Technological Developments on digitalisation in IWT

Masterplan DIWA project, results activity 3

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Executive summary

Digitalisation in inland waterway transport refers to the integration of digital technologies and data analytics in the management and operation of inland waterway transportation systems. This includes a wide range of technologies, such as digital mapping, vessel tracking and monitoring, digital logistics management, and automation of navigational and operational processes.

From a technical perspective, digitalisation involves the use of sensors, cameras, and other digital devices to collect data on vessels, cargo, and the environment. This data can then be analysed and used to optimise the performance of the transportation system. For example, real-time vessel tracking can be used to optimise routing and scheduling, while sensor data can be used to monitor the condition of vessels and cargo and to detect potential problems.

The technological developments analysed and assessed in the scope of activity 3 of the Masterplan DIWA project deal with the following thematic areas trying to enable business requirements on the one side and revealing the great potential of technology on the other side.

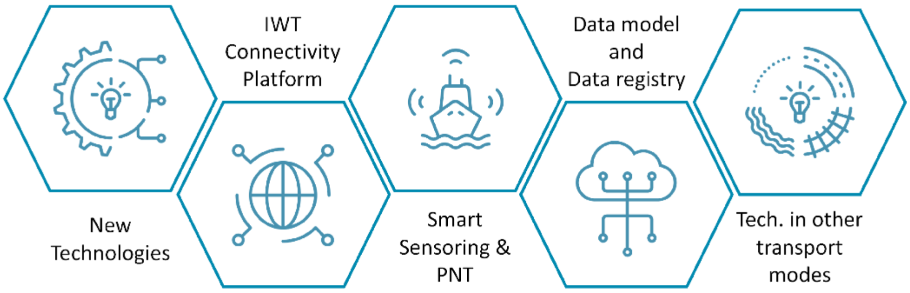

Figure 1: The five sub activities of activity 3 Technological Developments

The five studies carried out on the thematic areas followed a similar approach by describing the current state of digitalisation and deriving the future developments in the next decade based on the assessment deployed on the technology aspects (chapter 2). A summary of the five individual studies is highlighted in chapter 3, also giving the reader the chance to dive deeper in the topic via the annexed studies.

The main part of the report though, deals with the main conclusions and recommendations compiled from the full set of recommendations out of the individual studies (chapter 6.2).
Data exchange via platforms like EuRIS and interconnection with other systems (i.e. Port Community Systems, eFTI compliant applications, etc.) via standardised interfaces will play a key role in developing IWT. Having a harmonised data model (RIS.net) and advanced technologies like AI, Big Data, Cloud Computing implemented will further enhance data management. Gathering high quality data from sensors at vessels or infrastructure will utilise efficient processes and enable higher degrees of automation. This will only succeed with advanced communication links between the involved stakeholders, making connectivity and secure backup communication links a key pillar of digitalisation. But also, the sensor accuracy and reliability on-board of vessels needs to be improved via e.g. PNT systems being the prerequisite for remote control or higher degrees of automation. All this could be advanced within defined architecture models for IWT, always considering the need for good governance throughout all processes and involved players to bring digitalisation forward in a coordinated approach (chapter 4). These key findings depict the basis for the future state of digitalisation being "digital by default" supported by a holistic digital twin representation and synchro modal processes further detailed in chapter 5.

Finally, the main recommendations are assessed and plotted on a roadmap. The technology-oriented recommendations are evaluated using a technology assessment methodology providing a statement on the effort, adaptability needs and envisioned maturity level reached by implementing those recommendations (chapter 6.3). The main conclusions and measures are plotted on the "roadmap to

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the sun" schema (Figure 2) highlighting the time and roadmap component as a summarised output of this report.

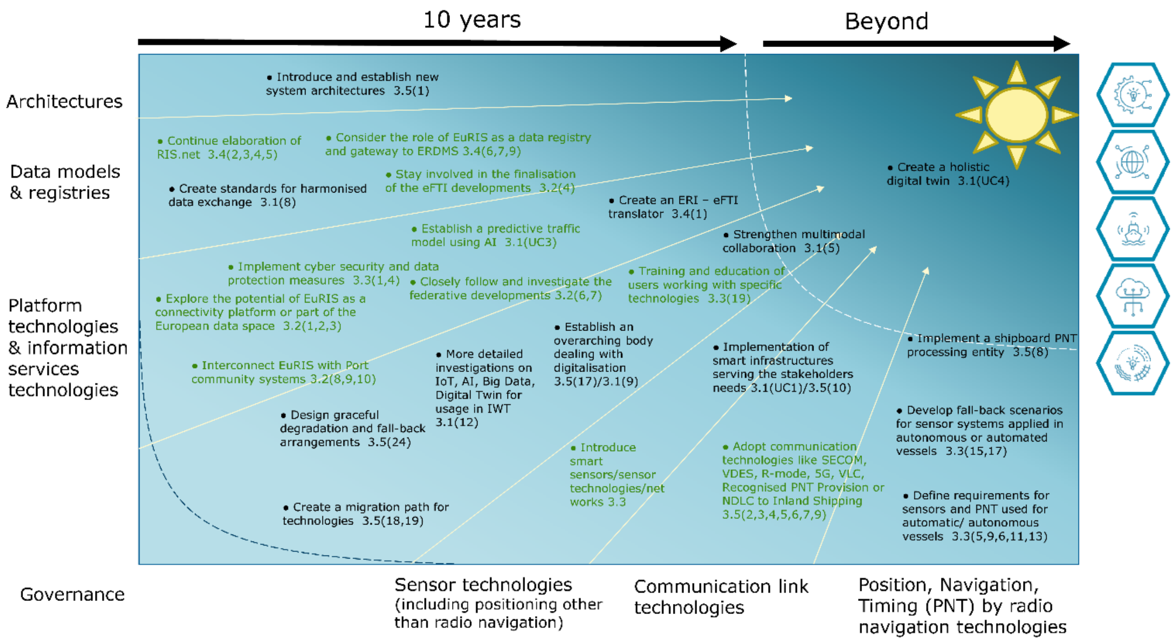

Figure 2: Assessment of main recommended activities in the "road to the sun" approach

1 Introduction

Inland Waterway Transport (IWT) is facing transformation towards digital systems for infrastructure and vessels throughout. Just like the business processes, the technologies used in IWT need a modernisation process. The availability of large amounts of digitalised or digital inland navigation data in (almost) real-time and with the best possible accuracy is a goal of the digital transformation. The use of improved technologies as well as a convenient system and data architecture shall support this process. The upgraded technological solutions shall provide the stakeholders of the waterway significantly improved services and data and thus provide necessary information for higher reliability and safety. Increased use of improved or advanced technologies will most likely be part of the future of inland waterways. Therefore, fairway authorities need to be prepared to cope with the upcoming digital developments and challenges of the digital transformation.

The result of the project "Masterplan Digitalisation Inland Waterways" (DIWA) has to become an essential basis for the digitalisation of inland waterways by the fairway authorities in the upcoming years and has the objective to lead to a digitalised Inland Waterway Network for those waterways under the responsibility of the participating fairway authorities.

These highly set goals are accompanied by the research performed and concluded on the following thematic areas:

- New Technologies
- IWT Connectivity platform
- Smart Sensoring including Positioning, Navigation and Timing (PNT)
- Data model and Data registry
- Technologies in other transport modes

The studies build the baseline on the current status quo and provide an overview of the relevant technological developments on digitalisation in those thematic areas. This report concludes the main findings and technological solutions to support the digital transformation in IWT related to traffic, transport and logistics.

2 Work approach

Within activity 3 the technological developments in the Inland Waterborne Traffic and Transport domain have been described. The focus is on information and communication technologies, data modelling and sharing as well as developments in other transport modes.

In the Masterplan DIWA project the participants represent 5 countries and cover a large part of the TEN-T network (corridors): North Sea - Baltic, North Sea - Mediterranean, Rhine - Alpine and Rhine - Danube. Also, the Danube region has been considered in the study by interviews and accessing other European projects.

This report will duly reflect on the technological developments in the IWT information and communication domain and will provide the related input to the Masterplan Digitalisation of Inland Waterways in activity 5.

The Technological developments in activity 3 of the Masterplan DIWA projects consist of five relevant sub activities/topics. The resulting studies on the technological developments will stimulate IWT and put requirements on the Digitalisation of IWT and the Masterplan Digitalisation of Inland Waterways.

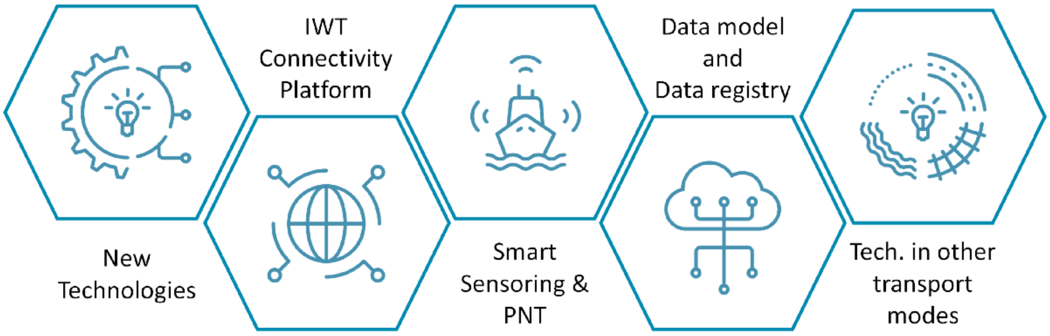

Figure 3: The five sub activities of activity 3 Technological Developments

These sub activities are managed by experts (or delegated expert consultants) of the participating countries. Also, external experts and business representatives have been involved.

2.1 DIWA Maturity Model

For ordering all these digitalisation initiatives a maturity model was introduced (see Figure 4). For each sub activity in Activity 3, an inventory of technologies or technological developments was compiled regarding the specific topic. Subsequently, an evaluation or assessment of the respective technology has been carried out. In many cases, it was also possible to make a link to the results of Activity 2. The investigations in the previous steps resulted in various recommendations for the upcoming years of digital developments in inland navigation.

For each sub activity the current situation of digitalisation and level of digitalisation was described. For the resulting (digitalisation related) issues and opportunities it was described (in general) what needs to happen on technological (e.g. expand mobile internet coverage), organisational, operational level and regarding facilitators in order to remove or mitigate an issue and/or capitalise on an opportunity which allows making the step to a next digitalisation level. All these elements have been addressed in the sub activities to make comparable scenarios in the roadmap.

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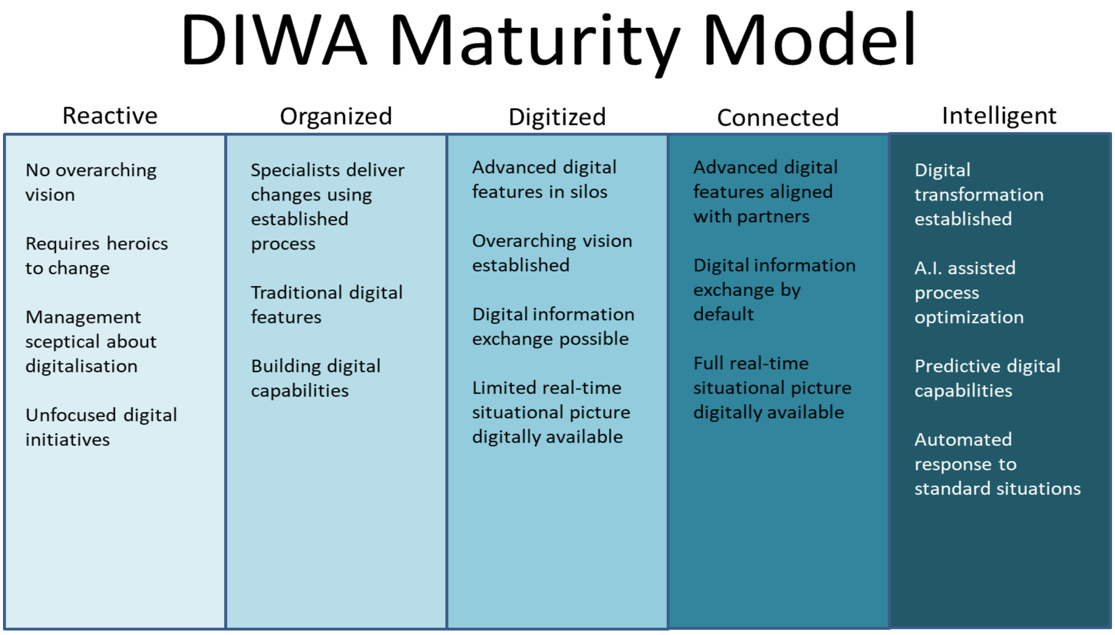


Figure 4: The DIWA digitalisation maturity model

The business developments (activity 2) and facilitation topics (activity 4) follow a similar approach. First present an overview is presented of the current (digitalisation related) state of things, discerning incremental innovation, new innovation and disruptive innovation, possibly addressing logistics and fairway & navigation separately as a sector. In the end, all relevant information will be integrated in the Masterplan itself (activity 5).

The described 3-step approach was carried out for each sub activity, as shown schematically in Figure 5.

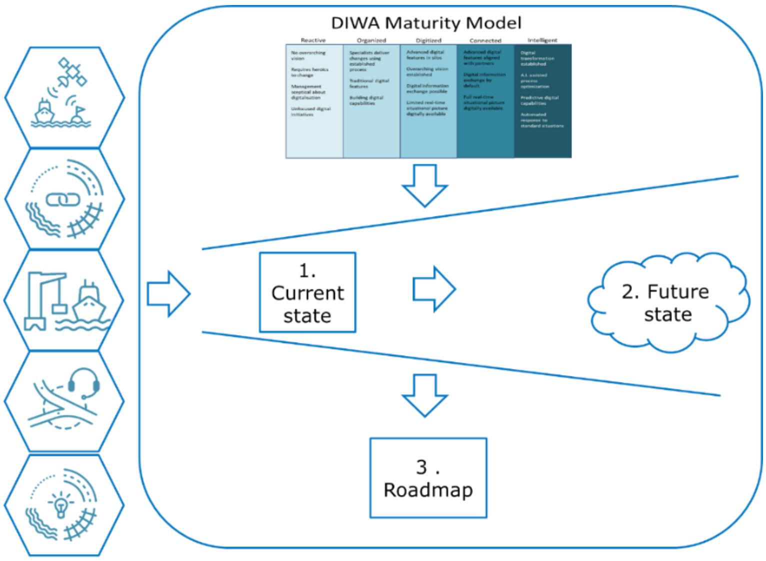


Figure 5: Work approach for all sub activities
(Source: Activity 2 report)

The summary for each sub activity is described in chapter 3. The coherence and synthesis will be described in chapters 4-6 based on the output of the five sub activities. For more information, please consult the individual reports as they contain all details.

2.2 Technology Assessment

A methodology to assess the identified technologies was developed to evaluate usability of the technologies in Inland Waterway Transport and the impact on the digitalisation level. A summary of the methodology elaborated in Appendix 6 is given in this chapter.

The IWT Digitalisation levels (short: IDL; see Figure 4) are foundational regarding the assessment of the individual contributions studied in the various sub activities of DIWA. The cornerstone question can be thus phrased as follows: 'What increase in terms of IDLs would be achieved when specifically incorporating a certain item, as studied in an DIWA (sub-)activity, in the roadmap?'.

