Machine interfaces at the communication terminals on both sides.

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Mixed Traffic designates fairway a traffic situation where sea-going vessels and/or estuary ships are operating concurrently with inland waterway ships and/or inland waterway leisure crafts.

Mode awareness 'The perception of the mariner regarding the currently active Modes of Control, Operation and Display of the INS including its subsystems, as supported by the presentations and indications at an INS display or workstation' ([IMO-SN.1/Circ.288], App. 1).

Nautical Datalink Communications is Datalink Communications designed and established for the purposes of vessels' navigation (as opposed to e.g. Controller-Pilot Datalink Communications at aviation). The context for the Nautical Datalink Communications (architecture) is provided by the Overarching IWT Fairway & Navigation Architecture.

Operational Relationship is any relationship between a vessel and another vessel or between a vessel and a centre that is relevant for the navigation of the vessel or vessels. A specific instance of an operational relationship is an Operational Service provided from ashore.

Operational Service in the context here is a consistent and concurrent set of functionalities for one specified part or facet of the overall navigation process. An Operational Service always, by its very definition, instantiates an Operational Relationship. For its context compare the Overarching IWT Fairway & Navigation Architecture.

Organised Fairway & Navigation means that specialists deliver changes using established process(es); that traditional digital features prevail; and that digital capabilities are being built. This IDL has been abbreviated '**0+**' throughout this report. For details refer to [DIWA SuAc3.5 2022b].

Overarching IWT Fairway & Navigation Architecture is the most fundamental generic system architecture that provides an overview of the generic entities involved in data/information flow from an ultimate source to an ultimate sink, and their relationships. The Overarching IWT Fairway & Navigation Architecture also provides the context for the Nautical Datalink Communications (architecture), the IWT Infrastructure Site Architecture, the IWT Fairway & Navigation System Interconnection Architecture (ISIA), the Inland-SSSA and the Inland-CSSA.

Physical Link is a data transmission performed by a (radio) communication technology while regularly being agnostic of the contents and purposes of the data transmitted, i.e. the Physical Link employs the communication technology as a 'carrier' for the data transmitted. Relevant characteristics of the data transmission determined by Physical Links are regularly e.g. range/coverage, bandwidth/transmission speed, and thus time behaviour.

Reactive Fairway & Navigation means that there is no overarching vision for the digital transformation of fairway & navigation; that changes require 'heroics' to accomplish them; that management is sceptical about digitalisation; and that unfocused digital initiatives are common. This IDL has been abbreviated '**0-**' throughout this report. For details refer to [DIWA SuAc3.5 2022b].

Recognised Position, Navigation, Timing is the set of systems contributing to (Resilient) PNT explicitly recognised by a competent body, in particular when considering fulfilment of carriage requirements at the shipboard side and provision requirements for the shore side.

Resilience 'is the ability of a system to detect and compensate external and internal disturbances, malfunction and breakdowns in parts of the system. This should be achieved without loss of functionalities and preferably without degradation of their performance' ([IMO-MSC.1/Circ.1575], Annex, page 30).

Resilient Position, Navigation, Timing (Resilient-PNT) Global Navigation Satellite Systems (GNSS) (see glossary entry on that) are the main source for PNT data at a vehicle. However, all GNSS operate by the same principle und thus share a 'common mode of failure'. To mitigate this, augmentation systems and terrestrial radio navigation systems have been designed and deployed globally. An alternative to radio navigation are position determination sensors on-board the vehicle, that don't use any radio communications to gain their position fixes, by employing e.g. motion inertia of a vehicle or map matching techniques when scanning the mapped environment. A comprehensive overview from a maritime perspective is given in [IMO-MSC.1/Circ.1575], Figure 4.

Remote Control Centre (RCC) is a shore-based centre that performs the remote operation of an ROV and is operated by or on behalf of the shipping company that also operates the ROV(s). RCC appears to be an established term beyond DIWA's scope and is used here for that reason, although remote control, strictly speaking, may be limited in scope compared to remote operation.

Remotely Operated Vessel (ROV) is a vessel the navigating functions of which are performed remotely as the regular case from a *Remote Control Centre* (RCC) by a human at that centre. Whether an ROV is actually manned or unmanned is irrelevant in regards to its navigating functions as long as they are performed remotely as the intended regular case. ROV appears to be an established term beyond DIWA's scope, too.

Remote Operation of Vessel is the main functionality supposed to be performed by a Remote Control Centre (RCC) on a regular basis. This functionality generally requires a high-availability, high reliability and very low-latency H2M-Nautical Datalink Communications between the Remotely Operated Vessel (ROV) (machine side) and the RCC (human side). This is a generic term defined solely for the purposes of the present Sub-Activity; there may be different names used outside that scope to designate the same functionality.

Sea-going ship is 'a vessel intended mainly for navigation at sea' ([UNECE-Res61],1-2.4). A sea-going ship has been designed and equipped in accordance with rules relevant to (international) sea voyages; the rules for international sea voyages have been mainly defined by the International Maritime Organization.

Service Portfolio (declaration / provision) is the set of individual services provided by a shore-based stakeholder (authority, vendor of data products, etc.). A service portfolio exists conceptually even if not explicitly declared by the stakeholder as soon as this stakeholder is providing at least one service, and a service portfolio also exists even if it is just one service provide (i.e. a service portfolio of one). When the intended or actual provision of a service portfolio is declared publically beforehand, this may be beneficial for planning and application building for the IWT fairway & navigation eco-system.

Situation awareness 'is the mariner's perception of the navigational and technical information provided, the comprehension of their meaning and the projection of their status in the near future, as required for timely reaction to the situation. Situation awareness includes mode awareness'([IMO-SN.1/Circ.288], App. 1).

Smart Hectometre Stone is a 'useful combination' of the IWT Infrastructure Site Architecture and of the necessary set of technologies for V2I/I2V co-operative interaction applied to upgrade existing hectometre stones,

Smart Grid 'A smart grid is an electricity network that can integrate in a cost-efficient manner the behaviour and actions of all users connected to it (generators and/or consumers) in order to ensure economically efficient, sustainable power system with high levels of quality and security of supply and safety' [CEN-CENELEC 2022].

Smart Sensoring uses the data gathered by a wide range of sensors placed on board vessels, on the fairway or on-shore, to derive – potentially after some post-processing by in particular AI techniques – operationally relevant information for the purposes of in particular positioning, collision avoidance and object detection, tracking & tracing, status monitoring and motion detection.

Technical Service in the context of this study and report is a consistent and concurrent set of technical functionalities for one specified part or facet of the overall navigation process provided from ashore to shipboard sides. For its context compare the Overarching IWT Fairway & Navigation Architecture.

Traditionally Operated Vessel is a vessel the navigating functions of which are performed by a human on-board by using appropriate Human-Machine-Interfaces (HMI) designed for that task. The degree of automation supportive of that task is encapsulated within the 'traditional operation' and is therefore irrelevant here as long as the human on-board is in charge of the vessel's navigation.

Useful combination is a category of inventory items under consideration that combines the other two categories Architecture and Candidate Technology or Technologies with the goal to achieve an overall technical functionality superior to the sum of the individual item's functionalities or with the goal to arrive at fall-back arrangements.

Vessel is an umbrella term for 'an inland waterway vessel or a sea-going ship' ([UNECE-Res61], 1-2.2) (and as opposed to a 'craft' that is defined as an even broader umbrella term as 'a vessel or item of floating equipment' (([UNECE-Res61], 1-2.1).

Wet-to-Wet designates a general and generic adaptability route of an item, where - in the context of this report - the first 'wet' designates the maritime domain as a source and second 'wet' as the target designates the IWT domain.

9 Abbreviations

0- IWT Digitalisation Level 'Reactive'

0+ IWT Digitalisation Level 'Organised'

2G 2nd generation of digital cellular mobile telecommunications

3G 3rd generation of digital cellular mobile telecommunications

3GPP 3rd Generation Partnership Project

4G 4th generation of digital cellular mobile telecommunications

5G 5th generation of digital cellular mobile telecommunications

AI Artificial Intelligence

AIS Automatic Identification System

AMRD Autonomous Maritime Radio Devices

APCO P25 Association of Public-Safety Communications Officials (APCO) International – Project 25 (APCO-25)

ARD Application Resources Demand

ASM Application Specific Message

ATC Air Traffic Control

ATIS Automatic Transmitter Identification System

AV Autonomous Vehicle or Autonomous Vessel (depending on context)

AVCC Autonomous Vessel Control Centre

BAM Bridge Alert Management

BDS BeiDou Navigation Satellite System

BES Bridge Equipment and Systems

C-V2X Cellular Vehicle-to-Everything

CCNR Central Commission for the Navigation of the Rhine

CCRS Consistent Common Reference System

CDLMR Conventional Digital Land Mobile Radio Systems

CEN Comité Européen de Normalisation – European Committee for Standardization

CENELEC Comité Européen de Normalisation Électrotechnique – European Committee for Electrotechnical Standardization

CEPT Conférence européenne des administrations des postes et télécommunications

CESNI Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure

CIRM Comité International Radio-Maritime

CLMR Conventional Land Mobile Radio Systems

CMDS Common Maritime Data Structure

CN Core Network

CPDLC Controller-Pilot Data Link Communications

CT Candidate Technology

DGON German Institute of Navigation (Deutsche Gesellschaft für Ortung und Navigation)

dPMR Digital Private Mobile Radio

DIWA Masterplan Digitalisation of Inland Waterways project

DIWA-TRL DIWA –Technology Readiness Level

DMR Digital Mobile Radio

DLT Distributed Ledger Technology

DSC Digital Selective Calling

DSRC Dedicated Short Range Communication

DTLF Digital Transport and Logistics Forum

ECDIS Electronic Chart Display and Information System

eFTI electronic Freight Transportation Information

ENC Electronic Navigational Chart

ENE Environmental Data Evaluation Service (of the Inland-CSSA)

ENDS Electronic Navigation Data Service

ERTMS European Rail Traffic Management System

ETCS European Train Control System

ETSI European Telecommunications Standards Institute

EuRIS European River Information Services (platform)

FRMCS Future Railway Mobile Communication System

GHz Giga Hertz

GMDSS Global Maritime Distress and Safety System (GMDSS)

GNSS Global Navigation Satellite System(s)

GPS Global Positioning System

GSM Global System for Mobile Communications

GSM-R GSM for Railways

H2H-NDLC Human-to-Human (H2H) Nautical Datalink Communications

H2M-NDLC Human-to-Machine (H2M) Nautical Datalink Communications

HetNet Heterogenous Network

HF High Frequency

HMI Human-Machine-Interface

HTTP Hyper Text Transfer Protocol

I IWT Digitalisation Level 'Digitised'

II IWT Digitalisation Level 'Connected'

III IWT Digitalisation Level 'Intelligent'

I2V Infrastructure-to-Vehicle/Vessel (depending on context)

IALA International Association of Marine Aids to Navigation and Lighthouse Authorities

ICAO International Civil Aviation Organization

ID Identity

IDL IWT Digitalisation Level.

IEC International Electrotechnical Commission

IEHG Inland ECDIS Harmonization Group

IMO International Maritime Organization

IMS IWT Messaging Service (of the Inland-CSSA)

IMT International Mobile Telecommunication

IMT-2020 IMT for 2020 and beyond

Inland-AIS AIS derivative adapted specifically for the needs of IWT navigation

Inland-CSSA IWT Fairway & Navigation Common Shore System Architecture

Inland-ECDIS ECDIS developed specifically for the needs of IWT navigation

Inland-SSSA IWT Fairway & Navigation Standard Shipboard Navigation System Architecture

INS Integrated Navigation System

IPR IWT Portfolio Registry Service (of the Inland-CSSA)

IoT Internet of Things

IRA IWT Reference Architecture

IRCS Integrated Radio Communication System

ISIA IWT Fairway & Navigation System Interconnection Architecture

ISO International Organization for Standardization

ITC Inland Transport Committee of the UNECE

ITU International Telecommunication Union

ITS Intelligent Transport System(s)

ITS G5 ITS tailored Vehicle-to-Everything WLAN system

IWT Inland Waterway Transport

JSON JavaScript Object Notation

LPWAN Low Power Wide Area Network

LTE Long-Term Evolution

LTE-V2X LTE Vehicle-to-Everything

M2M-NDLC Machine-to-Machine (H2M) Nautical Datalink Communications

MAF Maritime Architecture Framework

MASS Maritime Autonomous Surface Ships

MCP Maritime Connectivity Platform

MF Medium Frequency

MHz Mega Hertz

MKD Minimum Keyboard and Display

MMS Maritime Mobile Service

MMTC Massive machine type communicatoins

MRCP Maritime Radio Communications Plan (of IALA)

MSI Maritime Safety Information

MSC Maritime Safety Committee (of IMO)

NAVDAT Navigational Data

NAVTEX Navigational Telex

NCSR Navigation, Communications, Search & Rescue Sub-Committee (of IMO)

NDLC Nautical Datalink Communications (Architecture)

NXDN Next Generation Digital Narrowband

OBU On-board Unit

OEM Original equipment manufacturer

PIANC World Association for Waterborne Transport Infrastructure

PKI Public Key Infrastructure

PNT Position, Navigation, Timing

PNT-DP (shipborne) PNT Data Processing

POS Position Determination Service (of the Inland-CSSA)

PS Performance Standards (of IMO)

QZSS Quasi-Zenith Satellite System

R-Mode Ranging Mode

RAINWAT Regional Arrangement on the Radiocommunication Service for Inland Waterways

RAMI Reference Architecture Model for Industry 4.0

RAN Radio Access Network

RAT Radio Access Technology

Resilient-PNT Resilient Position, Navigation, Timing

RF Radio frequency

RIS River Information Services

ROV Remotely Operated Vehicle or Remotely Operated Vessel (depending on context)

RCC Remote Control Centre

REST Representational State Transfer

RR Radio Regulations (of ITU-R)

RSTT Railway Radiocommunication System(s) between Train and Trackside

S-Mode to switch into a default mode by single or simple operation action

SDA Ship Data Consistency Analysis Service (of the Inland-CSSA)

SECOM SEcure COMmunications protocol as defined in EN IEC 63173-2

SGAM Smart Grid Architecture Model

SID Shipping Industry Database Service (of the Inland-CSSA)

SIP Strategy Implementation Plan (of IMO's e-navigation strategy)

SMCP Standard Marine Communication Phrases

SOLAS Safety Of Life At Sea (convention)

SRD Short Range Devices

SSL/TLS Secure Sockets Layer / Transport Layer Security

TETRA Terrestrial Trunked Radio

TRL Technology Readiness Level(s)

UIC International Union of Railways

UKC Under Keel Clearance

UMTS Universal Mobile Telecommunications System

UNECE United Nations Economic Commission for Europe

UNECE ITC UNECE Inland Transport Committee

URLLC Ultra-low latency communications

V2I Vehicle-to-Infrastructure or Vessel-to-Infrastructure (depending on context)

V2V Vehicle-to-Vehicle or Vessel-to-Vessel (depending on context)

V2X Vehicle-to-Everything or Vessel-to-Everything (depending on context)

VDE VHF Data Exchange (of VDES)

VDE-TER VDES terrestrial component

VDE-SAT VDES satellite component

VDES VHF Data Exchange System

VEC Vector Chart Service (of the Inland-CSSA)

VHF Very High Frequency

VLC Visual Light Communications

WLAN Wireless Local Area Network

WRC World Radiocommunication Conference (of ITU)

WWRNS World Wide Radionavigation System (by IMO)

10 Bibliography

The Bibliography is arranged in alphabetical order of the reference mnemonics, which are created in accordance with the Author-Year-Principle, by default. Organisations acting as authors are given with their usual abbreviation (compare list of abbreviations), followed by the document designation used by that organisation regularly.

To reference a bibliography entry the following format is used throughout:
([Author/Publishing Body-Token], <page>|<section>)

[ACCSEAS 2015] Oltmann, Jan-Hendrik et al. 2015. *ACCSEAS e-Navigation Architecture Report.*

[Ando 2021] Ando, Hideyuki. 2021. *Scope of ship-shore communication panel. Presentation. ISO, 3rd ISO/TC8/WG10 Ship-shore Communication Panel Group Meeting, 16th-17thMar 2021.*

[Carson-Jackson+Pokorny 2021] Carson-Jackons, Jillian, and Peter Pokorny. 2021. 'Maritime communications'. In: [Fiorini+Gupta 2021], 177-227.

[CEN-CENELEC-ETSI 2012] CEN-CENELEC-ETSI Smart Grid Coordination Group. 2012. *Smart Grid Reference Architecture.* November 2012. https://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_reference_architecture.pdf Accessed 04 October 2022.

[CEN-CENELEC 2022] CEN-CENELEC. 2022. *Smart Grids and Meters.* https://www.cencenelec.eu/areas-of-work/cen-cenelec-topics/smart-grids-and-meters/smart-grids/ Accessed 11 October 2022.

[China-MSA 2021] China Maritime Safety Agency. 2021. "The Progress and Prospect on e-Navigation of China MSA". *14th IALA Symposium.* Rotterdam. 12 – 16 April 2021.

[DIWA 2021a] DIWA Masterplan Digitalisation of Inland Waterways Project. 2021. *Work Programme V2.0 (March 2021).*

[DIWA 2021b] DIWA Masterplan Digitalisation of Inland Waterways Project. 2021. *Masterplan's content and framework V2.0. Final Version. (March 2021).*

[DIWA-SuAc2.5 2022] DIWA Masterplan Digitalisation of Inland Waterways Project. 2022. *Sub-Activity 2.5: ITS, ERTMS, E-Navigation.*

[DIWA-SuAc3.5 2022a] DIWA Masterplan Digitalisation of Inland Waterways Project. 2022. *Sub-Activity 3.5: Guidelines on capturing Remotely Operated Vessels (ROV) and Autonomous Vessels (AV) for Inland Waterway Transport future planning.* (December 2022).

[DIWA-SuAc3.5 2022b] DIWA Masterplan Digitalisation of Inland Waterways Project. 2022. *Sub-Activity 3.5: Manual on Inland Waterway Transport Digitalisation and Assessment Methodology.* (December 2022).

[European Standards] European Standards. www.eu-standard.eu Accessed 17 October 2022.

[EU 2020/1426] EU Commission. 2020. "Commission Implementing Decision (EU) 2020/1426 of 7 October 2020 on the harmonised use of radio spectrum in the 5875-5935 MHz frequency band for safety-related applications of intelligent transport systems (ITS) and repealing Decision 2008/671/EC." *Office Journal of the European Union.* 09 Oct 2020. L328/19-22.

[Fiorini+Gupta 2021] Fiorini, Michele and Natalie Gupta (Eds). 2021. *ICT Solutions and Digialisation in Ports and Shipping.* London: The Institution of Engineering and Technology.