One assessment metric can be derived from that IDL definition directly, namely the 'IDL Impact' metric, which indicates how important the usage of an item is for achieving a higher IDL. The IDL's 'Reactive' and 'Organised' can be frequently found in the present, 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.

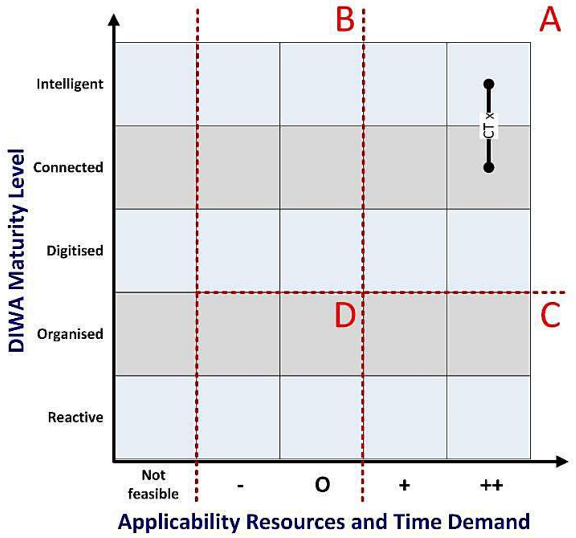
The other assessment metrics are based on the three different additional issues as follows:

- What is the inherent maturity of an item? Resulting from this is the metric '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.
- Looking into the future, when will a certain item potentially be fully deployable in the IWT fairway & navigation domain? Resulting from this is the Technology Radar metric including technologies as items.

DIWA Assessment metric	Assessment value	Assessment results
Technology Readiness level	9 8 7 6 5 4 3 2 1	Market expansion Initial market introduction Pilot production demonstrated Pilot production – pre-production product Prototyping & Incubation – testing prototype in user environment Concept Validation – lab prototype Concept Validation – first feasibility assessment Invention – technology concept Invention – basic principles
Adaptability	++ + 0 - --	Seamless Adaptability Adaptability with minor modifications Adaptable with substantial modifications Adaptable by redesign in analogy Not adaptable
Adaptability demand	++ + 0 - --	Little application resource/time demand Intermediate application resource/time demand Substantial application resource/time demand High application resource/time demand Not feasible
Technology RADAR	2022-2026 2027-2032 Future	
Digitalisation Level Impact	 III II I 0+ 0-	Supportive for transformation into Intelligent Fairway & Navigation Connected Fairway & Navigation Digitised Fairway & Navigation Organised Fairway & Navigation Reactive Fairway & Navigation

Table 1: Summary table for DIWA assessment metrics (Source: Manual for the Assessment Methodology)

In the final step, the assessment results of the different items can be directly put into a decision-making context by using a 4-Quadrant-Matrix model (Figure 6).



Quadrant A: Item enables a high(er) digitalisation level at low effort

Quadrant B: Item enables a high(er) digitalisation level at high effort

Quadrant C: Item enables a low digitalisation level at low effort

Quadrant D: Item enables a low digitalisation level at high effort

Figure 6: The 4-quadrant model adapted for DIWA (Source: Manual for the Assessment Methodology)

How recommendations can be derived from it directly, is finally introduced in the manual (compare Appendix 6).

2.3 Autonomous and Remotely Operated Vessels

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 (see Appendix 7). Here, a summary is given.

From the perspective of the inland waterway vessel traffic situation and also of the fairway authorities responsible for inland waterway vessel traffic, the most important relevant point of the advent of AVs and ROVs are the operational interactions with them and with the shore centres that operate or control them, and how these are supported by functional/physical links. It is the mode of operation and which entity operates the vessel that is most relevant. The degree of automation built into a vessel is less important as long as it is traditionally operated by a human on-board. A (likely complete) representation of the generic entities thus identified is given in Figure 7 (there may be different names used by different stakeholders).

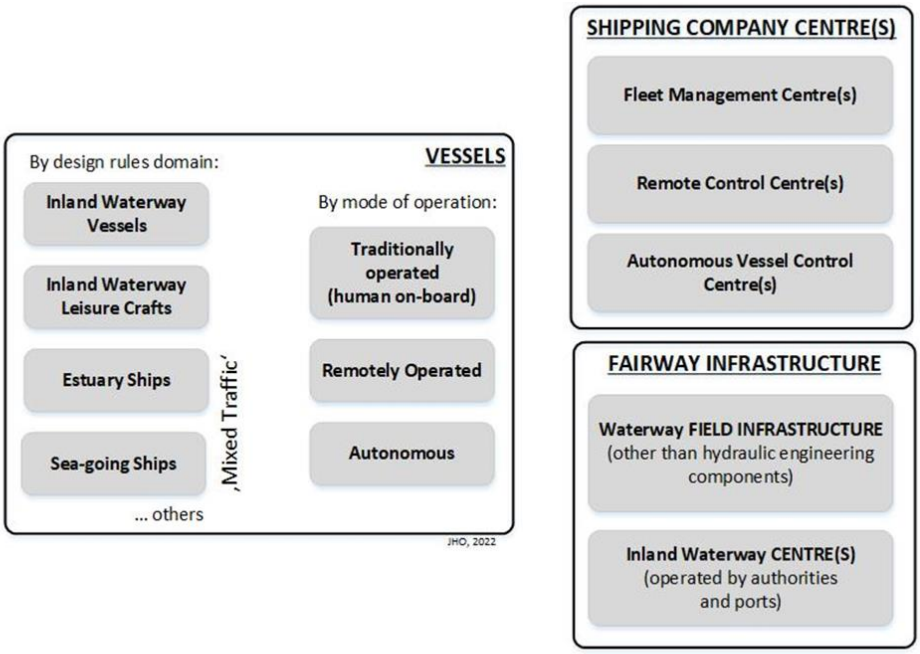


Figure 7: Relevant operational entities in the IWT Fairway & Navigation domain (Source: Appendix 7)

For any future meaningful regulatory and technology deployment, it is necessary to manage the complexity of operational relationships and consequentially of the functional and physical links between these generic entities: When unfolding the generic operational relationships between the generic entities thus introduced, the situation emerges as given in Figure 8. There, also the functional and physical links supporting the operational relationships by technology are given.

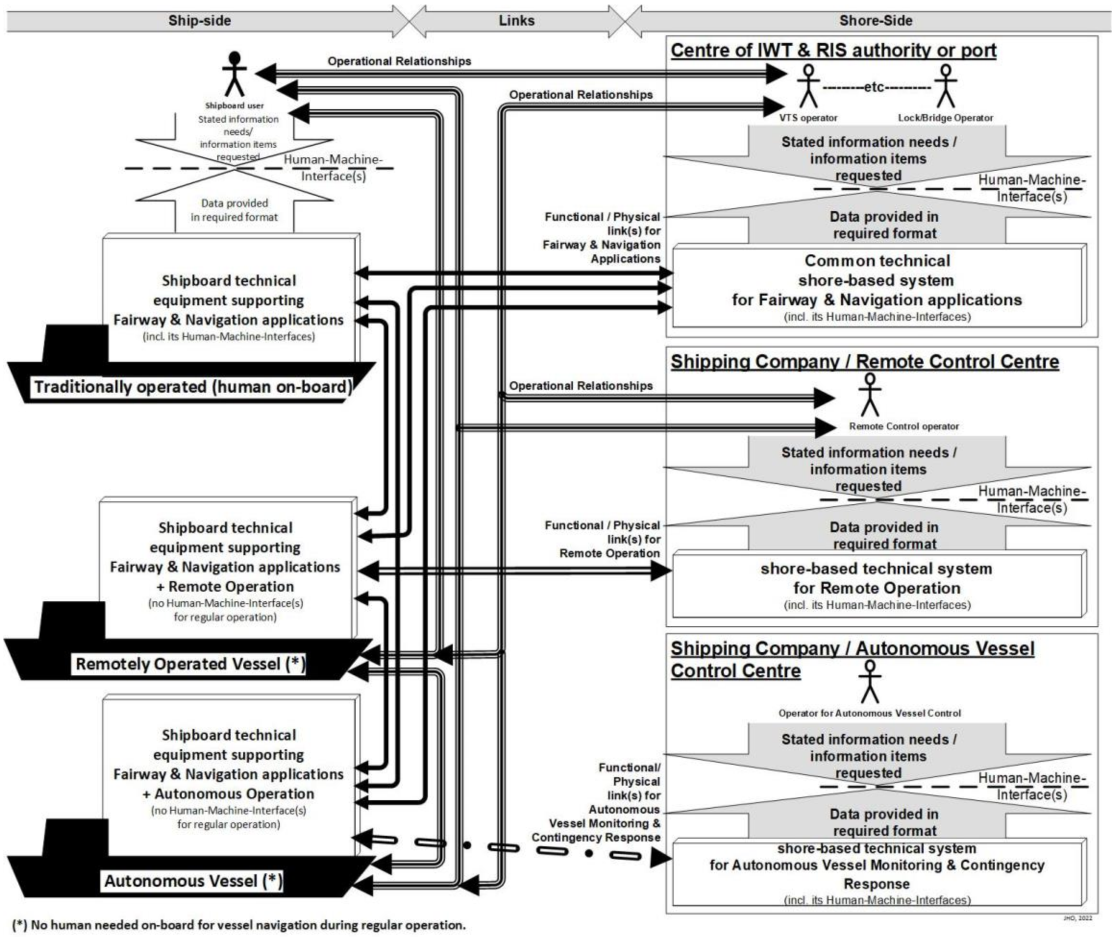


Figure 8: Operational relationships and required functional/physical links due to the advent of remotely operated and autonomous vessels (source: Appendix 7)

There are Human-to-Human, Human-to-Machine, and Machine-to-Machine operational relationships that can and should be individually identified, specified, implemented, and regulated generically on the entity level, to start with and increasing potential in the future. Detailed recommendations to that end are given in Appendix 7.

It should be noted, that the maritime domain, led by the International Maritime Organization (IMO) has determined a roadmap for and started systematic work on the creation of a future international convention on the operation of autonomous vessels in the maritime domain – called Maritime Autonomous Surface Ships (MASS) - including topics indicated in Figure 8. According to that roadmap, it is planned to have the bespoke international convention enter into force by 1 January 2025 as non-mandatory and to progress it to a second version afterwards with the goal to have it enter into force by 1 January 2028 as mandatory. This roadmap runs in parallel with the DIWA roadmap for the digitalisation of the IWT fairway & navigation domain, and also the IMO planned dates fall within the time scope of the DIWA roadmap (up to 2032). Due to the 'Mixed Traffic' situations (compare Figure 7) and due to the general import of maritime concepts and technologies, as far as applicable to IWT, it can be expected that these developments at maritime will have an impact on the DIWA roadmap, too. In addition, the International Standardization Organization (ISO), being involved in above IMO work, has published a Technical Specification on 'vocabulary related to autonomous ship systems' (ISO/TS 23860:2022), thus providing relevant definitions with a global scope.

3 Summary of the five sub activities of the technological developments' studies

3.1 New Technologies

The sub activity 3.1 "New Technology" is focused on new technologies in logistics, navigation and traffic management and the potential relevance for fairway authorities and IWT. The study gives an overview of ten technologies which are new and relevant to the above-mentioned areas: 5G technology, Distributed ledger technology, Internet of Things, Cloud Technology, Artificial Intelligence, Big Data, Virtual Reality, Augmented Reality, Drones, Digital Twin. The authors rated each technology based on a scoring system. Based on the assigned score and the feedback of the DIWA experts, four use cases were developed which utilise some or all of the relevant technologies. They aim at creating a more predictable, plannable, and holistic waterway. To facilitate the further development of such use cases, recommendations are given relevant to innovation management. Lastly, a roadmap has been developed which gives indications about the optimal order of use cases and their interdependencies. New technologies are an essential part of the effort to digitalise and modernise inland waterways transport. They can improve the usability and competitiveness of inland waterways in comparison to other modes of transport, which makes them integral to a future-proof IWT concept.

Use cases

Based on the ten defined technologies, four use cases were developed, which have a logical order (see Figure 9).

Use case 1: A cross border data exchange platform represents the basis for all following endeavours. The platform is the central hub for all activities conducted under national and European initiatives. It serves as an extension of current RIS systems. It incorporates planning tools from private or public logistics stakeholders (such as the RiverPorts Planning and Information System (RPIS)) and data based on the actual state of the waterway (i.e. EuRIS). Its open APIs allow external stakeholders to increase planning capacity and transparency.

Use case 2: Smart Infrastructure encompasses two main concepts, which are both made possible by the installation of sensors in critical parts of the respective structure. Firstly, the observation and analysis of existing infrastructure (e.g. bridges, locks) for the purpose of predictive maintenance. This allows for a more reliable and efficient waterway management system and sophisticated strategic decisions. Secondly, sensory data can be used to make local infrastructure react to common external conditions (e.g. a vessel approaching) by using simple algorithms, eliminating the need for human assistance in many cases.

Use case 3: The Predictive Traffic Concept case builds extensively on the previous two. It requires an extensive pool of data which combines a multitude of different dimensions, such as planning data from shipping companies and accurate real-time data from RIS systems. Using AI systems to recognise patterns in historical and current data, it can make predictions about the state of traffic on the waterway. As such, it provides an increase in accuracy and reliability and thus contributing to safety. In addition to recommendations provided by the system, it can make some basic decisions, thus assisting the vessel operators and others for an optimised use of the IWT.

Use case 4: The holistic digital twin is the product of all previous use cases in conjunction with similar applications from other modes of transport (i.e., rail, road, and air). In its ideal state, it represents the consolidation of previously separated but interdependent applications in the logistics sector. Its goal is to harmonise all modalities and create a platform or application which allows the user to find the most efficient and sustainable mode of transport for the respective product. In addition, it allows for a comprehensive, intuitive overview of the entire waterway (and possibly the entirety of all modes of transport).