[IALA 2022] Jeon, Minsu (IALA Technical Coordinator). 2022. *S-200 World. Presentation given to the IALA ARM Committee on its 16th meeting,* 24 October 2022.

[IALA-R0140] IALA. 2015. *IALA Recommendation R0140. The Architecture for Shore-Based Infrastructure 'Fit for e-Navigation'. Edition 2.1.* St-Germain-en-Laye: IALA. May 2015. https://www.iala-aism.org/product/r0140/?download=true Accessed 11 October 2022.

[IALA-G1113] IALA. 2015. *IALA Guideline 1113. Design and Implementation Principles for Harmonised System Architectures of Shore-Based Infrastructure. Edition 1.1.* St-Germain-en-Laye:

IALA. May 2015. https://www.iala-aism.org/product/g1113/?download=true Accessed 11 October 2022.

[IALA-G1114] IALA. 2015. *IALA Guideline 1114. A Technical Specification for the Common Shore-based System Architecture. Edition 1.1.* St-Germain-en-Laye: IALA. May 2015. https://www.iala-aism.org/product/g1114/?download=true Accessed 11 October 2022.

[IALA-G1117] IALA. 2017. *Guideline G1117. VHF Data Exchange System (VDES) Overview. Ed. 2.0.* St-Germain-en-Laye. IALA. December 2017.

[IALA-G1128] IALA. 2022. *Guideline G1128. The Specification of e-Navigation Technical Services. Ed. 1.4.* St-Germain-en-Laye. IALA. July 2022.

[IALA-G1133] IALA. 2019. *Guideline 1133 Requirement Traceability.* St-Germain-en-Laye: IALA. June 2019. https://www.iala-aism.org/product/g1133/?download=true Accessed 11 October 2022.

[IALA-G1158] IALA. 2020. *Guideline 1158. VDES R-Mode.* St-Germain-en-Laye. IALA. December 2020.

[IALA MRCP] IALA.2017. *Maritime Radio Communications Plan (MRCP).* Ed. 3. St-Germain-en-Laye. IALA. December 2017.

[IALA NAVGUIDE 2018] IALA. 2018. *NAVGUIDE 2018. Marine Aids to Navigation Manual. 8th Edition.* St-Germain-en-Laye: IALA. https://www.iala-aism.org/product/iala-navguide-2018-digital-copy/?download=true Accessed 11 October 2022.

[IALA R0124] IALA. 2020. *R0124 (A-124) The AIS Service.* Ed 2.2. St-Germain-en-Laye: IALA. September 2020.

[IEC 62923-Series] IEC. 2018. *Maritime navigation and radiocommunication equipment and systems – Bridge Alert Management, Part 1: Operational and performance requirements, methods of testing and required test results (IEC 62923-1:2018), Part 2: Alert and cluster identifiers and other additional features (IEC 62923-2:2018).* Geneva: IEC.

[IEC-63173-1] IEC. 2021. *IEC 63173-1, Maritime navigation and radiocommunication equipment and systems – Data Interface – Part 1: S-421 Route Plan Based on S-100. Edition 1.0.* Geneva: IEC. June 2021.

[IEC-63173-2] IEC. 2022. *IEC63173-2-ED1. Maritime navigation and radiocommunication equipment and systems – Data interface – Part 2: Secure communication between ship and shore (SECOM). Final Draft International Standard 80/1030/FDIS.* Geneva: IEC. 11 March 2022.

[IHO S-100] IHO. 2022. *S-100 – Universal Hydrographic Data Model. Edition 5.0.0.* Monaco: IHO. December 2022.

[IMO-A.811(19)] IMO. 1995. *Performance Standards for a Shipborne Integrated Radiocommunication System (IRCS) when used in the GMDSS.* London: IMO. 23 November 1995.

[IMO-A918(22)] IMO. 2001. *IMO Assembly Resolution A.918(22). IMO Standard Marine Communication Phrases.* London: IMO. 29 November 2001.

[IMO-A.1046(27)] IMO. 2011. *IMO Assembly Resolution A.1046(27). Worldwide Radionavigation System.* London: IMO. 20 December 2011.

[IMO-MSC-Res-232] IMO. 2006. *Resolution MSC.232(82). Adoption of the Revised Performance Standards for Electronic Chart Display and Information Systems (ECDIS).* London: IMO. 5 December 2006.

[IMO-MSC-Res-302] IMO. 2010. *Resolution MSC.302(87). Adoption of Performance Standards for Bridge Alert Management.* London: IMO. 17 May 2010.

[IMO-MSC-Res- 401] IMO. 2015. *Resolution MSC.401(95). Performance Standards for Multi-System Shipborne Radionavigation Receivers.* London: IMO. 8 June 2015.

[IMO-MSC-Res-432] IMO. 2017. *Resolution MSC.432(98). Amendments to Performance Standards for Multi-System shipborne radionavigation receivers (Resolution MSC.401(95)).* London: IMO. 16 June 2017.

[IMO-MSC-Res-466] IMO. 2019. *Resolution MSC.466(101). Amendments to the Performance Standards for the Presentation of Navigation-Related Information on Shipborne Navigational Displays (Resolution MSC.191(79)).* London: IMO. 14 June 2019.

[IMO-MSC-Res-467] IMO. 2019. Resolution *MSC.467(101). Guidance on the Definition and Harmonization of the Format and Structure of Maritime Services in the Context of e-navigation.* London: IMO. 14 June 2019.

[IMO-MSC/Circ.982] IMO. 2000. *MSC/Circ.982. Guidelines on Ergonomic Criteria for Bridge Equipment and Layout.* London: IMO. 20 December 2000.

[IMO-MSC.1/Circ.1389] IMO. 2010. *MSC.1/Circ.1389. Guidance on Procedures for Updating Shipborne Navigation and Communication Equipment.* London: IMO. 07 December 2010.

[IMO-MSC.1/Circ.1512] IMO. 2015. *MSC.1/Circ.1512. Guideline on Software Quality Assurance and Human-Centred Design for e-navigation.* London: IMO. 13 July 2015.

[IMO-MSC.1/Circ.1575] IMO. 2017. *MSC.1/Circ.1575. Guidelines for Shipborne Position, Navigation and Timing (PNT) Data Processing.* London: IMO. 16 June 2017.

[IMO-MSC.1/Circ.1593] IMO. 2018. *MSC.1/Circ.1593. Interim Guidelines for the Harmonized Display of Navigation Information received via Communication Equipment.* London: IMO. 25 May 2018.

[IMO-MSC.1/Circ.1595] IMO. 2018. *MSC.1/Circ.1595. E-navigation Strategy Implementation Plan – Update 1.* London: IMO. 25 May 2018.

[IMO-MSC.1/Circ.1609] IMO. 2019. *MSC.1/Circ.1609. Guidelines for the Standardization of User Interface Design for Navigation Equipment.* London: IMO. 14 June 2019.

[IMO-MSC.1/Circ.1610] IMO. 2019. *MSC.1/Circ.1610. Initial Descriptions of Maritime Services in the Context of e-navigation.* London: IMO. 14 June 2019.

[IMO-MSC.1/Circ.1644] IMO. 2021. *MSC.1/Circ.1644. Deliberate Interference with the United States' Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS).* London: IMO. 18 October 2021.

[IMO-MSC-104/15/7] EU countries, EU-Commission and Republic of Korea. 2021. *Proposal for a new output to amend the revised ECDIS performance standards (resolution MSC.232(82)) to facilitate a standardized digital exchange of vessels' route plans.* London: 2021. 1 July 2021.

[IMO-MSC105-INF.10] Finland, Germany, Poland. 2022. *R-Mode (Ranging-Mode), terrestrial positioning for resilient navigation.* London: IMO. 15 February 2022.

[IMO-NAV58/6] Norway. 2012. *Development of an e-Navigation Strategy Implementation Plan. Report from the Correspondence Group on e-navigation to NAV 58.* IMO-NAV58/6. 30 March 2012. London: IMO.

[IMO-NCSR7/INF.6] IALA. 2019. *3rd Generation partnership project (3GPP) in the maritime domain.* London: IMO. 5 November 2019.

[IMO-NCSR8/14/1] IMO Secretariat. 2021. *IMO NCSR 8/14/1. Report to the Maritime Safety Committee.* London. IMO. 21 May 2021.

[IMO-NCSR-9-5] Germany. 2022. *IMO NCSR 9/5. Report of the Correspondence Group on Development of Generic Performance Standards for shipborne satellite navigation system receiver equipment.* IMO: London. 19 February 2022.

[IMO-NCSR9/12] IMO Secretariat. 2021. *Report of the seventeenth meeting of the Joint IMO/ITU Experts Group on Maritime Radiocommunication Matters.* London: IMO. 16 November 2021.

[IMO-NCSR9/12/7] EU-Countries and EU Commission. 2022. *Comments on the proposed revision of Recommendation ITU-R M.1371-5, including the proposal on deactivation or cancellation protocol for AIS-enabled locating devices.* London: IMO. 30 March 2022.

[IMO-NCSR9/12/9] IALA. 2022. *NCSR 9/12/9.Proposal on WRC-23 agenda item 10*. London: IMO. 18 April 2022.

[IMO-NCSR9/16/1] IHO, CIRM and INTERTANKO. 2022. *Proposed amendments to resolution MSC.232(82)*. London: IMO. 17 March 2022.

[IMO-NCSR9/16/2] China and CIRM. 2022. *Proposed amendments to MSC.1/Circ.1503/Rev.1 and amendments to ECDIS Performance Standards (Resolution MSC.232(82))*. London: IMO. 18 April 2022.