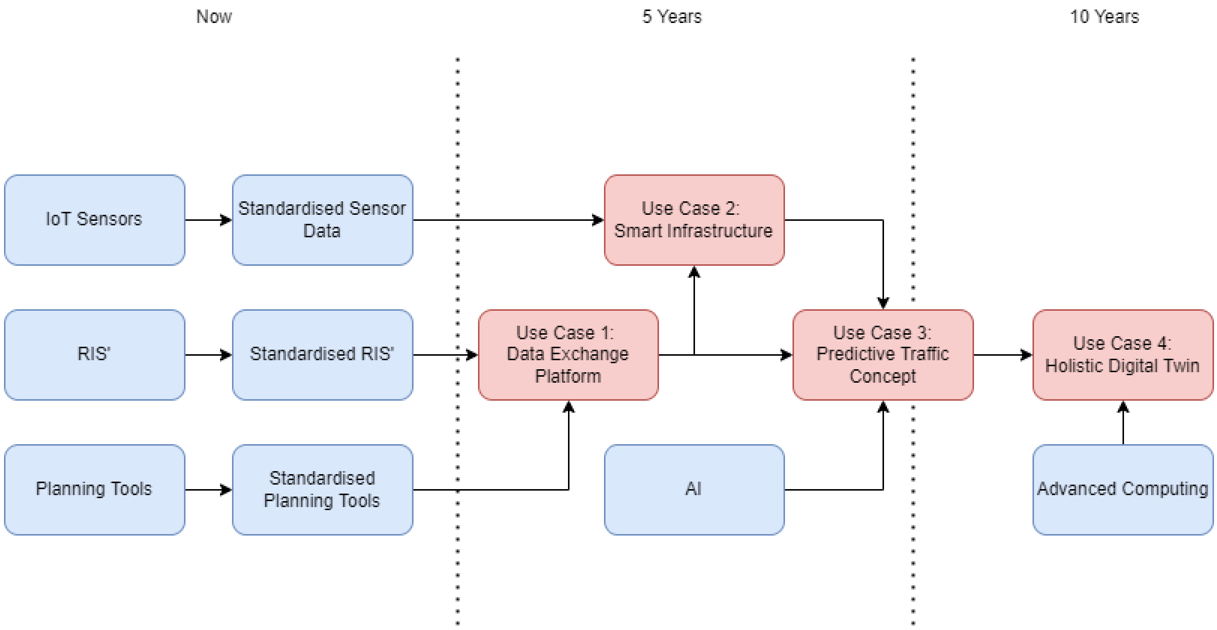


Figure 9: Roadmap overview including use cases

Blue: Required technological developments for the successful implementation of the Use Cases
Red: Use Cases

The use cases require high quality data to work properly. All use cases combined aim to collect the following data (see Figure 10):

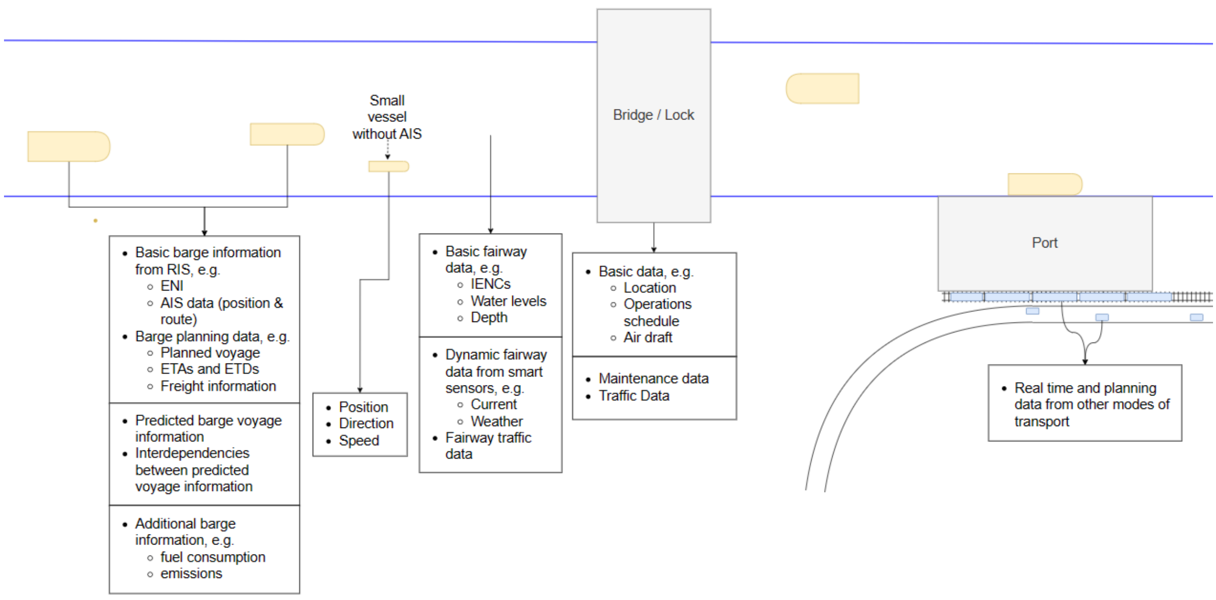


Figure 10: Required data to enable use cases

Most data can be collected by fairway authorities either directly or through service providers. Consequently, the authorities can be the main driver in the development of these use cases. Only use case 4 requires considerable external input, e.g. from other modalities/logistic service providers. However, by ensuring compatibility and extensive cooperation, fairway authorities can still make an important impact.

Actions needed to facilitate the proposed use cases:

Fairway authorities and IWT will benefit greatly from implementing certain innovation management procedures. The list discussed in the report is:

- **Utilise existing cases for new technologies** to save effort and capacity which are spent on pursuing redundant projects.
- **Identify minimum viable products (MVP) for each use case** to provide tangible results through a pilot which can guide further efforts.
- **Initiate and strengthen multimodal and international collaboration** to benefit from the interdependencies between different stakeholders.
- **Cooperate with private and public private partnership (PPP) initiatives** to combine private efforts closer to the market with public initiatives closer to the solution.
- **Create standards and provide data of the waterways/objects/fleet** to harmonise European efforts, helping the development of a more connected and intermodal solution.
- **Establish permanent digital innovation teams** to foster the continuous development of new applications with a focus on advanced technologies.
- **Establish a knowledge management** platform to benefit from the extensive expertise gathered through European fairway initiatives.
- **Establish a collaboration tool for projects and ideas** to reduce the time it takes for an idea to reach relevant stakeholders and potential partners in other fairway authorities.

Roadmap for proposed use cases:

Some of the outlined use cases can be pursued individually, specifically use case 1 and 2. However, use case 2 greatly benefits from a sophisticated platform (use case 1), especially for the harmonised management of smart infrastructure on specific corridors or entire waterway systems. As a result, the platform should be developed first. Due to it being very close to the current EuRIS, it may take less than five years to reach the required level of advancement. Use Case 2 can be developed in parallel, since it uses very different technologies and requires different expertise. The deployment may take more time since such solutions are less established. Nonetheless, expectations are that it is feasible to reach a certain standard on some corridors or waterway systems within the next five years.

The Predictive Traffic Concept requires a high degree of maturity within the two previous use cases because it applies the technologies used for these applications to create a much more advanced and powerful tool. It may be feasible to reach this important milestone within the next ten years if the initiatives are on time and deployed on a large scale. The Holistic Digital Twin is a vision which will be realised once all previous use cases are explored extensively and cooperation between different modes of transport well established. It will most likely take longer than 10 years to realise this vision to its full exploit.

3.2 IWT Connectivity platform

The sub activity 3.2 “IWT Connectivity platform” is focused on technological developments on information management in inland transport on European corridors. Linking data sources to one another via a Connectivity Platform, thus creating a one-stop-shop for information is investigated. The point of view from the rail transport is investigated as well and also new and upcoming initiatives and technologies (like eFTI, FEDeRATED, FENIX, Linked Data and European Data Spaces) and some Port Community Systems.
The report describes new technological developments on IWT connectivity platforms and related digital transformations. The focus is on a set of proposals for integral and harmonised technological solutions for the (future) business developments related to the digital transformation of Inland Waterways for each development. Given the many current (and often early stage) developments related to this sub activities’ topic, the study focuses on high level information, identifying trends and interesting avenues rather than investigating and clarifying technical implementations or detailed architectures of initiatives that may not reach the required maturity or level of adoption that is required to make them an actual candidate for implementation in IWT.

Connectivity Platform initiatives and technologies
At the start of the Masterplan DIWA project conception in 2018 the Maritime Connectivity Platform (MCP) was envisioned to be developed to support the electronic exchange of information for e-Navigation services. It would be beneficial to coastal states of the EU if there was synergy between such a platform and separate development for maritime and IWT could be prevented.
The MCP is an architecture with a set of standards covering ship – shore data exchange, enabling seagoing vessels to consume the same services all over the world via MCP implementations, regardless of the underlying (legacy) implementation of the local shore system(s).

Data Spaces (like the European Data Spaces) have a similar goal of enabling data-sharing and providing services for transparent data pooling and processing, while adhering to all relevant legislation. The Common European Data Spaces have an even bigger goal, as their aim is to also overcome existing legal barriers to data sharing.
Although this goal could be reached by setting up brand new (eco)systems, the EU acknowledges that some sectors (e.g. the mobility and transport sector) already have important frameworks and initiatives for sharing relevant data B2B, B2G, G2B and G2G. Moreover, they are aware of the fact that several initiatives (by both governmental and private actors) aim to further improve/extend on these frameworks and provide data governance, technical infrastructure and economic models to create a data economy in the mobility sector. Given this state of affairs, a (European) mobility data space should not be construed as a (single) operational (technological) instance where data consumers can plug in and extract mobility data from plugged in data providers, but rather as an alliance of parties that can assist with some or all aspects of mobility data exchange via both existing and new systems.

eFTI, FEDeRATED and FENIX are interesting initiatives concerning (decentralised) data sharing and information exchange. They are the result of the Digital Transport and Logistics Forum (DTLF) which is a consultative platform of the European Commission for the coordination and cooperation between stakeholders from a cross-modal and cross-sectorial perspective to support the European Commission in promoting the digital transformation of the transport and logistics sector.

The Regulation on electronic freight transport information (eFTI) aims to encourage the digitalization of freight transport and logistics to reduce administrative costs, improve enforcement capabilities of competent authorities, and enhance the efficiency and sustainability of transport. The eFTI Regulation establishes the legal framework for electronic exchange of information that is required by the EU and national legislation to prove compliance with EU and national rules on the movement of goods by rail, road, inland waterways and air between the economic operators and the Member States authorities on the movement of cargo in the European Union. The three main aspects of eFTI are the common data set, the platforms and the certification process. This report focusses on the eFTI platforms, which will be approved software that can be accessed by a national authority to retrieve information made available by an economic operator. eFTI platforms need to comply with certain functional requirements to ensure, among others, data authenticity, integrity and cybersecurity. The related service providers

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must also meet a set of requirements (keep data for a certain period of time, provide access to authorities, secure data) and receive certification. While each economic operator can use any certified eFTI platform for providing their data in an electronic way, they are not obliged to do so and can keep reporting their information on paper (unless national legislation states otherwise). The relevant authorities, on the other hand, are obliged to support eFTI and accept data that is provided via an eFTI platform.
The timeline for implementing eFTI is very short, with the eFTI Regulation published on July 15th 2020 and the deadline for full compliance by the relevant authorities set for August 2025, with no clear view on the common data set, overall architecture and certification process at the time of writing.

FEDeRATED and FENIX are two very similar initiatives for federated (decentralised) data exchange in freight transport and logistics. Their objectives are to create an open and neutral data sharing infrastructure that is accessible to all stakeholders, offering interoperability between existing and future platforms. Using a translation layer (called a connector or a basic data sharing infrastructure) between the external network and the internal system (called a platform or node), all systems are able to communicate and share data in the same way, regardless of their internal implementation. By using a common language, guarding data sovereignty, applying identity and authentication mechanisms and enabling discoverability, a safe and trustworthy decentralised data sharing solution can be built. Via living labs (proof of concepts) and pilot projects and sites, the potential of both FEDeRATED and FENIX is investigated in different European projects.

While the aforementioned initiatives are mostly still in a conceptual phase, Port Community Systems already provide operational platforms for sharing information with and from IWT with relevant stakeholders. These platforms often support a wide range of existing standards for data exchange from different transport modes, including translation services, alongside their own custom (real-time) APIs and data formats for specific use cases. These Port Community Systems form a rapidly growing ecosystem in the transport chain, providing added-value services to the transport community, and are often looking to connect to River Information Systems such as EuRIS to increase the Quality of Service they can offer to their clients. The Port Community Services PortBase, RiverPorts Planning and Information System, Bremer Hafentelematik, Dakosy and Hamburg Vessel Coordination Centre are investigated in this report and we can conclude that some do already use RIS services and some don't.

When looking across the modal borders, the RailNetEurope association, a body for the coordination of the individual railway infrastructure managers, is acting as this so-called 'one-stop shop' by coordinating, harmonising, developing and offering several services to international railway undertakings. Using a Common Interface, they link the internal systems of rail operators and other rail stakeholders to each other in a Peer-to-peer network, a setup that is very similar to the FENIX Connector. While the main goal of this Common Interface is to enable message exchange for the TAF TSI regulations (TAF TSI = Technical specification for the interoperability of 'telematics applications for freight subsystems'), the system is flexible and allows message exchange beyond that scope as long as the communicating parties adhere to the basic message structure.

From the pure technology side, an interesting development is Linked Data and the Linked Data Event Stream (LDES), which use a combination of HyperText Transfer Protocol (HTTP) Uniform Resource Identifiers (URIs) to identify and locate information, the SPARQL Protocol and Resource Description Framework (RDF) Query Language to retrieve and modify the data, and metadata containing related URIs to link the data to other data, enabling the discovery of more information.

A Technology Readiness Level analysis is made of the researched initiatives and technologies to assess their maturity and determine if they are ready for adoption by the waterway authorities.

Recommendations

An analysis is made of the input from the other DIWA sub activities regarding connectivity platforms, resulting in a list of requirements for an IWT Connectivity Platform (CP). The other DIWA sub activities also indicated that EuRIS has a very close match to the features they expect from an IWT Connectivity Platform. As a result, the EuRIS platform is investigated on a high level, with focus on its CP potential. It is concluded that, although the centralised setup of EuRIS may seem in contradiction with the idea of a CP, EuRIS has a lot of potential to provide CP functionality. A recommendation is formulated to

extend EuRIS with Connectivity Platform functionality on two levels: (1) Web Modules for human readable information and (2) Connectivity Services for machine readable information.

When considering European Data Spaces, it can be concluded that EuRIS meets all of the requirements for a European Data Space. A recommendation is made to **validate conformance of EuRIS with the European Data Spaces requirements** and to **promote the role of EuRIS as an inland waterway transport Data Space**. Several other recommendations are made to further increase the EU Data Space compliance of EuRIS and start preparing for the connection of EuRIS with other EU Data Spaces and obtain the necessary funding to **realise the potential of EuRIS as an EU-wide common data space in the domain of inland waterway transport**.

Naturally, the implications for EuRIS on the operational, governance, legal and funding level are also considered, and important questions that should be answered before transforming EuRIS into a Connectivity Platform and/or EU Common Data Space are formulated.

3.3 Smart Sensoring including Positioning, Navigation and Timing (PNT)

A main and important aspect in the digitalisation of the IWT is the ability to retrieve digital data and information. This data can come from existing platforms where the data is brought together or can be the input by, for example, the skipper who enters voyage data.
Another source of data are sensors that are used for measuring water levels, temperatures, heights, positions or distances. The existing technologies for sensors are evolving so rapidly that it is necessary to create an inventory of the existing sensors in general, without exception. Decreased size and increased capabilities of sensors create new possibilities for IWT and can enable new business developments.

Definition of (smart) sensors

During the desktop research, many different sensors were identified but several of these sensors could not be classified as a 'smart sensor'. A definition of what a smart sensor is, becomes a necessity., Although the difference between a conventional sensor and smart sensor are quite clear, a different look at both types lead to interesting results. The main difference is that smart sensors are capable of processing and transmitting the outcome of the measurement while conventional sensors miss the processing unit. In this sub activity, not only smart sensors and PNT (Position, Navigation and Timing) are handled but also conventional sensors which can be used in a smart way, seem to be very interesting. For instance, combining RADAR with GPS allows Inland ECDIS to overlay the RADAR image with the IENC. Using an infrared sensor for measuring the distance together with a water level meter and the chart data, will allow an application to decide whether a vessel can pass a bridge.

Inventory on smart sensors and PNT systems

After defining what a (smart) sensor means, an inventory of more than 50 smart sensors was created describing the properties of the sensors. The sensors are described according to the intended usage (Appendix 3, 6.1 Usage: position of vessel or navigation), data availability (Appendix 3, 6.2 Real-time data provided by sensors) and business developments (Appendix 3, 6.3 Business developments). The inventory was created through desk research and the main focus lays on currently available sensors or PNT systems. In addition, the inventory also looked at sensors or PNT systems that would become available in the future. This inventory was presented to members of the business community. Feedback showed that the inventory, both for current technological developments and those that would become available in the future, offered a proper overview.