[IMO-NCSR9/16/4] Canada. 2022. *Comments on document NCSR 9/16/1 on proposed amendments to resolution MSC.232(82)*. London: IMO. 28 April 2022.

[IMO-NCSR9/24] IMO NCSR. 2022. *NCSR 9/24. Report to the Maritime Safety Committee*. IMO: London. 5 August 2022. (including NCSR 9/24-Add.1 containing Annexes).

[IMO-NCSR9-INF.12] IALA. 2022. *Report of the trial on digital voice communication in the maritime VHF band*. London: IMO. 18 April 2022.

[IMO-NSCR9-INF.13] IALA. 2022. *VDES ranging mode (R-Mode)*. London: IMO. 18 April 2022.

[IMO-NCSR9-INF.14] China. 2022. *Considerations on the implementation arrangement for onboard ECDIS updates in relation to IHO standards*. London: IMO. 18. April 2022.

[IMO-NCSR9-INF.15] Republic of Korea. 2022. *Ongoing status of using IMT technology for providing e-navigation services in the near coast of the country*. London: IMO. 18 April 2022.

[IMO-SN.1/Circ.243,Rev2] IMO. 2019. *SN.1/Circ.243/Rev.2. Guidelines for the Presentation of Navigation-Related Symbols, Terms + Abbreviations*. London: IMO. 14 June 2019. + SN.1/Circ.243/Rev.2-Corr.1 of 11 Nov 2020.

[IMO-SN.1/Circ.274] IMO. 2008. *SN.1/Circ.274. Guidelines for application of the modular concept to performance standards*. London: IMO. 10 Dec 2008.

[IMO-SN.1/Circ.288] IMO. 2010. *SN.1/Circ.288. Guidelines for Bridge Equipment and Systems, their Arrangement and Integration (BES)*. London: IMO. 02 June 2010.

[IMO-SN.1/Circ.289] IMO. 2010. *SN.1/Circ.289. Guidance on the Use of AIS Application-Specific Messages*. London: IMO. 02 June 2010.

[IMO-SN.1/Circ.329] IMO. 2016. *SN.1/Circ.329. Recognition of the Beidou Satellite Navigation System (BDS) as a Component of the World-wide Radionavigation System*. London: IMO. 21 November 2014.

[IMO-SN.1/Circ.334] IMO. 2016. *SN.1/Circ.334. Recognition of the Galileo Global Navigation Satellite System as a Component of the Worldwide Radionavigation System*. London: IMO. 20 May 2016.

[IMO-SN.1/Circ.340] IMO. 2020. *SN.1/Circ.340. Recognition of the Indian Regional Navigation Satellite System (IRNSS) as a Component of the Worldwide Radionavigation System*. London: IMO. 11 November 2020.

[Intergo 2021] Intergo – International Centre for Safety Ergonomics & Human Factors. 2021. *Human factors root causes of accidents in inland navigation: HMI and wheelhouse design. Phase 2a-Report*. Amersfoort. Publically available via CESNI: http://files.ccr-zkr.org/cesnipt21_94en_2.pdf

[ISO 19131:2007] International Standards Organization. 2007. *ISO 19131:2007. Geographic Information – Data product specification*. Geneva. ISO.

[ITU-Council-Res 1399] ITU Council. 2020. *Resolution 1399 - Agenda of the World Radiocommunication Conference (WRC-23)*. Geneva: ITU. 28 July 2020.

[ITU-R-ITS-HDB-2021] ITU. 2021. *Intelligent transport systems. Handbook on Land Mobile (including Wireless Access)*. Volume 4. 2021 edition. Geneva: ITU. 2021.

[ITU-R-REC-M1371] ITU. 2014. *Recommendation ITU-R M.1371-5. Technical characteristics for an automatic identification system using time division multiple access in the VHF maritime mobile frequency band*. Geneva: ITU. February 2014.

Co-funded by the European Union

[ITU-R-REC-M2083] ITU. 2015. *Recommendation ITU-R M.2083-0. IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond.* Geneva: ITU. September 2015.

[ITU-R-REC-M2092] ITU. 2022. *Recommendation ITU-R M.2092-1. Technical characteristics for a VHF data exchange system in the VHF maritime mobile band.* Geneva: ITU. February 2022.

[ITU-R-REC-M2101] ITU. 2017. *Recommendation ITU-R M.2101-0. Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies.* Geneva: ITU. February 2017.

[ITU-R-REC-M2135] ITU. 2019. *Recommendation ITU-R M.2135-0. Technical characteristics of autonomous maritime radio devices operating in the frequency band 156-162.05 MHz.* Geneva: ITU. October 2019.

[ITU-R-REC-SM2103] ITU. 2017. *Recommendation ITU-R SM.2103-0. Global harmonization of short-range devices categories.* Geneva: ITU. September 2017.

[ITU-R-REP-M2418] ITU. 2017. *Report ITU-R M.2418-0. Description of Railway Radiocommunication Systems between Train and Trackside (RSTT).* Geneva: ITU. November 2017.

[ITU-R-REP-M2474] ITU. 2019. *Report ITU-R M.2474-0. Conventional digital land mobile radio systems.* Geneva: ITU. September 2019.

[ITU-R-REP-SM2153] ITU. 2022. *Report ITU-R M.2153-9. Technical and operating parameters and spectrum use for short-range radiocommunication devices.* Geneva: ITU. July 2022.

[ITU-R-REP-SM2422] ITU. 2019. *Report ITU-R SM.2422-1. Visible light for broadband communications.* Geneva: ITU. June 2019.

[ITU-R-REP-SM2423] ITU. 2018. *Report ITU-R SM.2423-0. Technical and operational aspects of low power wide area networks for machine-type communication and the Internet of Things in frequency ranges harmonised for SRD operation.* Geneva: ITU. June 2018.

[ITU-RR] ITU. 2020. *ITU Radio Regulations. 2020 edition.* Geneva: ITU.

[ITU-WRC2019-Res-361] ITU-R World Radiocommunication Conference 2019. *Resolution 361 (WRC-19). Consideration of possible regulatory actions to support modernization of the Global Maritime Distress and Safety System and the implementation of e-navigation.* Geneva: ITU.

[ITU-WRC2019-Res-363] ITU-R World Radiocommunication Conference 2019. *Resolution 363 (WRC-19). Considerations to improve utilization of the VHF maritime frequencies in Appendix 18.* Geneva: ITU.

[ITU-WRC2019-Res-812] ITU-R World Radiocommunication Conference 2019. *Resolution 812 (WRC-19). Preliminary agenda for the 2027 World Radiocommunication Conference.* Geneva: ITU

[Oltmann 2021a] Oltmann, Jan-Hendrik. 2021. 'Is <5G> for VTS and e-navigation?' *14th IALA Symposium.* Rotterdam. 12 – 16 April 2021.

[Oltmann 2021b] Oltmann, Jan-Hendrik. 2021. "Emerging radio communication technologies in the maritime domain – an overview with a critical evaluation of technologies' promises. In: [Fiorini+Gupta 2021], 229-252.

[Megow 2020] Megow, Jörg. 2020. *Reference Architecture Models for Industry 4.0, Smart Manufacturing and IoT. An Introduction.* Berlin: Begleitforschung PAiCE. https://www.digitale-technologien.de/DT/Redaktion/DE/Downloads/Publikation/PAiCE_Leitfaden_Reference_Architecture.pdf?__blob=publicationFile&v=6 Accessed 19 Sep 2022.

[RAINWAT 2016] Austria, Belgium, Bulgaria et al. 2016. *Regional Arrangement on the Radiocommunication Service for the Inland Waterways (RAINWAT), Revised 11 Oct 2016.*

https://www.bipt.be/operators/publication/rainwat-agreement. Accessed 20 Sep 2022.

[Schneider 2014] Schneider, Peter. 2014. 'Conversion of light buoys in the North and Baltic Seas on compact lighting units with LED- and solar technology, AIS and remote monitoring'. *Proceedings of the IALA Conference.* (2014).

[Schröder-Fürstenberg 2021] Schröder-Fürstenberg. Jens. 2021. 'E-Navigation and shore-based monitoring systems'. In: [Fiorini+Gupta 2021], 69-106.

[Schweichhart 2016] Schweichhart, Karsten. 2016. *Reference Architectural Model Industrie 4.0 (RAMI 4.0). An Introduction.* Plattform Industrie4.0. https://ec.europa.eu/futurium/en/system/files/ged/a2-schweichhart-reference_architectural_model_industrie_4.0_rami_4.0.pdf Accessed 04 October 2022.

[SKYbrary 2022] SKYbrary. 2022. 'Controller Pilot Data Link Communications (CPDLC). https://www.skybrary.aero/articles/controller-pilot-data-link-communications-cpdlc. Accessed 02 August 2022.

[Turner 2022] Turner, William, II. 2022. 'Fifty shades of green in the waters of the Rhine Danube IWT Corridor with particular reference to river gorge vortexes' *The Lyrical IWT Traveller.* 22(2022)2, 48-56.

[UIC-FRMCS-Brochure] UIC Rail System Department. 2020. *FRMCS and 5G for rail: challenges, achievements and opportunities.* Paris: UIC. https://uic.org/spip.php?action=telecharger&arg=3283 Accessed 23 March 2022.

[UIC-FRMCS-FU7100] UIC FRMCS Functional Working Group. 2020. F*uture Railway Mobile Communication System. User Requirements Specification.* Paris: UIC. 19 February 2020. https://uic.org/IMG/pdf/frmcs_user_requirements_specification-fu_7100-v5.0.0.pdf Accessed 23 March 2022.

[UNECE ITC 2022] United Nations Economic Commission for Europe, Inland Transport Committee (ITC). 2022. *ITC Strategy until 2030.* Adopted 19-22 Feb 2019, published January 2022. https://unece.org/sites/default/files/2022-01/ITC%20Strategy%20until%202030.pdf Accessed 23 Sep 2022.

[UNECE-Res61] United Nations Economic Commission for Europe. 2020. *Resolution No. 61, Revision 2. Recommendations on Harmonized Europe-wide Technical Requirements for Inland Navigation Vessels. (ECE/TRANS/SC.3/172/Rev2).* Geneva. https://unece.org/sites/default/files/2021-07/ECE-TRANS-SC.3-172-Rev.2e_for_web.pdf. Accessed 04 August 2022.

[Weinert et al 2016] Weinert, Benjamin, A. Hahn, A. Bolles, S. Doyle, A. Galperin, J. Jensen, M. Lind, T. Lutz, K. Nielsen, J-H. Oltmann, M. Renz, C. Rihacek, A. Rydlinger, M. Semann, M. Siegel, and M. Uslar. 2016 *Maritime Architecture Framework.* Abstract to e-Navigation Underway 2016 Conference.

[Weinert et al 2017] Weinert, Benjamin, M. Uslar, and A. Hahn, 2017. „System-of-systems: How the maritime domain can learn from the Smart Grid". *2017 International Symposium ELMAR.*

[Weinert 2018] Weinert, Benjamin. 2018. *Framework zur Architekturbeschreibung von sozio-technischen maritimen Systemen.* Dissertation, Oldenburg University.

[Wikipedia-EN 2022a] English Wikipedia. 2022. *Digital Transformation.*15 Sep 2022. Accessed 21 Sep 2022.

[Wikipedia-EN 2022b] English Wikipedia. 2022. *Controller-pilot data link communications.* 06 July 2022. Accessed 11 October 2022.

11 Sources of Figures and Tables

The sources of the Figures used in this report are own creations by the present author (Jan-Hendrik Oltmann) *unless indicated otherwise as follows:*

- Figure 1: IWT Digitalisation Levels – Source: [DIWA 2021b], 5
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- **Figure 27: Confidentiality vs. Timing Behaviour in communication profiles** - Source: own assessment, informed by [Ando 2021] and [ITU-REC-M2083].
- **Figure 28: Overarching IWT Fairway & Navigation Architecture; functional links highlighted + NDLCs introduced** - Adapted from Figure 18.
- **Figure 29: Overview of SECOM protocol's ecosystem with required entities** - Own creation as informed by [EN IEC 63173-2 SECOM],Figure 1.
- **Figure 30: Overarching IWT Fairway & Navigation Architecture with physical links highlighted** - Adapted from Figure 18.
- **Figure 31: General design objectives of ITU-R when defining the IMT-2020 and beyond** - Source: [ITU-REC-M2083], Figure 2. Used with permission by ITU.
- **Figure 32: Cell layout adaptability of IMT-2020** - Source: [ITU-REC-M2101], Figure 1. Used with permission by ITU.
- **Figure 33: Overview radio communication technologies in the maritime domain** - Source: [Oltmann 2021].
- **Figure 36: Overarching IWT Fairway & Navigation Architecture with entities highlighted that employ sensor technologies** - Adapted from Figure 18.
- **Figure 37: Overarching IWT Fairway & Navigation Architecture with IWT Fairway & Navigation Data Structure highlighted as affecting all data domain entities** - Adapted from Figure 18.
- **Figure 38: 'S-200 World' - Overview of IALA's contribution to the 'S-100 World'** - Source: [IALA 2022]. Used with permission.
- ***Figure* 41: 'Solarkompaktaufsatz' as a maritime example of an existing 'infrastructure site' optimised for remote, self-contained operation in a robust environment** – Source: [Schneider 2014]. Used with permission.
- **Figure 42: Example of integration of shore-based services using Inland-CSSA and being populated with relevant CTs and higher IDL-functionality** - Source: Adapted from Figure 20.

The sources of the Tables used in this report are own creations by the present author (Jan-Hendrik Oltmann) unless indicated otherwise as follows:

- **Table 1: DIWA Maturity Level impact assessment (DIWA IDL Impact)** - Source: [DIWA SuAc3.5 2022b].
- **Table 2: Assessment metrics as defined for DIWA** - Source: [DIWA SuAc3.5 2022b].
- **Table 13: Compilation of meaning of the Axis of Views** - Source: Adapted from [Schweichhart 2016], 9-10.

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12 Annex – Recommendations from Sub-Activity 3.5

12.1 General

Recommendations *all* carry their *respective context* in order to reduce ambiguity for the reader. The recommendations are therefore, for ease of reference, labelled with a *meaningful name* – as opposed to a running number.

Recommendations are *arranged in the order of appearance in the report* of Sub-Activity 3.5 to reflect the topical progression from general via specific inventory items (architectures, candidate technologies, useful combinations) to final conclusions, Thus, the reader may easily consult the report for further information and rationales.

Recommendations which should be treated as *a matter of priority* within the DIWA project ***and also in the roadmap*** are indicated with a margin highlight.

Recommendations are grouped into *Study*- and *Action-Recommendations*. While the planning for further study also is an action in itself and is thus also incorporated in the Action-Recommendation, a Study-Recommendation implies that for the topic at hand additional studies are *required to arrive at the capability for final decision making*. For Action-Recommendations one or more Study-Recommendations may need to be accomplished beforehand.

For each Recommendation, an estimation is given to the *size of work incurred* by following this Recommendation: 'C' meaning, what a committee can possibly accomplish in the course of several meetings, over e.g. two years; 'SubAc' meaning a sub-activity workload of a project; 'Ac' meaning an activity workload of a project with the view to integrate several facets of the topic at hand; 'P' meaning a dedicated two- to three-year project solely for the topic indicated; 'Multiple P' meaning more than one project.

12.2 Study-Recommendations

- Study-REC-Complete-NDLC-Identification: *Identify* all generically-specific operational relationships in the IWT fairway & navigation domain taking into account the advent of Remotely Operated and Autonomous Vessels which could and should be modelled and implemented as H2H-, H2M-, and M2M-NDLCs.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-NDLC-for-Voicelesser-IWT-Fairway&Navigation-Domain-1: *Study* the potential of employing the NDLC for voicelesser communications in the IWT fairway & navigation domain following the example of aviation, based on proper encoding of standard IWT fairway & navigation phraseology, in particular when migrating towards IDLs II and III, where 'digital information exchange by default' is required.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-NDLC-for-Voicelesser-IWT-Fairway&Navigation-Domain-2: *Conduct* an IWT fairway & navigation regulatory scoping exercise with the goal of extensive introduction of H2H- and H2M-NDLCs and provide migration suggestions how operational procedures and regulations would need to be amended to facilitate a voicelesser IWT fairway & navigation domain.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-NDLC-Consequences-for-Technical-Standards: *Determine* the consequences of extensive application of H2M-, H2M-, and M2M-NDLCs to the domain of technical standards, in particular when migrating towards IDLs II and III, where 'digital information exchange by default' is required, and provide migration suggestions how technical standards would need to be amended.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-NDLC-Consequences-for-Data-Quality-Demands: *Determine* the consequences of extensive application of H2M-, H2M-, and M2M-NDLCs to the data quality required, and provide migration suggestions how data quality management would need to be amended to that end.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-NDLC-Cyber-Security-Demands: *Determine* the consequences of extensive application of H2M-, H2M-, and M2M-NDLCs on cyber security and the consequential requirement, and provide migration suggestions to that end.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-IWT-Fairway&Navigation-System-Interconnection-Architecture-1: *Study* the definition and the implications of the ISIA for technical standardisation, regulations, data quality, and cyber security in more detail with the goal to eventually reap its benefits as indicated.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-IWT-Fairway&Navigation-System-Interconnection-Architecture-2: *Map* the NDLCs as determined in particular in Study-REC-Complete-NDLC-Identification to the ISIA to fulfil the requirements of the NDLCs identified.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Service-Portfolio-Declaration-Demands-On-Regulations-1: *Study* the required operational, regulatory, and legal pre-requisites to facilitate and safe-guard public service portfolio declarations by authorities.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Service-Portfolio-Declaration-Demands-On-Regulations-2: In addition to Study-REC-Service-Portfolio-Declaration-Demands-On-Regulations-1, *study* the *digital* public service portfolio declarations by authorities when migrating towards IDLs II and III, where 'digital information exchange as a default' would particularly prompt even digitally declared service portfolios.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Service-Portfolio-Declaration-Demands-On-Technical-Standards: *Study* the required technical standards and/or amendment of existing technical standards to facilitate public digital service portfolio declarations by authorities when ramping up towards IDLs II and III.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Service-Portfolio-Declaration-Demands-On-Data-Management: *Study* the required data management and required data quality to facilitate public digital service portfolio declarations by authorities when ramping up towards IDLs II and III.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Service-Portfolio-Declaration-Demands-On-Cyber-Security: *Study* the required cyber security measures to safe-guard public digital service portfolio declarations by authorities when ramping up towards IDLs II and III.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-IWT-Recognised-PNT-Provision-1: *Study* the pre-requisites for the introduction of the concept of a Recognised PNT Provision in the IWT fairway & navigation domain and a formal recognition process for its components in operational, technical, and regulatory terms, following – as a suggestion – the example of the IMO formal recognition.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-IWT-Recognised-PNT-Provision-2: As a consequential follow up to Study-REC-PNT-IWT-Recognised-PNT-Provision-2, *study* in particular the *specific* GNSS, satellite-based and/or terrestrial augmentation as well as terrestrial backup systems under consideration globally to be candidate components for the IWT Recognised PNT Provision and provide migration path suggestions to that end.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Shipboard-PNT-Processing-Entity: *Study* the pre-requisites to a future introduction of a shipboard PNT processing entity, taking into account relevant developments in the maritime domain. and provide migration path suggestions to that end.