Position of vessel or navigation

Looking at PNT systems, four grades were identified by IMO[1] for different vessel usage requirements:

- Grade A supports the description of position and movement of a single on-board point (e.g. antenna location of a single GNSS receiver);
- Grade B ensures that horizontal attitude and movement of vessel's hull are unambiguously described;
- Grade C provides additional information for vertical position of a single on-board point and depth; and
- Grade D is prepared for the extended need on PNT data e.g. to monitor or control vessel's position and movement in three-dimensional space.

[1] Source: IMO-MSC.1/Circ. 1575, §41

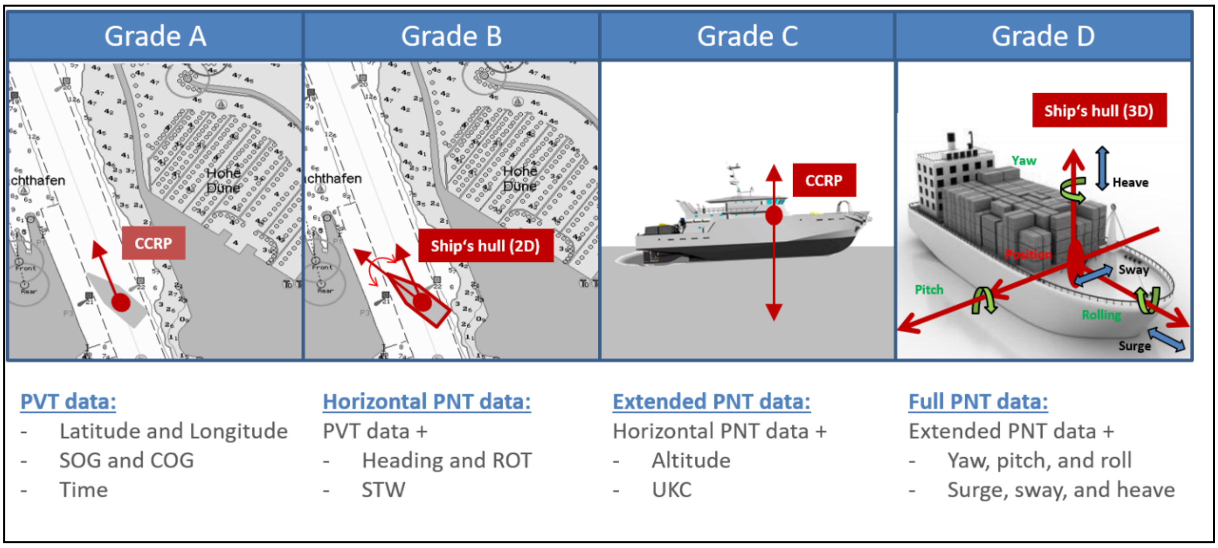

Figure 11: Application Grades of PNT-Data Processing (+provided with improved accuracy) (Source: IMO MSC.1/Circ.1575, Figure 5)

Real-time data provided by sensors

Using the results and demands of activity 2 and sub activity 3.1, potential sensors have been extracted from the inventory and are described. For the following types of information, the type of requested data was described, possible data providers were defined and potential sensors were listed:

- Fairway related information (e.g. water level, current)
- Network infrastructure information (e.g. vertical clearance, structural conditions)
- Vessel dynamics information (e.g. vessel position, vessel dynamics)
- Smart Shipping information (e.g. movement of other vessels, detection of bridge)
- Environmental impact related information (e.g. fuel consumption)
- Location related information (e.g. actual passage time at specific waypoint, duration at harbour)
- Cargo/vehicle related information (e.g. tracking of cargo, free cargo space)
- Object related information (e.g. exact location of vessel at berth)

Business developments

In the previous classification, the type of information is used as a base, but activity 2 is divided in five different business developments. Therefore, an exercise to classify the sensors in relation with these business developments (also shown in chapter 2) and the possibility to use them in the framework of these developments was made.

Installation and/or configuration of sensors

The installation of navigation and information equipment (e.g. sensors, PNT, AIS, RADAR, etc.) has to be performed according to minimum requirements provided in European Standard laying down Technical Requirements for Inland Navigation vessels (ESTRIN, Appendix 5).

Another important issue for automated vessels which carry various sensors and/or PNT equipment is to define a location on the vessel, to which all horizontal measurements such as target range, bearing, relative course, relative speed, closest point of approach (CPA) or time to closest point of approach (TCPA) are referenced. In the maritime domain, this point is defined as Consistent Common Reference Point (CCRP). It is this point that may best represent the actual vessel's position also for other recipients of dynamic vessel data because it implies consolidation of inputs from different available sensors at the originating vessel ('own vessel') already, as opposed to just one sensor's position data as has been the case traditionally. Due to its importance – for own vessel and for all recipients of own vessel's position data – efforts should be made in the future to improve the data quality of vessels' PNT equipment.

Fall-back option

The several different Global Navigation Satellite Systems (GNSS) have become the primary source for on-board PNT data provision. Furthermore, PNT data is used by many applications on vessels, like Inland AIS (Inland Automatic Identification System), IECDIS (Inland Electronic Chart Display and Information System), for communication systems and GMDSS (Global Maritime Distress and Safety System) to obtain accurate position in case of emergency.

Many systems depend on the result of at least one GNSS and can only work properly when the position data is reliable. When this is not case or when the positioning system is out of order due to whatever reason, alternative ways of retrieving correct data is important. Fall-back options must be foreseen and redundancy becomes important (also for cybersecurity reasons).

This is also concerning the smart sensors which deliver important data for safe navigation. E.g. water level information should be available not only by the use of one sensor but by combining for instance the information of multiple surrounding sensors in case of a malfunction.

Issues/considerations

During the desktop research and the discussions in the sub activity, it became clear that several issues and considerations needed to be clarified to avoid misunderstanding and misconceptions:

- The difference between AIS and PNT
- Privacy
- Cybersecurity
- Safety of navigation
- Issues in the logistics sector
- Usage of sensors

Main conclusions

Many different sensors were identified, some resulting in very accurate data, others for very specific purposes. But for all sensors the same observations can be made:

1. **Fall-back, recommendation regarding necessary integrity levels**
   Every sensor can malfunction and when this happens there should be measures taken in the total system to detect this and take mitigating actions to temper the effect of the malfunction of a sensor. After detecting a malfunction of a sensor, automated by a system or a user, there are two ways to mitigate this problem depending on the sensor and the total system:
   - Implement/activate the fall-back.
   - Go to a "Gracefully shutdown"

2. **Guidelines concerning setup of sensors**
   Depending on the use (cases) and need of the data from a sensor it is totally depending on the purpose for which the sensors are designed and how they integrate in the complete system and surrounding.

3. **Accuracy indication and protection**
   To enable the different systems to use data in a correct and intended way, some kind of indication must be provided by the sensor. This indication should preferably be a single number that tells the user of the data the accuracy value. This could be an absolute figure or a descriptive number.

4. **Training and education**
   The user (on board, on shore, authority) should be educated in the use of the sensors. They need to know the intended purpose, the expected results/output and certainly the vulnerabilities of the sensors or systems. The result of the training should be awareness.

3.4 Data Model and Data Registry

The sub activity 3.4 "Data model and Data registry" is focused on the technological developments for the harmonised and interoperable collection, integration, exchange, presentation and analysis of navigation, traffic, transport and logistics related information for the Inland Waterway Transport sector. The focal point of this report is on Data Registries and Information Models, considering both examples from other transport modes and potential (existing) solutions from within the IWT community.

The report describes the new technological developments on IWT information models and data registries on the digital transformation. The main part of it is the set of proposals for integral and harmonised technological solutions for (future) business developments related to the digital transformation of Inland Waterways for each development.

The aim of this sub activity is not to describe or propose a single information model and/or a single data register for inland navigation. Instead, the reuse and, where necessary, extension of existing platforms and models wherever possible is the best course of action. Especially considering the strongly related topic of sub activity 3.2 on an IWT Connectivity Platform that could link new and existing Data Registries and provide a next step towards a one-stop-shop for IWT related information. This does of course not exclude the introduction of new Information Models and/or Data Registries if no sufficient match is found in the existing ecosystem.

Data Registries

A Data Registry is defined as:

An official record of uniquely identifiable data covering a field of importance for a specific domain.

It is seen as an authoritative list of one kind of information where it is possible to see who has changed what information and when. All records in the registry have a unique reference ID, and (pull) requests can be made to update data.

Data registries can be set up as a centralised system or in a decentralised way. IWT examples of the former are the EHDB (European Hull database) and ERDMS (European Reference Data Management System), examples of the latter the ECDB (European Crew database) and R2D2 (RIS Data exchange Reference Documentation). The pros and cons of both approaches are discussed, and the conclusion is drawn that a critical architectural evaluation should be made before setting up new data registries, ensuring the final setup will be the one best fit for serving the intended use cases.

EuRIS, a single web portal that seamlessly combines River Information Services of 13 European partners and one of the results of the EU funded RIS COMEX project, is investigated. As EuRIS offers a broad selection of IWT and RIS reference data, most of it directly provided by the competent authorities that 'own' the data, it meets all the requirements of a data registry, even though it currently does not have an authoritative character.

Information Models

The RIS Index is an information model with a corresponding registry that was established 20 years ago. As the RIS Index lacks information on the relation between objects and was also not designed to cover the characteristics of the waterways, it was necessary to develop a spatial database model to cover the needs of the RIS COMEX project. The resulting VisuRIS COMEX Reference Network Model had some issues and room for improvement, detected during the implementation of EuRIS, and as a result the elaboration of the RIS.net concept was started, a spatial dataset including objects and the links/relations between them, for both professional and recreational navigation. This concept is currently further elaborated by the CESNI/TI/NtS TWG with the aim to eventually replace the RIS Index and formalise the new aspects introduced by the VisuRIS COMEX Reference Network Model.

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The Maritime Resource Name (MRN) concept was developed by the International Association of Lighthouse Authorities (IALA). The MRN is “a naming scheme that can uniquely identify any maritime resource on a global scale” and both IHO and IALA strongly recommend to incorporate the MRN into S-100, including S-101 (ENC) and by logical extension S-401 (iENC). The MRN is a decentralised concept, meaning that any competent authority is able to independently generate MRNs for their resources, as long as they stick to the subdomain they have been assigned. While there are currently no specific sub-domains for important IWT infrastructure (locks, bridges, berths, etc.) requiring the use of the ‘object‘ wildcard, these sub-domains can be requested from IALA or IHO (depending on the nature of the infrastructure) if the MRN would be adopted by IWT. This will most likely be a task taken up by the IEHG during their elaboration of S-401 and the inclusion of the MRN therein.

The IHO Geospatial Registry contains, among other things, a Concept Registry (or Data Registry) and a Data Dictionary Registry (or Information Model) for relevant terms and features in S-100. As such it is a valuable source of information, especially when aiming to further harmonise terms and feature types between IWT and the maritime domain.

Another information model is related to the Trans-European Transport Network (TEN-T) which addresses the implementation and development of a Europe-wide network of railway lines, roads, inland waterways, maritime shipping routes, ports, airports and railroad terminals. The corresponding TENtec portal provides a comprehensive overview of the European Commission’s work in relation to TEN-T, and needs to be kept up-to-date with the network and infrastructure data of the responsible authorities, a task currently performed manually for the inland waterway’s information.

eFTI (electronic Freight Transport Information) is an important European development in the reporting of freight transport information, replacing paper documents and smoothing the exchange of information in the transport chain. eFTI is discussed in detail in the report of DIWA sub activity 3.2 – IWT Connectivity Platform. Although the eFTI data model was not finalised at the time of writing, it seems logical that there will be significant overlap between the eFTI data model and the information in the ERI messages.

Recommendations

RIS.net will be one of the pillars of the future of RIS. While it already tackles many of the known issues of the RIS Index and the VisuRIS COMEX Reference Network Model, it still requires a lot of elaboration. Replacing the RIS Index can have a huge impact on the RIS Technical Services and most, if not all, RIS Operational Services. Therefore, sufficient time and funding should be made available to further elaborate RIS-Net with the help of, at least, the CESNI/TI working groups and the IEHG, for example in a follow-up project of RIS COMEX.

As the **Maritime Resource Name can harmonise the identification of objects** between the maritime and the inland domain, this sub activity proposes to adopt the MRN in RIS.net. It is also recommended to set up a line between the IEHG and CESNI/TI/NtS (which is elaborating RIS.net) considering the MRN to avoid divergence in the final implementations in S-401 and RIS.net, and to set up a sustainable governance model for keeping the MRN values synchronised between S-401 and RIS.net.

The IHO GI Registry contains a treasure of information on S-100 and maritime concepts, features/entities, etc. In light of harmonisation between the maritime and the inland waterway world, it would be advisable to **use the definitions and feature types as defined in the IHO GI Registry in RIS.net** wherever possible. Especially for newly introduced entities (e.g. Traffic Point) it is highly recommended to investigate if a corresponding feature is already available in the IHO GI Registry.

Ensuring that the information in RIS.net covers the information needs of TEN-T would mean that the data only needs to be collected once (for RIS.net) and could then be exported to TEN-T. This strongly reduces the possibility of discrepancies between the TEN-T data and the data visualised on, for example, EURIS. This is much preferred to the current situation of maintaining multiple (manually construed) networks of the waterways and making sure they are all up to date. Moreover, a single RIS.net → TEN-T translator could be developed by TENtec, immediately covering the IWT TEN-T data needs.

eFTI should be considered an opportunity for IWT. The final eFTI data model and the ERI data model should be aligned wherever feasible and beneficial, and the creation of a common eFTI<->ERI translator service could be considered. Although such a translator service will most likely not be fully self-contained, requiring additional input from the user, it could alleviate the administrative burden for the IWT community and authorities.

It is recommended to **consider extending the role of EuRIS as a Data Registry**, and this sub activity recommends to investigate the possibility of uploading the reference data of the EuRIS partners towards the ERDMS via EuRIS. A thorough investigation of the reference data contained within ERDMS and EuRIS will of course need to be performed to ensure a 1-on-1 match for the data the EuRIS partners are responsible for. If brought into practice, this recommendation will also require some changes to EuRIS, and thus sufficient funds should be made available.

This sub activity would also like to suggest a closer cooperation between the main involved parties, like the European Commission, CESNI, the CCNR and the RIS Authorities, during all phases of the life-cycle of the Data Registries for IWT (ERMDS, EHDB, ECDB, etc.). This might increase the overall efficiency, level of adoption and general level of satisfaction related of the Data Registries and create a multi-level benefit for the IWT community at large. Another suggestion would be to consider using EuRIS as a gateway between the RIS Authorities and the ERDMS, and possibly allow EuRIS, in its role as a single-stop-shop for a wide range of IWT information, to act as a cache of the ERDMS data.

There are many interesting recommendations and suggestions from this DIWA sub activity. Together they paint an ambitious path towards a safer, more sustainable, (multimodal-)harmonised, efficient and digitised IWT, built upon a solid foundation of Data Registries and Information Models, and ready to take on the challenges of the future.

3.5 Technologies in other transport modes

The objective of 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 extent – 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 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.

The results are reflected 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.

Generally, it can be concluded 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.