Estimation of size of work incurred: 'SubAc'

- Study-REC-Communication-Profiles-1: *Study– as a matter of priority –* the operational, regulatory, data quality, and cyber security requirements for communication profiles of the operational relationships supported by (digital) data exchange between traditionally operated vessels on one hand with waterway infrastructure and/or administration's Inland Waterway Centres on the other hand, taking into account relevant developments in the maritime domain.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Communication-Profiles-2: As a follow up to Study-REC-Communication-Profiles-1 – *as a matter of priority –* specifically *build a case* for continuation of open access digital data communication links in the future.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Communication-Profiles-3: *Study* the operational, regulatory, data quality, and cyber security requirements for communication profiles of the operational relationships between ROV and/or AV and associated Remote Control and Autonomous Vessel Control centres on one hand with waterway infrastructure and/or administration's Inland Waterway Centres on the other hand, taking into account relevant developments in the maritime domain.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Carrier-Agnostic-Usage-Of-ASM: *Study* the use cases, benefits, and operational, regulatory, data quality, and cyber security requirements for the carrier-agnostic usage of Application Specific Messages in the IWT fairway & navigation domain in general for transmission by different relevant physical link technologies (without considering their data content definitions), taking into account developments in the maritime domain.

  Estimation of size of work incurred: 'SubAc' to 'Ac'

- Study-REC-SECOM-Impact-1: *Study* based on the results of the prioritised recommendations Study-REC-Communication-Profiles-1 and Study-REC-Communication-Profiles-2 – *as a matter of priority –* the applicability, pre-requisites, resulting requirements and benefits of the two options 'Full Functionality SECOM implementation' and 'Just Secure Data Protocol SECOM implementation' at IWT fairway & navigation domain.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-SECOM-Impact-2: As motivated by Study-REC-SECOM-Impact-1, *study – as a matter of priority –* potential impact on IWT Fairway & Navigation in general, and on the ICT infrastructure of authorities in particular of the required SECOM data product ecosystem as implied by EN IEC 63173-2.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-VDES: *Study* based on the results of the prioritised recommendations Study-REC-Communication-Profiles-1 and Study-REC-Communication-Profiles-2 – *as a matter of priority* – the operational, regulatory, and technical pre-requisites, resulting requirements and benefits of VDES adaptation to IWT fairway & navigation domain *per se,* taking into account current developments in the maritime domain.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-IMT-2020: *Study* based on the results of the prioritised recommendations Study-REC-Communication-Profiles-1 and Study-REC-Communication-Profiles-2 – *as a matter of priority –* the operational, regulatory, and technical pre-requisites, resulting requirements and benefits of an IMT-2020 adaptation to IWT fairway & navigation domain (data, voice) *per se,* taking into account current developments in the maritime domain.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-CDLMR: *Study* based on the results of the prioritised recommendations Study-REC-Communication-Profiles-1 and Study-REC-Communication-Profiles-2 – *as a matter of priority –* the operational, regulatory, and technical pre-requisites, resulting requirements and benefits of an CDLMR adaptation to IWT fairway & navigation domain (voice primarily, potentially data) *per se*, taking into account current developments in the maritime domain.

Estimation of size of work incurred: '**SubAc**'

- **Study-REC-VLC**: *Study* the operational, regulatory, and technical pre-requisites, resulting requirements and benefits of a Visual Light Communication (VLC) adaptation to IWT fairway & navigation domain, taking into account increasing automation in the IWT fairway & navigation domain at large and the advent of autonomous vessels in particular.

  Estimation of size of work incurred: '**SubAc**'

- **Study-REC-Vessel-Swarm-Collection-Of-Data**: *Study* the potential adaption of vessel swarm collection of environmental and/or waterway infrastructure related data forwarded to IWT fairway & navigation authorities and ports by appropriate (radio) communication means, as under consideration in other modes of transport, in particular maritime, and identify the operational, architectural, technical and regulatory pre-requisites.

  Estimation of size of work incurred: '**SubAc**'

- **Study-REC-Earth-Exploration-Satellite-Technologies**: *Study* the potential usage of relevant environmental and/or waterway infrastructure related data received from Earth Exploration Satellite system providers in the IWT fairway & navigation domain, as under consideration in other modes of transport, in particular maritime, and identify the operational, architectural, technical and regulatory pre-requisites.

  Estimation of size of work incurred: '**SubAc**'

- **Study-REC-Space-Weather-Sensors**: *Study* the potential usage of relevant space weather data related received from space weather observatories in the IWT fairway & navigation domain, as under consideration in other modes of transport, and identify the operational, architectural, technical and regulatory pre-requisites.

  Estimation of size of work incurred: '**SubAc**'

- **Study-REC-Carrier-Agnostic-Use-Of-ASM**: *Study* the operational, regulatory, and technical pre-requisites, resulting requirements and benefits of an carrier agnostic use of the internationally defined Application Specific Message (ASM) in the IWT fairway & navigation domain, taking into account specifically the definition work done and current developments in the maritime domain.

  Estimation of size of work incurred: '**SubAc**'

- **Study-REC-Data-Model-For-Voicelesser-IWT**: *Study – as a matter of priority* - the operational, regulatory, and technical pre-requisites, resulting requirements and benefits of the introduction of a data model for using Nautical Datalink Communication (NDLC) with the goal of a voicelesser IWT fairway & navigation domain, taking into account specifically the stepwise approach described, the definition work done in the maritime domain, as well as the examples provided by the aviation and rail domains.

  Estimation of size of work incurred: '**SubAc**' to '**Ac**'

- **Study-REC-Imminent-Introduction-of-S100-World-Paradigm-1**: *Study – as a matter of priority* - the potential implications of the introduction of the 'S-100 World' paradigm on the present state as well as on the migration towards higher IDLs of the IWT fairway & navigation domain, as suggested by IMO's pending revision of its ECDIS Performance Standards while other international organisations concurrently continue to develop other standards and recommendations for the S-100 framework, with a view to identify the operational, architectural, technical and regulatory pre-requisites for facilitating its introduction.

  Estimation of size of work incurred: '**SubAc**' to '**Ac**'

- **Study-REC-S101(ECDIS)-Introduction**: *Study – as a matter of priority* - the potential implications of the introduction of S-100-based ECDIS in parallel to the S-57-based ECDIS on Inland-ECDIS in particular and on the digitalisation of IWT Fairway & Navigation at large, as IMO is about to revise their existing ECDIS Performance Standards and thereby, amongst other things, allow for the practical usage for navigation of the IHO developed S-100-based ECDIS (S-101), with a view to identify the operational, architectural, technical and regulatory pre-requisites for facilitating its introduction.

Estimation of size of work incurred: 'SubAc' to 'Ac'

- Study-REC-S100-Metadata-Registry-Impact: As motivated by Study-REC-Imminent-Introduction-of-S100-World-Paradigm – *study* the potential impact of the S100-Metadata-Registry of the S-100-Framework which is built in conformity to ISO 19135 Metadata standard and allows for, amongst many other things, the capture of data quality per data object.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Imminent-Introduction-of-S100-World-Paradigm-2: As motivated by Study-REC-Imminent-Introduction-of-S100-World-Paradigm-1, *study* ***– as a matter of priority –*** the potential implications of the introduction of all other existing or planned data products of the 'S-100 World', as forecasted by IHO, on the present state as well as on the migration towards higher IDLs of the IWT fairway & navigation domain, with a view to identify the operational, architectural, technical and regulatory pre-requisites for facilitating their potential introduction.

  Estimation of size of work incurred: 'SubAc' to 'Ac'

- Study-REC-Standardised-Route-Plan-Exchange-via-S421: *Study* ***– as a matter of priority –*** the potential implications of the introduction of a standardised route exchange of route plans using S-421 in the context of a S-100-based ECDIS on the present state as well as on the migration towards higher IDLs of the IWT fairway & navigation domain, as suggested by IMO's pending decision, with a view to identify the operational, architectural, technical and regulatory pre-requisites for facilitating its introduction.

  Estimation of size of work incurred: 'SubAc' to 'Ac'

- Study-REC-IALA-S200-World-Data-Product-Adoption: *Study* ***– as a matter of priority –*** the potential implications of the introduction of the S-200 World data product specifications as under development at IALA to the IWT fairway & navigation domain as soon as IMO will have taken the fundamental decision to migrate towards the S-100 based ECDIS (and potentially S-421 based route exchange) on the present state as well as on the migration towards higher IDLs of the IWT fairway & navigation domain, with a view to identify the operational, architectural, technical and regulatory pre-requisites for facilitating their introduction.

  Estimation of size of work incurred: 'SubAc' to 'Ac'

- Study-REC-Reconciliation-of-ASM-with-S100-World-Data-Models: *Study* ***– as a matter of priority –*** the options to reconcile the several different data modelling approaches (existing ASM definitions, the emerging S-100 world way of data modelling as well as existing IWT specific data modelling approaches), taking into account a criteria base from an IWT fairway & application point of view.

  Estimation of size of work incurred: 'SubAc' to 'Ac'

- Study-REC-Data-Evalution-Methods+Technologies: *Study* the increasing application of data evaluation methods and technologies, in particular decision support methods & technologies, in other modes of transport, in particular maritime, with the view to adapt those to both the shipboard and the shore-side functional entities of the IWT fairway & navigation domain.

  Estimation of size of work incurred: 'SubAc'

- Study-REC-Smart-IWT-Infrastructure-Site-Deployment: *Study* the operational, regulatory, data quality, and cyber security requirements for a generic 'smart' IWT infrastructure site deployment along relevant inland waterways, taking in particular into account the operational relationships to be supported by 'smart' IWT infrastructure sites to traditionally operated vessels, ROVs and AVs on one hand with different classes of shore based centres on the other hand.

  Estimation of size of work incurred: 'SubAc' to 'Ac'

- Study-REC-Inland-SSSA: *Study* ***– as a matter of priority –*** the operational, regulatory, data quality, and cyber security requirements for a mature generic system engineering concept based on the Inland-SSSA from an administration's perspective (as working together in DIWA), taking into account potential future imports of technologies from other modes of transport and taking in particular into account the operational relationships between traditionally operated vessels, ROVs and AVs on one hand with different classes of 'smart' IWT infrastructure and shore based centres on the other hand.

Estimation of size of work incurred: 'SubAc' to 'Ac'

12.3 Action-Recommendations

- Action-REC-NDLC-for-Voicelesser-IWT-Fairway&Navigation-Domain: *Assess* the consequences of the extensive introduction of NDLCs in general and voicelesser IWT fairway & navigation domain; in particular when migrating towards IDLs II and III, where 'digital information exchange by default' is required.

  Estimation of size of work incurred: 'P'

- Action-REC-IWT-Fairway&Navigation-System-Interconnection-Architecture-1: *Adopt – as a matter of priority -* the ISIA as the standard architectural tool for harmonisation of all relevant aspects of system interconnections supporting all relevant operational relationship by communication means, in particular the Nautical Datalink Communications.

  Estimation of size of work incurred: ('Ac' to) 'P'

- Action-REC-Overarching-IWT-Fairway&Navigation-Architecture: *Adopt – as a matter of priority -* the Overarching IWT Fairway & Navigation Architecture to be used extensively throughout the IWT fairway & navigation domain for architectural guidance.

  Estimation of size of work incurred: 'C'

- Action-REC- Service-Portfolio-Declaration-Demands: *Facilitate and safe-guard* conventionally and digitally published service portfolio declarations by authorities when migrating towards IDLs II and III, where 'digital information exchange as a default' would particularly prompt even digitally declared service portfolios.

  Estimation of size of work incurred: 'P'

- Action-REC-IWT-Recognised-PNT-Provision: *Implement* in the IWT fairway & navigation domain an IWT Recognised PNT Provision, taking into account relevant developments in the maritime domain.

  Estimation of size of work incurred: 'P'

- Action-REC-Shipboard-PNT-Processing-Entity: *Introduce* in the Inland-SSSA a shipboard PNT processing entity, taking into account relevant developments in the maritime domain.

  Estimation of size of work incurred: 'P'

- Action-REC-R-Mode-For-IWT-Fairway&Navigation-Domain: *Introduce* in the IWT Fairway & Navigation domain R-Mode as a terrestrial and backup radio navigation system based on any suitable signal-of-opportunity along the inland waterways, taking into account relevant developments in the maritime and the ITS domains.

  Estimation of size of work incurred: 'P' to 'Multiple P'

- Action-REC-Communication Profiles-1: *Determine – as a matter of priority -* the operational, regulatory, data quality, and cyber security requirements for communication profiles of the operational relationships supported by (digital) data exchange between traditionally operated vessels on one hand with waterway infrastructure and/or administration's Inland Waterway Centres on the other hand, including the necessary open access digital data communication links in the future, taking into account relevant developments in the maritime domain.

  Estimation of size of work incurred: ('Ac' to) 'P'

- Action-REC-Communication Profiles-2: *Determine* in co-operation with relevant stakeholders *– as a matter of priority -* the communication profiles of operational relationships between ROV and/or AV and associated Remote Control and Autonomous Vessel Control centres on one hand with waterway infrastructure and/or administration's Inland Waterway Centres on the other hand, taking into account relevant developments in the maritime domain.

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Estimation of size of work incurred: ('Ac' to) 'P'

- Action-REC-Carrier-Agnostic-Usage-Of-ASM: *Determine* the operational, regulatory, data quality, and cyber security requirements for the carrier-agnostic usage of Application Specific Messages in the IWT fairway & navigation domain in general for transmission by different relevant physical link technologies (without considering their data content definitions), taking into account relevant developments in the maritime domain.

  Estimation of size of work incurred: 'Ac'

- Action-REC-SECOM-Impact: *Determine – as a matter of priority -* the operational, regulatory, data quality, and cyber security requirements and consequences of the two options 'Full Functionality SECOM implementation' and/or 'Just Secure Data Protocol SECOM implementation' at IWT fairway & navigation domain, taking into account relevant developments in the maritime domain, and take appropriate actions if any of the SECOM options appears to be justified and desirable.

  Estimation of size of work incurred: 'Ac'

- Action-REC-VDES: *Determine – as a matter of priority -* the operational, regulatory, data quality, and cyber security requirements and consequences of the potential VDES adaptation to the IWT fairway & navigation domain, as appears to be justified and desirable, taking into account current developments in the maritime domain regarding radio communication technologies at large.

  Estimation of size of work incurred: 'Ac'

- Action-REC-IMT-2020: *Determine – as a matter of priority -* the operational, regulatory, data quality, and cyber security requirements and consequences of the potential IMT-2020 adaptation to the IWT fairway & navigation domain (data, voice), as appears to be justified and desirable, taking into account current developments in the maritime domain regarding radio communication technologies at large.

  Estimation of size of work incurred: 'Ac'

- Action-REC-CDLMR: *Determine – as a matter of priority -* the operational, regulatory, data quality, and cyber security requirements and consequences of the potential CDLMR adaptation to the IWT fairway & navigation domain (voice primarily, potentially data), as appears to be justified and desirable, taking into account current developments in the maritime domain regarding radio communication technologies at large.

  Estimation of size of work incurred: 'Ac'

- Action-REC-VLC: *Determine* the operational, regulatory, data quality, and cyber security requirements and consequences of the potential Visual Light Communication (VLC) adaptation to the IWT fairway & navigation domain, as appears to be justified and desirable, taking into account increasing automation in the IWT fairway & navigation domain at large and the advent of autonomous vessels in particular.

  Estimation of size of work incurred: 'Ac'

- Action-REC-Plan-For-Emerging-Sensor-Technologies: *Take appropriate actions* on emerging co-operative sensor technologies such as vessel swarm collection of environmental and/or waterway infrastructure related data, on potential usage of Earth Exploration Satellite technologies, and Space Weather Monitoring data, following the example of other modes of transport, with the view to adapt those to both the shipboard and the shore-side functional entities of the IWT fairway & navigation domain.

  Estimation of size of work incurred: ('Ac' to) 'P'

- Action-REC-Data-Model-For-Voicelesser-IWT: *Determine* the operational, regulatory, data quality, and cyber security requirements and consequences of the introduction of a data model for using Nautical Datalink Communication (NDLC) with the goal of a voicelesser IWT fairway & navigation domain, taking into account specifically the stepwise approach described, the definition work done in the maritime domain, as well as the examples provided by the aviation and rail domains.

Estimation of size of work incurred: 'P'

- Action-REC-Imminent-Introduction-of-S100-World-Paradigm: *Introduce harmonised and deploy – **as a matter of priority** –* the S-100-Framework in IWT Fairway & Navigation.

  Estimation of size of work incurred: Multiple 'P'

- Action-REC- Standardised-Route-Plan-Exchange-via-S421: *Introduce harmonised and deploy – **as a matter of priority** –* the standardised route plan exchange via EN-IEC63173-1/S-421 in IWT Fairway & Navigation, if deemed necessary after evaluation.

  Estimation of size of work incurred: 'P'

- Action-REC- IALA-S200-World-Data-Product-Adoption: *Introduce harmonised and deploy – **as a matter of priority** –* those IALA S-200 world data products deemed relevant in IWT fairway & navigation.

  Estimation of size of work incurred: 'Multiple P'

- Action-REC Reconciliation-of-ASM-with-S100-World-Data-Models: *Reconcile – **as a matter of priority** –* the different data modelling approaches represented by the existence of both the ASM and the S-100 world way of data modelling together with the exiting IWT fairway & navigation specific data modelling approaches, taking into account a criteria base from an IWT fairway & application point of view.

  Estimation of size of work incurred: 'P'

- Action-REC-Plan-For-Indepth-Study-of-Data-Evalution-Methods+Technologies: Based on studies done beforehand, *plan for implementation projects* of data evaluation methods and technologies, in particular decision support methods & technologies, *with the view to adapt those* to both the shipboard and the shore-side functional entities of the IWT fairway & navigation domain.

  Estimation of size of work incurred: 'Ac'

- Action-REC-IWT-Future-Optimum-IWT-HetNet-1: *Define the strategy and migration path – **as a matter of priority** –* to the establishment of an ISIA for selection of digital radio communication technologies for the IWT fairway & navigation domain in order to fulfil all required functionality.