IWT Architectures

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. The following technology-oriented architectures were adapted to IWT fairway & navigation domain as informed by the other modes and 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 (see Figure 12). 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.

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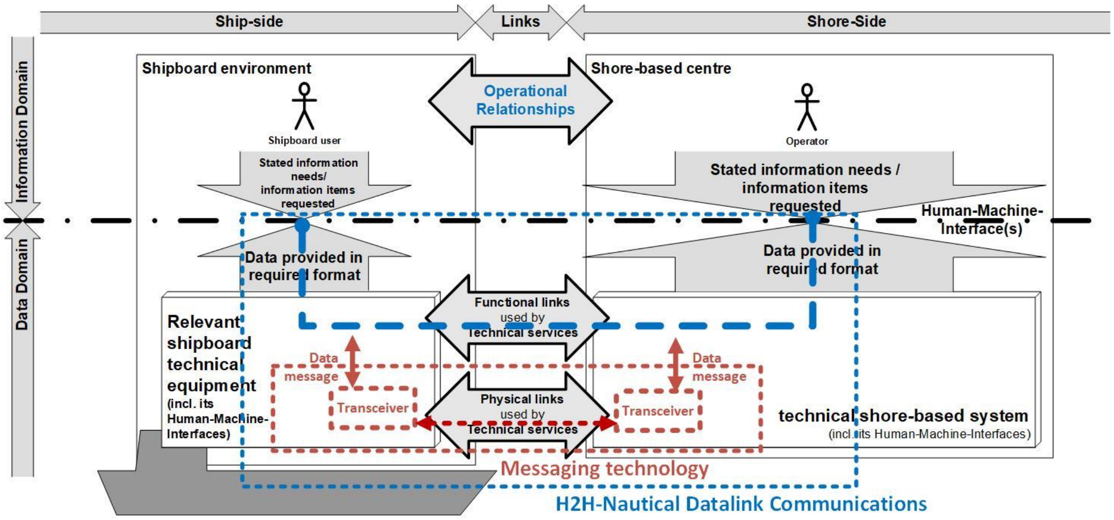

Figure 12: Human-to-Human Nautical Datalink Communications in architectural context

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 or beacon application[2] in the digital domain (see Figure 13). 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.

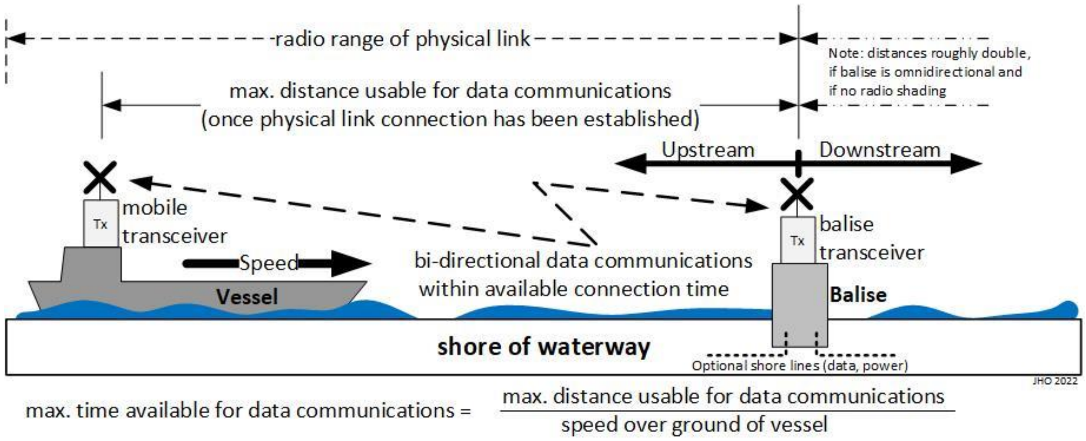

Figure 13: The IWT Infrastructure Site Architecture and working principle

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.

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[2] ‚Balise' is a concept well established in the rail, road, and maritime domains. At rail – where the name is used as such -, balises are important fixed points of communication between train and trackside; in the road/ITS domain, balises installed in gates over the road are used e.g. in electronic toll collection applications; in the maritime domain, the notion equals the concept of a beacon, i.e. a fixed aid-to-navigation transmitting relevant data to vessels passing by.

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Moving towards higher levels of system integration, the **IWT System Interconnection Architecture (ISIA)** as inspired by ITS is adapted by analogy (see Figure 14). 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 contributes to the 'useful combination' of a **'Future optimum IWT Fairway & Navigation Heterogeneous Network'.**

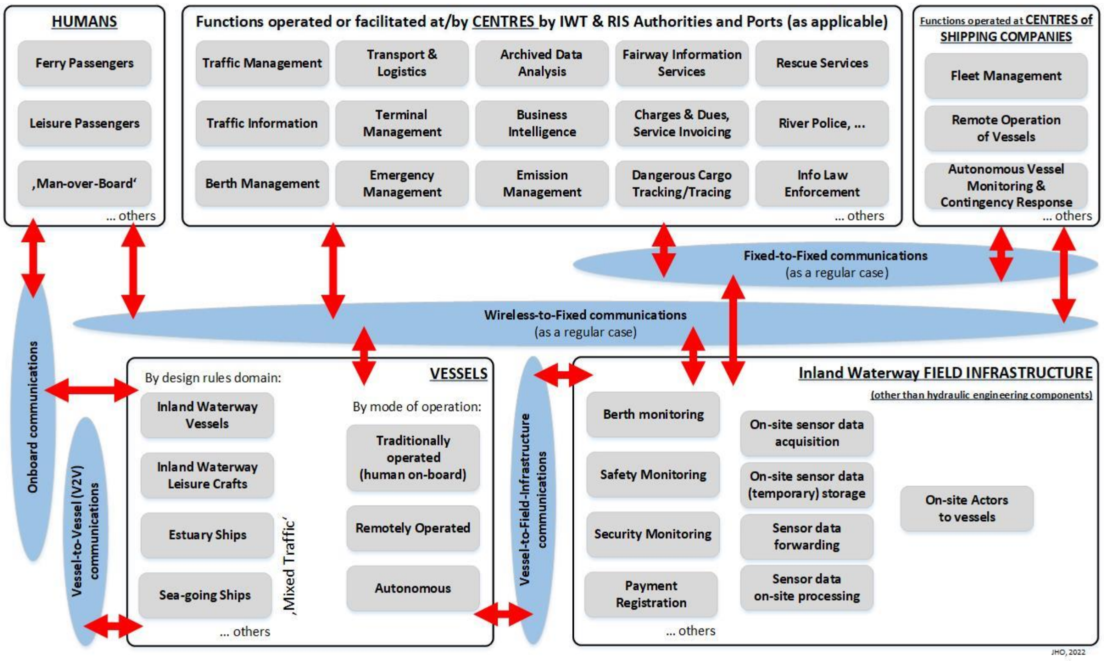

Figure 14: IWT Fairway & Navigation System Interconnection Architecture (ISIA)

Moving even higher in system integration, the **Overarching IWT Fairway & Navigation Domain Architecture** comes into view (see Figure 15). 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.**

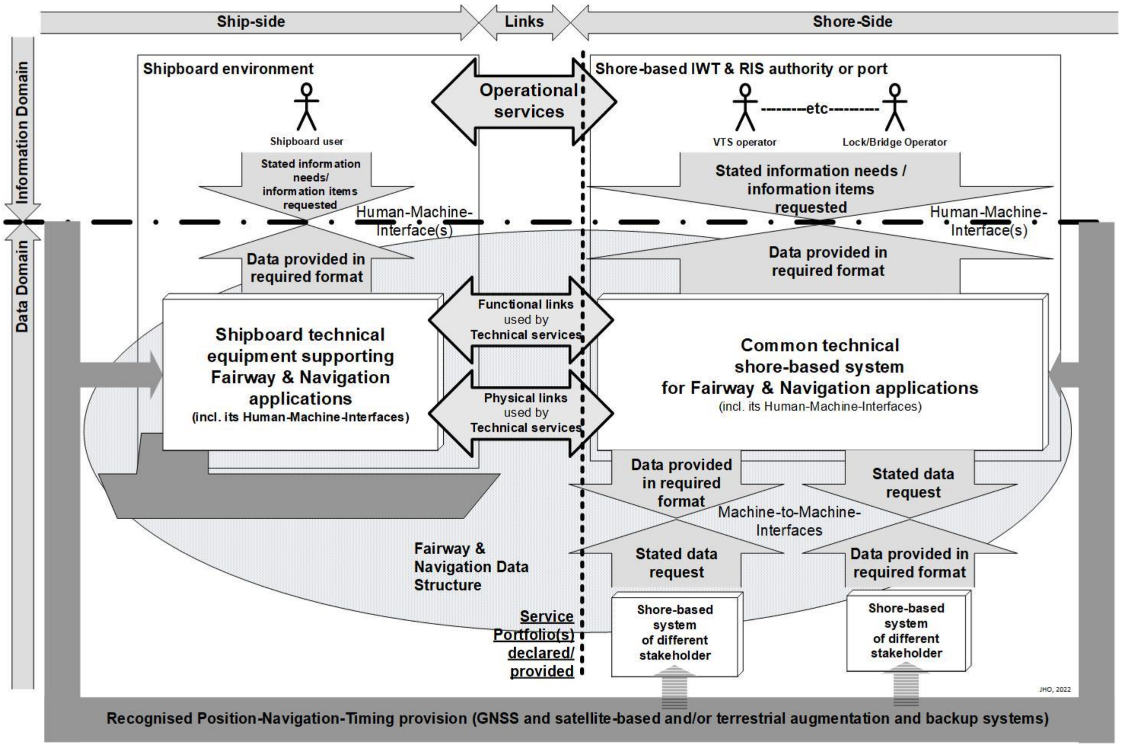

Figure 15: Overarching IWT Fairway & Navigation Architecture, as adopted by sub activity 2.5 and further amended

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 IWT Standard Shipboard Navigation System Architecture (Inland-SSSA, see Table 2) and IWT Common Shore System Architecture (Inland-CSSA, see Figure 16) to that end in due course, also incurring their inbuilt flexibilities each.

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

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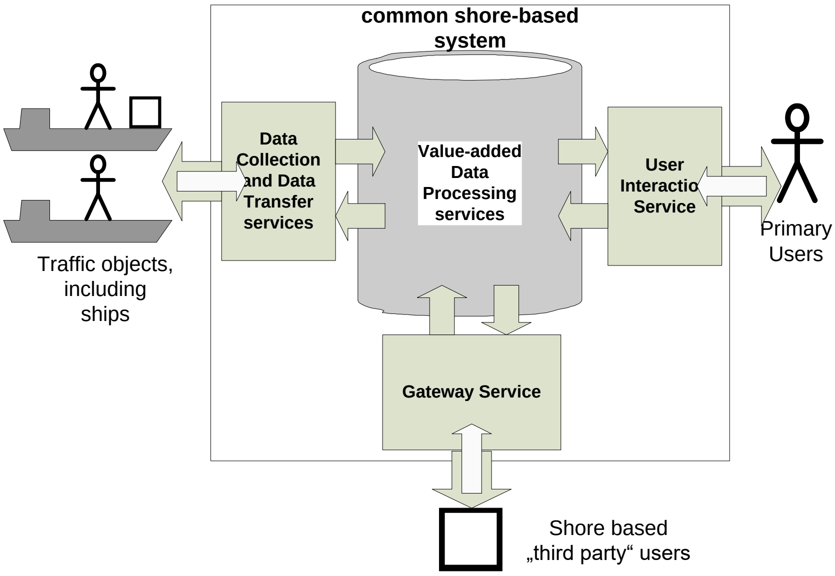

Figure 16: Structural overview on Common Shore-based System Architecture (CSSA)

It should further be noted, that the concept of the Integrated Navigation System (INS) as core of the shipboard navigation system architecture is taken up in the recent IMO work on the autonomous vessels by the proposed definition of an Autonomous Navigation System (ANS), thus also incurring the correlated standard shipboard navigation system architecture for autonomous vessels.

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 (see Figure 17).

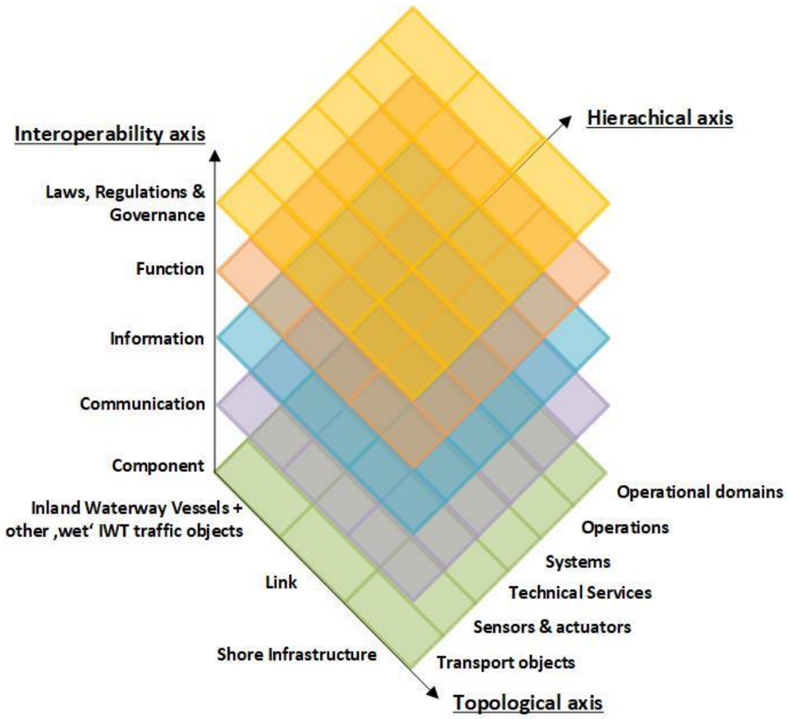

Figure 17: IWT Reference Architecture (IRA) (informed by Maritime Architecture Framework)

These architectures are further explained in the sub activity 3.5 report.

Identified Candidate Technologies

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:

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 Radio navigation 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 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 (Figure 18).

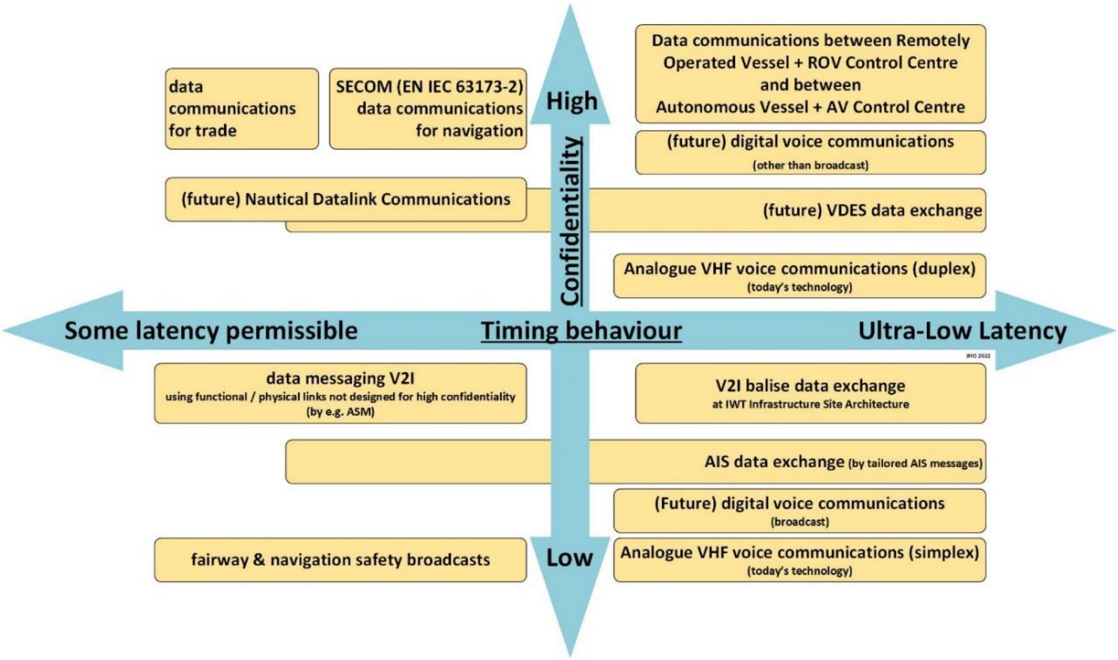

Figure 18: Confidentiality vs. Timing Behaviour in communication profiles

- 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.