  Estimation of size of work incurred: 'SuAc' to 'Ac'

- Action-REC-IWT-Future-Optimum-IWT-HetNet-2: *Define the strategy and migration path – **as a matter of priority** –* towards a potential consolidated future version of the (Inland-)AIS being complemented by the introduction of other digital radio communication technologies in parallel, taking into account current developments in the maritime domain.

  Estimation of size of work incurred: 'SuAc' to 'Ac'

- Action-REC-IWT-Future-Optimum-IWT-HetNet-3: *Define the strategy and migration path – **as a matter of priority** –* of the potential VDES adaptation to the IWT fairway & navigation domain, as appears to be justified and desirable, taking into account current developments in the maritime domain and as a preparation for a concluding evaluation amongst the digital radio communication technologies.

  Estimation of size of work incurred: 'SuAc' to 'Ac'

- Action-REC-IWT-Future-Optimum-IWT-HetNet-4: *Define the strategy and migration path – **as a matter of priority** –* of the potential IMT-2020 adaptation to the IWT fairway & navigation domain, as appears to be justified and desirable, taking into account current developments in the maritime domain and as a preparation for the a concluding evaluation amongst the digital radio communication technologies.

  Estimation of size of work incurred: 'SuAc' to 'Ac'

- Action-REC-IWT-Future-Optimum-IWT-HetNet-5: *Define the strategy and migration path – **as a matter of priority** –* of the potential CDLMR adaptation to the IWT fairway & navigation domain, as appears to be justified and desirable, taking into account current developments in the maritime domain and as a preparation for the a concluding evaluation amongst the digital radio communication technologies.

Estimation of size of work incurred: **'SuAc' to 'Ac'**

- **Action-REC-IWT-Future-Optimum-IWT-HetNet-6**: *Conduct a concluding evaluation* amongst the digital radio communication technologies and consequentially *determine the* future optimum IWT Fairway & Navigation HetNet – ***as a matter of priority*** – in order to provide all required functionalities.

  Estimation of size of work incurred: **'Ac'**

- **Action-REC-Smart-IWT-Infrastructure-Site-Deployment-1**: *Determine* the operational, regulatory, data quality, and cyber security requirements the deployment of 'smart' IWT infrastructure sites along relevant inland waterways, taking into account the necessary functional and physical co-operation of the 'smart' IWT infrastructure sites with appropriately equipped vessels ('smart' inland waterway vessels), thus requiring substantial consultation between all affected stakeholders.

  Estimation of size of work incurred: **'P'**

- **Action-REC-Smart-IWT-Infrastructure-Site-Deployment-2**: *Determine* in co-operation and agreement with all relevant stakeholders a strategic implementation plan for deployment of 'smart' IWT infrastructure sites along relevant inland waterways,

  Estimation of size of work incurred: **'Ac' to 'P'**

- **Action-REC-Inland-SSSA-Introduction-1**: *Determine* – ***as a matter of priority*** – the operational, regulatory, data quality, and cyber security requirements for an Inland-SSSA from an administration's perspective, taking into account a) potential future imports of technologies from other modes of transport and taking in particular into account b) the operational relationships between traditionally operated vessels, ROVs and AVs on one hand with different classes of 'smart' IWT infrastructure and shore based centres on the other hand.

  Estimation of size of work incurred: **'Ac' to 'P'**

- **Action-REC-Inland-SSSA-Introduction-2**: *Define and eventually adopt together with all relevant stakeholders* – based on **Action-REC-Inland-SSSA-Introduction-1** and also ***as a matter of priority*** – a mature generic system engineering concept of Inland-SSSA in all necessary detail as a common reference framework for (minimum) future shipboard functionality and equipment to be relied on by IWT fairway & navigation applications.

  Estimation of size of work incurred: **'Ac' to 'P'**

- **Action-REC-Inland-CSSA-Introduction-1**: *Determine* – ***as a matter of priority*** – a mature generic system engineering concept based on Inland-CSSA from an administration's perspective, taking into account a) the Inland-SSSA engineering concept (as defined in **Action-REC-Inland-SSSA-Introduction-2**) and b) taking in particular into account the operational relationships between traditionally operated vessels, ROVs and AVs on one hand with different classes of 'smart' IWT infrastructure and shore based centres on the other hand.

  Estimation of size of work incurred: **'SuAc' to 'A'**

- **Action-REC-Inland-CSSA-Introduction-2**: *Define and eventually adopt* – based on **Action-REC-Inland-CSSA-Introduction-1** and also ***as a matter of priority*** – a migration plan of a mature generic system engineering concept based on Inland-CSSA as a common reference framework for (minimum) future shore-based functionality and equipment.

  Estimation of size of work incurred: **'SuAc' to 'A'**

- **Action-REC-Mutually-Supportive-Architectures**: *Adopt* in the IWT fairway & navigation domain – ***as a matter of priority*** – the architectures developed to provide **one** harmonised multi-facetted common reference for the migration towards higher IDLs.

  Estimation of size of work incurred: **'C'**

- **Action-REC-Very-High-IDL-Impact-Low-Effort-Inventory-Items**: *Adopt* that relevant selection of the items in Quadrant A of the DIWA-4Quadrants-Matrix reaching IDL III that covers the required functionality in the IWT fairway & navigation domain - ***as a matter of priority and in accordance with the more specific recommendations given at each item.***

This applies to the Overarching IWT Fairway & Navigation Architecture and IWT Fairway & Navigation Common Shore System Architecture (Inland-CSSA).

Estimation of size of work incurred: 'C'

- Action-REC-High-IDL-Impact-Low-Effort-Inventory-Items: *Adopt or deploy respectively* that relevant selection of the items in Quadrant A of the DIWA-4Quadrants-Matrix reaching IDLs I + II that covers the required functionality in the IWT fairway & navigation domain – ***in accordance with the more specific recommendations given at each item***.

  This applies to: the Nautical Datalink Communications (NDLC) architecture, the IWT Fairway & Navigation System Interconnection Architecture (ISIA), the fundamental decision to transition to S-100 concurrently with the IMO ASM Data Model, usage of S-421 on route plan based on S-100, the carrier agnostic usage of ASM concurrently with SECOM, IMT-2020 or CDMLR, VDES, High bandwidth Visual Light Communications, Optimum IWT HetNet, Smart Infrastructure Site ('Smart Hectometre Stone'), Shipboard PNT Unit, formal PNT Recognition, and R-Mode.

  Estimation of size of work incurred: 'C' (adoption) to 'Multiple P' (deployment)

- Action-REC-Very-High-IDL-Impact-But-Long-Term-Development-Inventory-Items: *Adopt or deploy respectively* that relevant selection of the inventory items *in Quadrant B* of the DIWA-4Quadrants-Matrix that covers the required functionality in the IWT fairway & navigation domain ***in the medium to long run and start with the preparation for this as a matter of priority and in accordance with the more specific recommendations given at the item***.

  This applies to: the IWT Reference Architecture (IRA), the IWT Fairway & Navigation Standard Shipboard Navigation System Architecture (Inland-SSSA), the IWT Infrastructure Site Architecture, the Inland shore services integration based on Inland-CSSA, the inland shipboard equipment integration based on Inland-SSSA, and the data model for voicelesser IWT using NDLC.

  Estimation of size of work incurred: 'C' (adoption) to 'Multiple P' (deployment)

- Action-REC-Legacy-System-Treatment: *Determine* - within the context of an overarching migration path concept to be established – compelling needs for existing technologies a) to be kept (with potential modifications in detail) or b) to be kept for a period as bridge technologies and then phased-out.

  Estimation of size of work incurred: 'SuAc'

- Action-REC-Harmonisation-Need-Awareness-At-Competent-Bodies: *Trigger or foster* - ***as a matter of priority*** – at *all* existing competent bodies of the IWT fairway & navigation domain growing understanding for the need of harmonisation across *all* competent bodies in the IWT fairway & navigation domain for *any* increased digitalisation maturity.

  Estimation of size of work incurred: 'Ac' to 'P'

- Action-REC-Intermediate-Harmonisation-Stages: *Plan* – ***as a matter of priority*** - for specific intermediate stages in terms of harmonisation across the existing competent bodies of the IWT fairway & navigation domain towards a) acceptable intermediate solutions fulfilling their tasks ('stepping stones'), b) migration path(s) from one acceptable intermediate solution to the next .

  Estimation of size of work incurred: ''

- Action-REC-Need-For-Harmonisation-Governing-Body: *Promulgate for acceptance* – ***as a matter of priority*** – the notion of the one coordinating competent body ('spider in the web') needed into the migration path development.

  Estimation of size of work incurred: 'Ac' to 'P'

- Action-REC-IDL-Maturity-Round-Table: *Plan* – ***as a matter of priority*** - for establishing a IWT fairway& navigation IDL maturity round table of affected organisations.

  Estimation of size of work incurred: 'Ac' to 'P'

- Action-REC-IWT-Reference-Architecture(IRA): *Plan* for a migration path to further develop the IRA with a view to eventually adopt it as the harmonisation framework for both IWT fairway & navigation and logistics domains ***in the medium to long run and start with the preparation for this as a matter of priority,*** including further studies as needed.

  Estimation of size of work incurred: 'Ac' to 'P'

- Action-REC-Influence-Maritime-Domain: *Take a stance* by recommending areas for pro-active IWT activity with a view to be able in some future to influence maritime wet(IWT)-to-wet(Maritime) accordingly for good strategic reasons.

  Estimation of size of work incurred: 'C'