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 containers 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.

Conclusion

Sub activity 3.5 finally reflected their 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 between all (international) organisations with responsibilities for the IWT fairway & navigation domain 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, considering 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.

Finally, sub activity 3.5 considered 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. Sub activity 3.5 identified certain inventory items where this might be possible – immediate start and due diligence assumed.

4 Overall conclusions of the current situation and level of digitalisation

In the following table the conclusions of the five sub activities have been merged into one coherent overview regarding the pathway of technological developments and digitalisation. For more detailed and extensive information see the individual sub activity reports and their individual recommendations extracted in chapter 6.2.

The table consists of four columns:

- Numbering of conclusion
- Conclusion
- Reference to sub activity
  - 3.1 New Technologies
  - 3.2 IWT Connectivity Platform
  - 3.3 Smart Sensoring and PNT
  - 3.4 Data model & data registry
  - 3.5 Technologies in other transport modes
- Reference to activity 2
  - 2.1 Smart Shipping
  - 2.2 Synchro modality
  - 2.3 Port & Terminal Services
  - 2.4 RIS enabled corridor management
  - 2.5 Developments in ITS, ERTMS, e-Navigation

Further, the recommendations are grouped into following categories:

- Governance
- Architectures
- Platform technologies & information services technologies
- Data models & registries
- Sensor technologies (including positioning other than radio navigation)
- Communication link technologies
- Position, Navigation, Timing (PNT) by radio navigation technologies

Number	Conclusion	Reference to sub activity	Reference to activity 2
Governance			
1	There is a need to foster a growing understanding for the necessity of harmonisation of terminology in the IWT fairway & navigation domain for any increased digitalisation maturity.	3.5	2.4 2.5
2	Measures are needed to build trust in sharing data.	3.2, 3.5	2.2 2.3 2.5
3	A knowledge base or a forum on European level for technology driven best practices, pilot projects and initiatives may help to avoid redundancies and research from scratch.	3.1	2.4
4	A coordinated approach in reaching multimodality/ synchro modality is necessary for all transport modes. The individual transport modes need to come to a common strategy identifying the individual information	3.1, 3.2, 3.5	2.2 2.3 2.5

	hubs to be interconnected and further enhanced. The problem cannot be solved within one mode alone.		
5	The development of EU data registries needs a coordinated approach to avoid redundancies as well as waste of resources and money. All relevant stakeholders and bodies should be involved.	3.4	2.4 2.5
6	Sustainable operation of European services is key for all involved stakeholders. That applies to EU services like ERDMS or EHDB but also EuRIS. A solid governance structures shall guarantee such permanent operation. Further investigation in the RailNetEurope governing structure may be helpful towards the evolution of the EuRIS performance.	3.2	2.4 2.5
7	The migration path to increase the IWT digitalisation levels (IDLs) should include fall-back provisions.	3.5	2.1 2.2 2.3
8	Backup and fall-back solutions are important aspects on smart vessels and the traffic situations surrounding them. Redundant systems are a pre-requisite for safe and secure operation but also fall-back scenarios need to be applied to reach a safe vessel status when important systems fail	3.3	2.1
9	In the future, some technologies will probably no longer be needed. Others will need modifications or stay as bridge technologies and then will need to be phased-out. Within the context of an overarching migration path concept to be established, these technologies need to be identified.	3.5	-
10	To ensure a harmonised development (in Europe) of the migration path, it is required to have one coordinating competent body. At the same time, the body should improve cooperation with other modes of transport.	3.1 3.5	2.1 2.2 2.3 2.4 2.5
Architectures			
11	New system architectures should be introduced to create a standard for further harmonised technological improvements and developments.	3.5	2.1 2.4 2.5
Platform technologies & information services technologies			
12	EuRIS should be positioned as a European information hub for IWT. The following possibilities were positively evaluated and can be evaluated further, also keeping an eye on the consequences of EuRIS itself: - EuRIS as a Connectivity Platform for IWT - EuRIS as an IWT node in the Mobility Data Space - EuRIS as Data Registry	3.2, 3.4	2.4

13	There is a great potential that the future IT/system architecture on national/regional/European/ international level is federated as it seems unrealistic that there will be a central one-stop-shop for everything also due to the grown nature. Even if EuRIS would be a central node for IWT, in a higher scale it would also be linked in a federative network for data exchange. Data exchange via APIs will be crucial which also requires agreed semantics, harmonised interfaces and language.	3.2, 3.4 3.5	2.2 2.4
14	Interconnection of Port Community Systems with EuRIS is a key element to create a first federated network in IWT. A common agreement on the required data and services from fairway authorities and potentially vice versa will lead to and understanding of exchange formats - Who will adapt - Position of EuRIS This may open the door for multimodal transport planning already.	3.2	2.2 2.3 2.4
15	eFTI will play a major role in the upcoming years. In IWT mainly the further developed area of ERI is affected. Therefore, existing reporting applications may be enhanced to act as eFTI service providers, again being a node in a federative approach. To ease efficiency a common ERI – eFTI translator service may be evaluated.	3.2, 3.4	2.2 2.3 2.5
16	Technologies like IoT, drones, Big Data, AI may play a key role in the upcoming years for the development/digitalisation of IWT. Different use cases require a different combination of those.	3.1	2.1 2.2 2.3
17	It requires several preceding steps to achieve a holistic representation of the digital twin of inland navigation, the entire logistics chain or beyond. A few milestones to the final goal: - Data Exchange platform (mainly EuRIS) - Smart Infrastructure ("Infostructure") - Predictive traffic concept/model	3.1	2.1 2.2 2.3 2.4
Data models & registries			
18	RIS.net should be the future data model in IWT. It should consider the information in the IHO Geospatial Information Registry, the Maritime Resource Name and the need of TENtec.	3.4 3.5	2.4 2.5
19	EuRIS can be used as a data registry as well as a gateway for reference data between RIS authorities and ERDMS.	3.4	2.4 2.5
***Sensor technologies** (including positioning other than radio navigation)*			

20	Data quality incl. metadata of data will play a crucial role in current and future applications. Accuracy and reliability of sensor/smart sensor data is an important KPI to be considered.	3.1, 3.3, 3.4	2.1
21	In the upcoming decade, a portion of the system of waterways can be developed into a smart infrastructure ("Infostructure") It will facilitate the use of smart vessels and (underwater) drones. In this context, technologies such as smart sensors, IoT, etc. will be used - Smart devices can be implemented to support IWT - Automated vessels need to be smarter than the infrastructure; they shouldn't rely on it, but can be assisted - Smart infrastructure can optimise the maintenance for facility operator - "Infostructure" can be used to fulfil the information needs of shipping and to support automated vessels (e.g. docking, berthing, locking) - Network of smart sensors and drones can be used to create Big Data and to meet the requirement for processing / processing capacity	3.1, 3.3, 3.5	2.1 2.2 2.3
22	Vessel swarms can be used to measure and gather environmental and/or waterway infrastructure data, which then forwarded the data to fairway authorities and ports via appropriate (radio) communication means.	3.5	2.1 2.2 2.3
23	Smart sensors can be used for various tasks on vessels or infrastructure as part of a network. But also, existing sensors can be used in a smart way adding post-processing or AI to it. Smart sensor systems/networks need cybersecurity measures to mitigate new risks. It is very important to comply with GDPR rules when generating new data.	3.3	2.1 2.2 2.3
Communication link technologies			
24	Connectivity and secure communication links on the waterways are getting more and more relevance, especially when considering automated/autonomous vessels. - IMT-2020 radio communication systems / 5G - WiFi - VDES - VLC (Visual Light Communications) - NDLC (Nautical Datalink Communications) - SECOM ('Full Functionality SECOM implementation' or 'Just Secure Data Protocol SECOM implementation') - CDLMR (Conventional Digital Land Mobile Radio System)	3.1, 3.5	2.1 2.2 2.3 2.4

	Solutions need to be found also considering backup channels (automated vessels cannot rely on only one communication link). Further investigations could go towards a so-called heterogeneous network as a communication system.		
25	Sensor networks and IoT networks can incur cybersecurity and privacy issues/threats to both infrastructure and vessels.	3.1, 3.3	2.1 2.2 2.3 2.4
Position, Navigation, Timing (PNT) by radio navigation technologies			
26	Future assistance systems or automated/ autonomous vessels require high precision positioning most probably via two different sources. Also, the increase of PNT data quality for presently known and implemented applications of any kind of vessel should be pursued because the current setup on vessels mainly using AIS and the built-in positioning is not adequate for such applications. AIS is not developed to be a PNT device. There are already more radio navigation systems available as well as advanced GNSS that can be adapted and introduced in IWT. The concept of Recognised PNT provision and a shipboard PNT processing entity can use multiple sources of PNT data from different sensors to provide reliable and resilient position information.	3.3, 3.5	2.1 2.4

5 Future state of digitalisation in IWT

Within the sub activities of activity 3 a description was made of the most optimal desired situation (long term) of the sub activity topic, based on existing studies, investigations and business interviews. To limit the scope somewhat a timeline of approximately 10 years was used for the designation “long term”. Taking a greenfield perspective (lacking the constraints of today) was encouraged.
Of course, it is fully recognised that the voyage towards this desired future state will encounter known and unknown constraints. With these constraints in mind, there is a definite probability that where we can be in ten years does not equal where we want to be in ten years.

5.1 Where do we want to be in 10 years?

The results of the DIWA activity 3 sub activities show a drive to reach the maturity level “connected” within 10 years including in some cases even maturity level “intelligent” (see Figure 4).

As was the case in activity 2 (business developments), also in activity 3 it is envisioned that EuRIS will have established itself in the upcoming decade as the default IWT connectivity platform/mobility data space for IWT with respect to real-time and forecasted fairway-, infrastructure-, traffic and transport information, covering the entire European fairway network relevant for IWT based on RIS.net [3.2, 3.4]. Interconnections with other modalities will have contributed to the transformation of systems into a holistic digital twin of the fairway system [3.1, 3.2]. Sizeable parts of the IWT Infrastructure will be able to digitally interact with vessels as well as vessels with each other through the extended use of sensors and standardised communication link technologies, used as intended, (cyber-)protected and certified where necessary [3.3, 3.5]. Should digital technologies fail, graceful degradation and fall-back measures are to a large extent in place to provide resilience and safeguard operations [3.3, 3.5]. As a result, vessel to vessel and vessel to shore (and vice versa) will be voicelesser than today [3.5].

The S-100 framework of maritime origin will have been largely integrated in IWT, providing digital services via screens and devices (e.g. ECDIS) at the skipper’s fingertips [3.5].

All efforts to reach higher maturity levels will have received strong guidance from technology-oriented architectures [3.5]. A competent and sufficiently mandated coordinating body will drive harmonisation across the board and strengthen multimodal and international collaboration [3.1, 3.5].

Concepts such as eFTI, linked data and federative platforms will have matured and be interoperable with platforms like EuRIS [3.2, 3.4].

Technological developments will support the ongoing drive towards remote and even autonomous operation of vessels [3.3, 3.5], although fully autonomous vessels are not expected to be a sizeable part of the inland fleet yet in 2032.
The advent of AV in specific areas or corridors is foreseen, and consequentially the operational and technical pre-requisites both for the shipboard and the infrastructure domains will have been implemented and rendered fully operational. The likewise advent of ROV will add additional complexity, and this will be considered by appropriate operational and technical means, too.

6 Roadmap

6.1 Introduction

Investigation of the current opportunities, obstacles and state of the topics within the DIWA activity 3 sub activities, combined with the envisioned developments and future state in 2032 has resulted in a collection of recommendations and topics to be further addressed by DIWA activities 4 and 5.

The overall and integrated roadmap, including the recommendations and actions from DIWA activity 2, 3 and 4 will be drafted in DIWA activity 5.

This chapter will group the recommendations into categories (chapter 6.2) and provide a first assessment of the expected timeline based on timing and importance (chapter 6.3).

6.2 Grouped recommendations

Recommendations and proposed actions in different DIWA 3 sub activities often contribute to similar (technological) goals or benefits. Therefore, the following categories are proposed for grouping recommendations and actions:

- Governance
- Architectures
- Platform technologies & information services technologies
- Data models & registries
- Sensor technologies (including positioning other than radio navigation)
- Communication link technologies
- Position, Navigation, Timing (PNT) by radio navigation technologies

Some recommendations may occur multiple times (different origin or applicable to multiple categories).

Category	Recommendation	Origin (Rec #)
Governance		
	Utilise existing projects or use cases involving New Technologies by identifying them (see recommendation about knowledge management platform) and assessing their level of maturity. The Authorities should use of these experiences and align the various activities.	3.1 (1)
	Define measures as meaningful key performance indicators (e.g. availability, downtime, time to repair, time between failures, etc.) for the IWT infrastructure Identify how these KPIs can be captured by implementing IoT devices (UC2)	3.1 (2)
	Identify minimum viable products (MVP) for each use case (UC1-UC4)	3.1 (3)
	Identify pain-points (UC3) in the existing traffic concepts (e.g. unforeseeable waiting times at locks) that ideally affect a group of stakeholders	3.1 (4)
	Initiate and strengthen multimodal and internal collaboration by intensifying multimodal pilot projects and initiatives to	3.1 (5)

	benefit from the interdependencies between different stakeholders	
	Shift from decision support to decision making tools, by offering traffic predictions (UC3) on the data exchange platforms	3.1 (6)
	Fairway authorities, as an enabler and provider of digital infrastructure, should consider to cooperate with private and public private partnership (PPP) initiatives, because private digital initiatives are driven by user and market demands and are often able to develop digital solutions in a quick and agile way	3.1 (7)
	Establish permanent digital innovation teams (project teams, work groups) on different areas of expertise on European level for development and implementation of innovation. Experts responsible for a single activity within the product/service help to foster expertise and innovation in the respective area.	3.1 (9)
	Establish a knowledge management platform to conserve best practices and manage acquired (innovation) knowledge. Authorities with a lack of innovative capacity would benefit from insights gained by authorities which are much more engaged in innovation and digitalisation	3.1 (10)
	Establish a collaboration tool for projects and ideas, like a forum avoiding redundant projects and research, to increase the potential for a more coordinated, effective innovation effort among all participating authorities	3.1 (11)
	Technologies like IoT, Cloud computing, AI and Big Data may be very relevant for the fairway authorities in the upcoming years. Therefore, investigate these topics in more detail and gain practical experience	3.1 (12)
	Consider the RailNetEurope governance structure as example for further evolving the EuRIS governance	3.2 (11)
	Raise awareness among the logistics industry to perform modifications to their vessels in a planned way	3.3 (7)
	Raising awareness with regards to cybersecurity risks of sensors both among the fairway authorities and among the vessel operators	3.3 (8)
	Users shall be trained and educated in the use of sensors/sensor systems	3.3 (19)
	Plan specific actions that trigger or foster at existing competent bodies in IWT growing understanding for the need of harmonisation across competent bodies in the IWT fairway & navigation domain for any increased digitalisation maturity	3.5 (16)
	Establish/address a competent Body for harmonisation in IWT (e.g. CESNI, UNECE) needed for the migration path development and consecutive execution	3.5 (17)
	Evaluate which non-cooperative technologies will be still needed on a regular basis and/or for fall-back arrangements	3.5 (18)
	Determine the need of 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	3.5 (19)

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	Define specific stages regarding the harmonisation across the existing competent bodies of the IWT fairway & navigation domain towards • acceptable intermediate solutions fulfilling their tasks ('stepping stones') • migration path(s) from one acceptable intermediate solution to the next one	3.5 (20)
	Create awareness at competent bodies of the IWT fairway & navigation domain growing understanding for the need of a harmonised operational framework for traffic situations with mixed presence of traditionally operated, remotely controlled, and autonomous vessels for IWT in the European Union	3.5 (21)
	Remove definition ambiguities from all relevant regulations, operational procedures, terminology and data models need as far as possible, in order to arrive at 'digital information exchange as a default'	3.5 (22)
	Consider measures to build trust amongst IWT stakeholders regarding sharing of data	3.5 (23)
	Design the graceful degradation and fall-back arrangements needed into the technical, regulatory, operational, business continuity planning domains from the outset	3.5 (24)
	Take a stance by recommending areas for pro-active IWT activity with a view to be able in some future to influence maritime accordingly for good strategic reasons.	3.5 (25)
Architectures		
	Introduce and establish new system architectures in IWT, like … • Nautical Datalink Communications architecture (NDLC) • Inland Infrastructure Site Architecture (ISA) • Inland System Interconnection Architecture (ISIA) • Inland Shipboard Navigation System Architecture (Inland-SSSA) • Inland Common Shore System Architecture (Inland-CSSA) • Inland shore services (based on Inland-CSSA) • IWT Reference Architecture (IRA) • Overarching IWT Architecture A combination and integration of the mutually supportive system architectures is recommended resulting in the use of them in inland navigation as a standard for further technological improvements/developments	3.5 (1)
Platform technologies & information services technologies		
	Setup a data exchange platform based on EuRIS	3.1 (UC1)
	Establish a predictive traffic model using AI	3.1 (UC3)
	Create a holistic digital twin empowered by advanced computing	3.1 (UC4)
	Shift from decision support to decision making tools	3.1 (6)
	Explore the potential of EuRIS as connectivity platform in IWT	3.2 (1)
	Validate the conformance of EuRIS with the European Data Space requirements and promote it as Data Space for IWT	3.2 (2)
	Prepare EuRIS as node in the data space for connection with other common European data space nodes	3.2 (3)

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	Evaluate the impact of improving existing national or regional reporting applications to certified eFTI service providers	3.2 (5)
	Closely follow the federative developments (e.g. project FeDERATED, FENIX) and the impact on our fairway information services (EuRIS)	3.2 (6)
	Investigate further if the gathered information via the FENIX network is relevant for IWT and to which extent information exchange with EuRIS is envisioned	3.2 (7)
	Start or further improve cooperation between Port community systems and fairway authorities (EuRIS) to optimise and digitalise processes	3.2 (8)
	Clarify data/service needs of PCS and define data exchange mechanisms	3.2 (9)
	Analyse the need for single sign on (SSO) amendments in EuRIS for e.g. PCS communities	3.2 (10)
	When using data from sensors, GDPR guidelines should always be taken into account by all parties.	3.3 (1)
	Cybersecurity measures should not merely be applied to the smart sensor. Applications connected to the Smart Sensors or applications using the data of these sensors must also comply with appropriate cybersecurity measures.	3.3 (4)
	Consider the creation of a common ERI - eFTI translator service	3.4 (1)
	Consider using EuRIS as a gateway for reference data between the RIS Authorities and the ERDMS	3.4 (6)
	Investigate the potential usage of relevant environmental and/ or waterway infrastructure related data received from Earth Exploration Satellite system providers	3.5 (13)
	Investigate 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	3.5 (14)
	Investigate the potential usage of relevant space weather data received from space weather observatories	3.5 (15)
	Establish one coordinating competent body to ensure harmonised development	3.5 (26)
Data models & registries		
	Create standards for harmonised data exchange in IWT (data sets and interfaces)	3.1 (8)
	Stay closely involved in the elaboration and finalisation of the eFTI architecture and data set	3.2 (4)
	Continue the elaboration of RIS.net as basic data model of IWT	3.4 (2)
	Consider the incorporation of the Maritime Resource Name (MRN) in RIS.net, in tight cooperation with the IEHG	3.4 (3)
	Consider the information available in the IHO Geospatial Information Registry when elaborating RIS.net	3.4 (4)
	Consider the TEN-T information needs in RIS.net, so that the RIS.net data can be translated into TEN-T data without the need for manual data additions	3.4 (5)

	Consider extending and formalising the role of EuRIS as a data registry	3.4 (7)
	Aim for a strong collaboration between all involved shareholders when existing IWT Data Registries need to be replaced or significantly redesigned in the future	3.4 (8)
	Consider the merits of EuRIS when existing IWT Data Registries need to be replaced or significantly redesigned in the future	3.4 (9)
	Introduce and deploy the S-100-Framework in IWT Fairway & Navigation.	3.5 (27)
	Introduce and deploy the standardised route plan exchange via S-421 format in IWT Fairway & Navigation, if deemed necessary after evaluation	3.5 (28)
	Introduce and deploy those IALA S-200 world data products (e.g. Aids to Navigation Information, VTS Exchange format, Port Call message, etc.) deemed relevant in IWT fairway & navigation domain	3.5 (29)
	Reconcile 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	3.5 (32)
***Sensor technologies** (including positioning other than radio navigation)*		
	Create a smart infrastructure network based on IoT	3.1 (UC2)
	Create a holistic digital twin empowered by advanced computing	3.1 (UC4)
	Camera recordings should be given special protection. They are also subjected to the GDPR rules.	3.3 (2)
	Recordings of sound are also subjected to GDPR regulation and therefore should be considered.	3.3 (3)
	When introducing a new sensor on a vessel, it becomes part of a larger network of sensors and applications. The security aspect should be revised to ensure the safety of the complete network.	3.3 (5)
	All sensors compiled in the inventory are cross checked with the business developments from activity 2. Investigate on the possibility to implement.	3.3 (10)
	Safety related sensors should be certified before use.	3.3 (12)
	The usage of a sensor should be well thought trough and should be according the supplier guidelines and/or the applicable certification process if available/needed.	3.3 (14)
	Ensure high data quality of data generated to sensors. Investigate the data quality parameters to be met, in function of smart sensors.	3.3 (16)
	Deployment of smart infrastructure sites along relevant inland waterways, like a Smart hectometre stone, which can be used for communication with Smart Ships.	3.5 (10)
Communication link technologies		
	Study the operational, regulatory, data quality, and cyber security requirements for communication profiles of the	3.5 (30)

	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.	
	Specifically build a case for continuation of open access digital data communication links in the future.	3.5 (31)
	Adopt SECOM, using one of two options: 'Full Functionality SECOM implementation' or 'Just Secure Data Protocol SECOM implementation' at IWT fairway & navigation domain for secure communication.	3.5 (2)
	Adopt VDES as a new or additional system for communication and data exchange of ship with shore services and other ship. The deployment is a pre-requisite for the implementation of one implementation option of the R-Mode.	3.5 (3)
	Adopt R-mode as a terrestrial radio navigation system as well as a backup system.	3.5 (4)
	Extend the use of IMT-2020 radio communication systems in IWT systems for seamless transmission of data and voice using its own frequency setup. It is independent of the maritime mobile service VHF frequency band. It can be used for R-mode and the deployment of smart IWT infrastructure site.	3.5 (5)
	Adopt (High bandwidth) Visual Light Communication (VLC) with regard to increasing automation in the IWT fairway & navigation domain	3.5 (6)
	Introduce the concept of a Recognised PNT Provision and a formal recognition process for GNSS, satellite-based and/or terrestrial augmentation as well as terrestrial backup systems.	3.5 (7)
	Adopt Nautical Datalink Communication for voiceless(er) communication as a basis for digital information exchange by default at higher IDLs under the aspects of Human2Machine and Human2Human	3.5 (9)
	Use the Inland System Interconnection Architecture (ISIA) for selection of appropriate candidate technologies for digital radio communication to establish a consolidated future version of the (inland) AIS with a digital radio communication operating in parallel	3.5 (11)
	Investigate applicability, prerequisites, requirements and benefits of a future optimum IWT HetNet (Heterogeneous network) including • Future version of (inland) AIS • "full functionality SECOM implementation" or "just secure data protocol SECOM implementation" • VDES • IMT-2020 (data, voice) • CDLMR (voice) • VLC	3.5 (12)
Position, Navigation, Timing (PNT) by radio navigation technologies		
	When introducing a new sensor on a vessel, it becomes part of a larger network of sensors and applications. The security	3.3 (5)

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	aspect should be revised to ensure the safety of the complete network.	
	When different sensors give different values, it becomes difficult to use the true value. Investigate the number of sensors needed to get accurate data in order to create redundancy.	3.3 (6)
	When different sensors and vessels start working together (autonomously), a central timing system is needed. Investigate central timing systems for deployments.	3.3 (9)
	Investigate the need of a security policy for vessel operators (dos and don'ts regarding IT and Data) regarding sensor data. This could also be demanded by authorities.	3.3 (11)
	Develop requirements for evolving sensors and PNT equipment used for automated/autonomous vessels.	3.3 (13)
	It is a necessity for fairway authorities to have fall-back options for autonomous sailing based on smart sensors.	3.3 (15)
	Integrate a fall-back solution in sensor systems applied on e.g. automated vessels	3.3 (17)
	Accuracy and reliability information shall be provided by sensors	3.3 (18)
	Implement a shipboard PNT processing entity. Provide migration path suggestions and follow developments in the maritime sector.	3.5 (8)

6.3 Assessment of recommendations

A basic technology related assessment of the grouped recommendations within chapter 4 shall be performed in this chapter for those actions where such assessment is applicable. An indication can be derived on the complexity and reachable IDL level explained in chapter 2.2.
Depending on the action item and its applicability the readiness level and adaptability can be split in smaller pieces resulting in different effort highlighted in the tables.

Platform technologies & information services technologies

#11 EuRIS as Connectivity Platform, EU Mobility Data Space and Data Registry

DIWA Assessment metrics	Assessment results
DIWA-TRL	5 (Prototyping & Incubation – testing prototype in user environment) 4 (Concept Validation – lab prototype) 3 (Concept Validation – first assessment feasibility)
DIWA-Adaptability	+ (Adaptability with minor modifications) 0 (Adaptable with substantial modifications)
DIWA-Adaptation demands	++ (Little adaptation resource/time demands) + (Intermediate adaptation resource/time demands) 0 (Substantial adaptation resource/time demands)
DIWA-Technology radar	2022-2026
DIWA-IDL impact	II (Connected IWT fairway & navigation domain)

Table 3: Assessment metrics of EuRIS

Rationale: European Mobility Data Spaces range from concepts and standardisation initiatives to actual implementations. Adaptability and effort depend on where the developments are going. If a standard or interaction concept differs greatly from the de facto IWT standard (e.g. the current EuRIS

implementation) substantial modifications will be necessary, requiring substantial effort. The requirements towards a Connectivity Platform or Data Registry are rather clear though. Should EuRIS be recognised as a European Mobility Data Space/Connectivity Platform/Data Registry as-is, the effort will be minor.
Recognition especially as a European Mobility Data Space will help raise the maturity level to Connected.

#13 Interconnection with Port Community Systems

DIWA Assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion)
DIWA-Adaptability	++ (Seamless Adaptability) + (Adaptability with minor modifications) 0 (Adaptable with substantial modifications)
DIWA-Adaptation demands	++ (Little adaptation resource/time demands) + (Intermediate adaptation resource/time demands) 0 (Substantial adaptation resource/time demands)
DIWA-Technology radar	2022-2026
DIWA-IDL impact	II (Connected IWT fairway & navigation domain)

Table 4: Assessment metrics of PCS

Rationale: Port Community Systems have been operational for several years and primarily cover business to business data exchange. Interconnecting an IWT Connectivity platform like EuRIS is relatively straightforward for governmental open data but, will require increasing amounts of efforts when incorporating B2B data. Interconnections will contribute to raising the maturity level to Connected.

#14 eFTI compliancy

DIWA Assessment metrics	Assessment results
DIWA-TRL	4 (Concept Validation – lab prototype) 3 (Concept Validation – first assessment feasibility)
DIWA-Adaptability	+ (Adaptability with minor modifications) 0 (Adaptable with substantial modifications)
DIWA-Adaptation demands	+ (Intermediate adaptation resource/time demands) 0 (Substantial adaptation resource/time demands)
DIWA-Technology radar	2022-2026 2027-2032
DIWA-IDL impact	II (Connected IWT fairway & navigation domain)

Table 5: Assessment metrics of eFTI

Rationale: Since eFTI as such is still in a conceptual phase, the official timeline (implemented before 2026) is very ambitious. Depending on the eventual outcome of the data model, architecture and applicability discussions impact could range from minor to major. eFTI in itself will contribute to raising the maturity level to Connected.

#15 Technologies like IoT, (underwater) drones, Big Data, AI

DIWA Assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion) 8 (Initial market introduction)
DIWA-Adaptability	+ (Adaptability with minor modifications) 0 (Adaptable with substantial modifications)
DIWA-Adaptation demands	+ (Intermediate adaptation resource/time demands) - (High adaptation resource/time demands)
DIWA-Technology radar	2022-2026

	2027-2032
DIWA-IDL impact	III (Intelligent IWT fairway & navigation domain)

Table 6: Assessment metrics of New Technologies

Rationale: These technologies are already implemented in many places. Although there are some remarkable prototype results for AI (e.g. ChatGPT[3]) the technology hasn't reached market level deployment in safety critical processes (i.e navigation) yet[4]. Other technologies (e.g. drones, IoT) are more mature and require less effort to deploy in IWT supporting processes. For Big Data the maturity and adaptability depend on the intended usage. Anomaly detection is notably easier to achieve than decision support based on Big Data[5].

#16 Holistic digital twin representation of IWT

DIWA Assessment metrics	Assessment results
DIWA-TRL	3 (Concept validation – first assessment feasibility)
DIWA-Adaptability	+ (Adaptability with minor modifications) 0 (Adaptable with substantial modifications)
DIWA-Adaptation demands	0 (Substantial adaptation resource/time demands) - (High adaption resource/time demands)
DIWA-Technology radar	'Future Box'
DIWA-IDL impact	III (Intelligent IWT fairway & navigation domain)

Table 7: Assessment metrics of Holistic Digital Twin

Rationale: The holistic digital twin requires many other technologies as a prerequisite, such as IoT, AI, Big Data, etc., but also a properly working data exchange with other traffic modes. There are already some companies and working groups investigating a mobility digital twin. Even if the necessary adjustments to realise the holistic digital twin for inland navigation could be modest, the effort remains very high in any case due to the complexity of this technology. A Holistic Digital Twin will certainly not be implemented before 2032, but it will assist to elevate IWT to the highest level of digitalisation Intelligent.

Data models & registries

#17 RIS.net concept

DIWA Assessment metrics	Assessment results
DIWA-TRL	4 (Concept Validation – lab prototype) 3 (Concept Validation – first assessment feasibility)
DIWA-Adaptability	+ (Adaptability with minor modifications) 0 (Adaptable with substantial modifications)
DIWA-Adaptation demands	+ (Intermediate adaptation resource/time demands) 0 (Substantial adaptation resource/time demands)
DIWA-Technology radar	2022-2026 2027-2032
DIWA-IDL impact	II (Connected IWT fairway & navigation domain)

Table 8: Assessment metrics of RIS.net

Rationale: The RIS.net concept is based on the EuRIS reference network model and its further development towards a harmonised reference model throughout IWT. A feasibility assessment with substantial modification needs is already planned within the next three years. However, the standardisation process including full rollout is envisaged for the next ten years. The implementation of RIS.net in IWT relevant systems will contribute to raising the maturity level to Connected.

[3] https://en.wikipedia.org/wiki/ChatGPT
[4] https://www.analyticsinsight.net/top-10-massive-failures-of-artificial-intelligence-till-date/
https://spectrum.ieee.org/ai-failures
[5] https://www.datascience-pm.com/project-failures/

Sensor technologies (including positioning other than radio navigation)

#19 Smart infrastructure

DIWA Assessment metrics	Assessment results
DIWA-TRL	8 (Initial market introduction) 4 (Concept Validation – lab prototype) 1 (Invention – Basic principles observed)
DIWA-Adaptability	+ (Adaptability with minor modifications) 0 (Adaptable with substantial modifications) - (Adaptable by redesign in analogy)
DIWA-Adaptation demands	+ (Intermediate adaptation resource/time demands) 0 (Substantial adaptation resource/time demands) - (High adaptation resource/time demands)
DIWA-Technology radar	2022-2026 2027-2032 'Future Box'
DIWA-IDL impact	II (Connected IWT fairway & navigation domain) III (Intelligent IWT fairway & navigation domain)

Table 9: Assessment metrics of smart infrastructure

Rationale: The application of smart infrastructure is manifold, starting from IoT devices providing live object status information and ending at cooperating with automated/autonomous vessels at docking or locking manoeuvres. This wide spectrum of applicability, adaptation demands and the required timeframe to reach a maturity level of Connected or Intelligent is reflected in the table. Nowadays, smart devices already create smart infrastructure/facilities but reaching an Intelligent maturity level for a high level of autonomy on a broader scope is beyond the timeline of DIWA.

Communication link technologies

#22 Connectivity and communication links

DIWA Assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion) 8 (Initial market introduction) 5 (Prototyping & Incubation – testing prototype in user environment)
DIWA-Adaptability	+ (Adaptability with minor modifications) 0 (Adaptable with substantial modifications)
DIWA-Adaptation demands	+ (Intermediate adaptation resource/time demands) 0 (Substantial adaptation resource/time demands) - (High adaptation resource/time demands)
DIWA-Technology radar	2022-2026 2027-2032 'Future Box'
DIWA-IDL impact	II (Connected IWT fairway & navigation domain) III (Intelligent IWT fairway & navigation domain)

Table 10: Assessment metrics of connectivity

Rationale: Connectivity and reliable communication links are seen as crucial backbone in future smart shipping applications. Although recognised as prerequisite, the implementation of new or advanced communication means on national or regional level requires huge effort. Even not speaking on the dependency on external service/telecom providers for mitigating the lack of high bandwidth communication on and near waterways in many European areas. Technology itself is most likely available but substantial or high adaptation requires sophisticated timeframes. Once established the links enable maturity level Connected or even Intelligent.

Position, Navigation, Timing (PNT) by radio navigation technologies

#24 PNT devices onboard

DIWA Assessment metrics	Assessment results
DIWA-TRL	9 (Market expansion)
DIWA-Adaptability	+ (Adaptability with minor modifications) 0 (Adaptable with substantial modifications)
DIWA-Adaptation demands	0 (Substantial adaptation resource/time demands)
DIWA-Technology radar	2022-2026 2027-2032
DIWA-IDL impact	II (Connected IWT fairway & navigation domain)

Table 11: Assessment metrics of PNT

Rationale: The higher the grade of autonomy the higher the demand on PNT devices onboard. Devices itself are available on the market but with a high price. The rather old vessel fleet comes with the need of huge individual investments for integrated onboard systems requiring substantial adaptation and much time. The developments will lead to maturity level Connected.

6.4 Timeline

A first assessment of the recommended actions indicates a place on the timeline according to their estimated urgency/complexity. In order not to "overload" the picture, some recommended actions have been summarised using a general encompassing term. Where applicable a reference to the sub activity and action point is mentioned. Items in green signify an ongoing effort across the entire timeline which is already started.

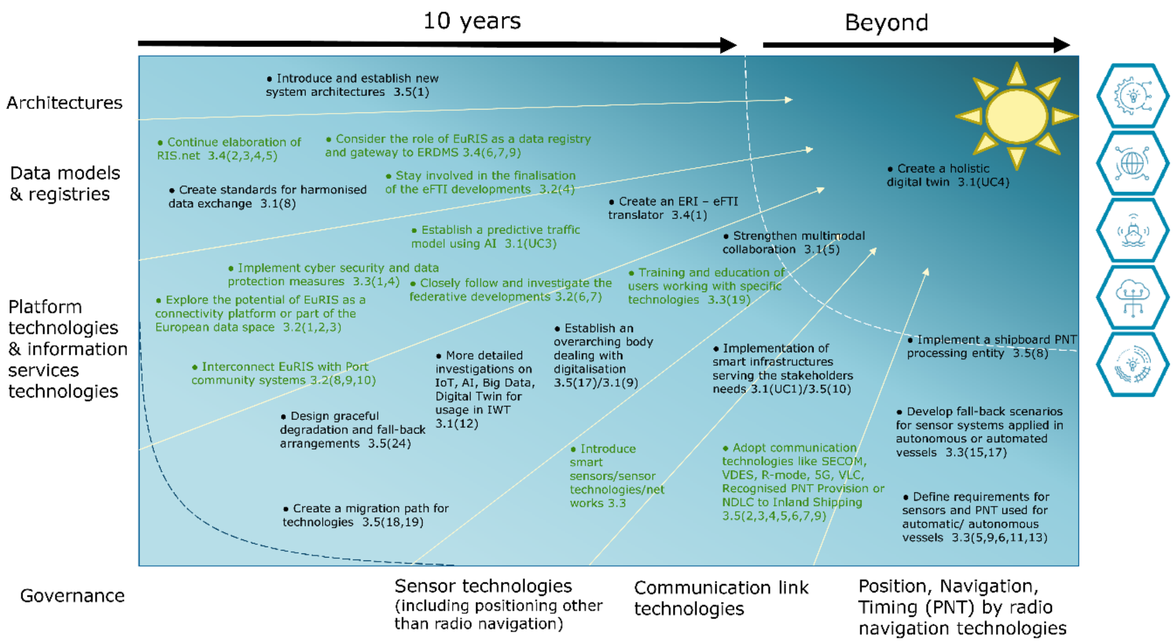

Figure 19: Assessment of main recommended activities in the "road to the sun" approach

In addition, the grouped recommendations out of Figure 19 were plotted on the 4-Quadrant-Matrix model (Figure 20) described in chapter 2.2 identifying the reachable and envisioned digitalisation maturity level by the corresponding effort (resources and time demand).

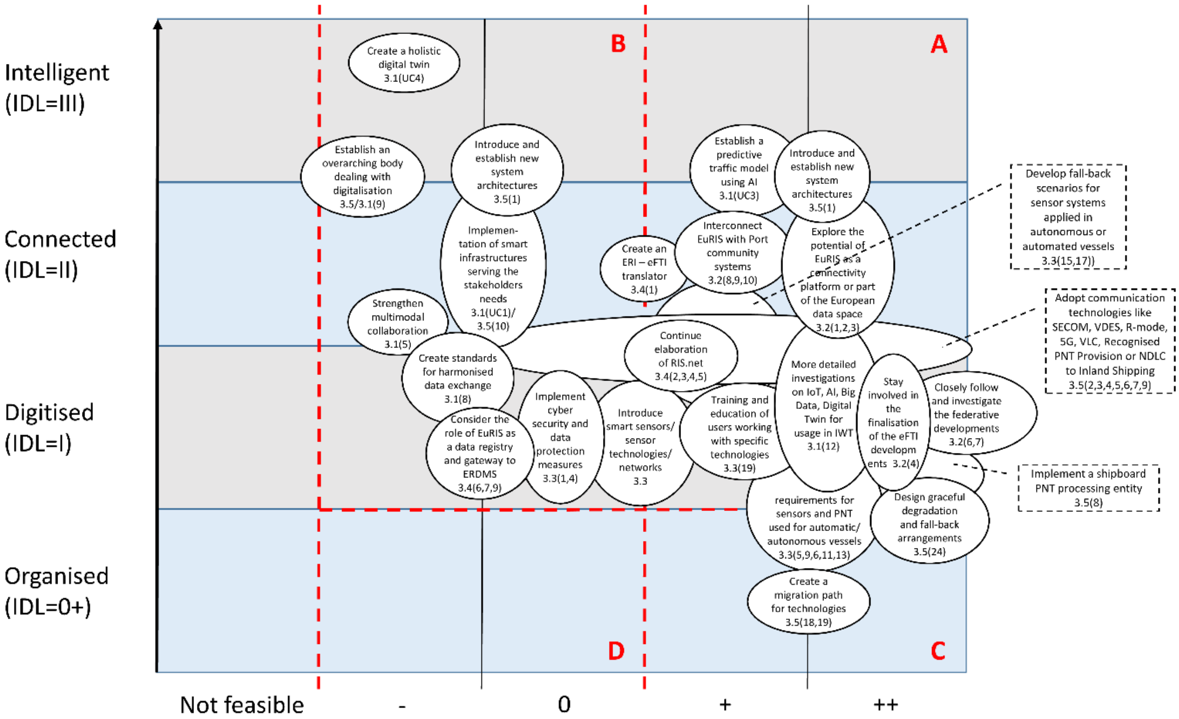

Figure 20: Assessment of main recommended activities in the 4-Quadrant-Matrix model approach

Influencing activities

Besides the envisioned activities within the IWT domain itself, influencing factors by defined timelines of developments from organisations like the European Commission or even other domains like maritime will impact the digital transformation and its priorities in various fields of application. The examples given provide a transition period for the adoption of the ECDIS standard (Figure 21) which has direct influence on the Inland ECDIS specifications as well as the implementation period of the eFTI regulation (Figure 22) which requires to run all related action in conjunction with the given timeline.

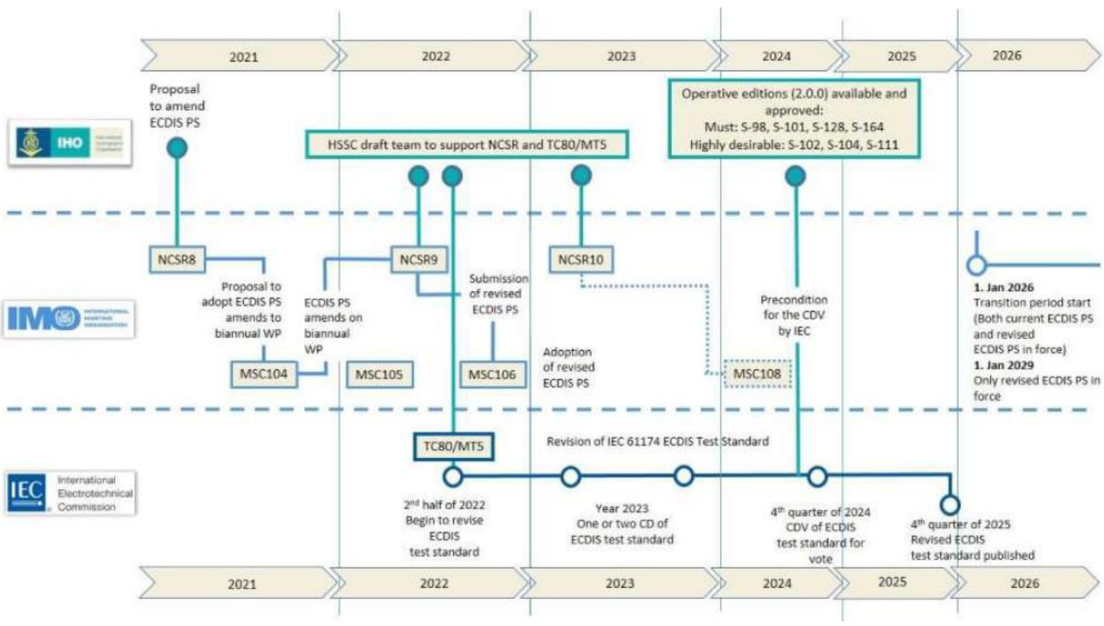

Figure 21: Transition period of the ECDIS performance standard defined by IHO, IMO, IEC

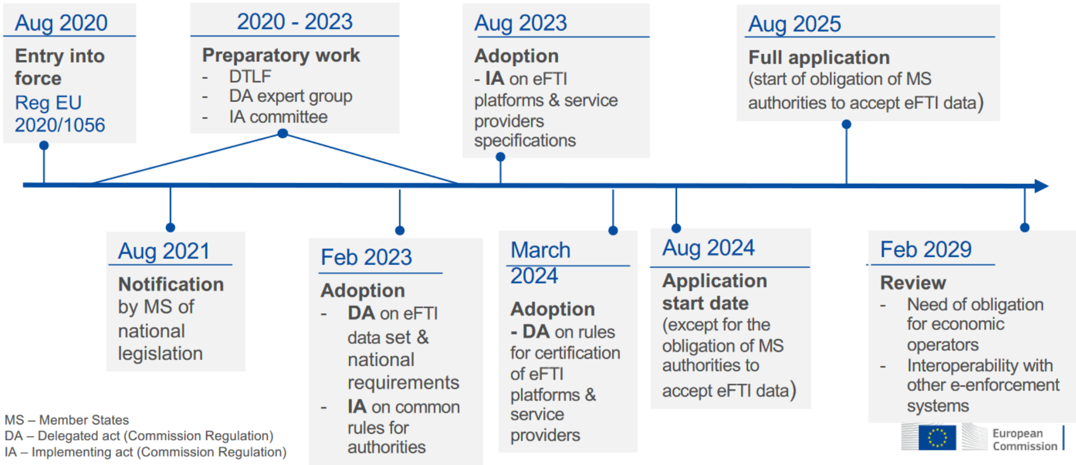

Figure 22: Implementation period of the eFTI regulation

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4. Report Technological developments Sub Activity 3.4 Data model and Data registry, project team DIWA
5. Report Technological developments Sub Activity 3.5 Technologies in other transport modes, project team DIWA
6. Report Manual on Inland Waterway Transport Digitalisation and Assessment Methodology, project team DIWA
7. Report Guidelines on capturing Remotely Operated Vessels (ROV) and Autonomous Vessels (AV) for Inland Waterway Transport future planning, project team DIWA