DIWA Report

Sub-Activity 3.3: Smart sensoring & PNT

Version: V0.9 (final draft version), March 2022

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Co-financed by the European Union
Connecting Europe Facility

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1 Executive summary

Activity 3 (Technical Developments) of the Masterplan Digitalisation of Inland Waterways (DIWA) project, is focusing on 5 topics. During one of the studies, Sub-Activity (SuAc) 3.3 "Smart Sensoring including Positioning, Navigation and Timing (PNT)" is comprising existing devices and classifying the sensors according to the identified business developments in Activity 2 and SuAc 3.1. These business developments and the "New Technologies" are part of the digitalisation of inland waterways.

Introduction

A main and important aspect in the digitalization of the inland waterway transport (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 of for example the skipper that enters his voyage data.

Another source of data are sensors that are used for measuring water levels, temperatures, heights, positions or distances. The existing technology for sensors is 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.

Smart sensors explained

During the desktop research, many different sensors are identified but several of these sensors can't be classified as a 'smart sensor'. A definition of what a smart sensor is, becomes a necessity and although the difference between a conventional sensor and smart sensor are quite clear, a different look at both types, lead to interesting results. In this sub activity, not only smart sensors and PNT are handled but also conventional sensors which can be used in a smart way, seems to be very interesting.

Inventory on smart sensors and PNT systems

After defining what a (smart) sensor means, an inventory of smart sensors has been created describing the properties of the sensors. The sensors are described according to the intended usage (6.1 Usage: position of vessel or navigation), data availability (6.2 Real-time data provided by sensors) and business developments (6.3 Business developments). The inventory is created through desk research and the main focus lays on currently available sensors or PNT systems. But on the other hand, 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 Position, Navigation and Time systems four grades are identified for different requirements in usage:

- Grade A supports the description of position and movement of a single onboard 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 onboard 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.

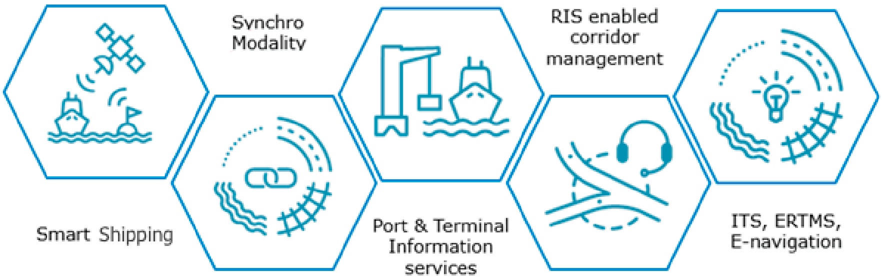
Real-time data provided by sensors

Using the results and demands of Activity 2 and SuAc 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
- Network infrastructure information
- Vessel dynamics information
- Smart Shipping information
- Environmental impact related information
- Location related information
- Cargo/vehicle related information
- Object related information

Business developments

In the previous classification, the type of information is used as a base, but Activity 2 also resulted in five different business developments. Therefore, an exercise to classify the sensors in relation with these business developments 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 such point is defined as Consistent Common Reference Point (CCRP).

Fallback option

Global Navigation Satellite System (GNSS) have become the primary source onboard 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 the 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. Fallback options must be foreseen and redundancy becomes important.

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 concerns can be made:

1. Fallback, recommendation regarding necessary integrity levels:
   Every sensor can malfunction and when this happens there should be measurements 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 of a user, there are two ways to mitigate this problem depending on the sensor and the total system:
   - Implement/activate the fallback.
   - Go to a "Gracefully shutdown"

2. Guidelines concerning setup 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 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

2 Introduction

Most business developments rely on data from a wide range of sensors placed on board of vessels, on the fairway or on-shore. In this report Inland Waterway vessels are meant with 'vessels'.
Sensor technologies such as positioning, RADAR, tracking & tracing, status monitoring and motion detection have improved safety, decision making and efficiency in transport and industry.

Decreased size and increased capabilities of sensors create new possibilities for IWT and enable new business developments. Also, the combination of information from multiple sensors will help to increase the integrity, availability, reliability and accuracy of sensor data. Artificial intelligence and applications can play an important role in deriving more useful information from sensor data. An example is the high dependency of positioning as one of the key sensor outputs on Global Navigation Satellite System (GNSS) technologies with the lack of an independent fallback technology. Depending on the use case, smart sensoring can help to mitigate current shortcomings or vulnerabilities. For example, a combination of RADAR-map matching with dynamic distance measuring or optical sensors like Light Detection And Ranging of Laser Imaging Detection and Ranging (LIDAR) could be a viable backup solution on Inland Waterways which also contributes to increase the accuracy and integrity of GNSS sensor information under regular conditions.

A special topic in this SuAc is the study on PNT. In inland navigation PNT has been an essential topic for decades, starting with RADAR-positioning for navigation and traffic management purposes and nowadays AIS-GPS PNT for both tactical as well as strategic objectives. Increased traffic densities, integration of systems on board of vessels and increased requirements on PNT systems caused by developments like autonomous sailing has resulted to this enhanced focus.

3 Work approach

3.1 Timeline

The timeline presented in *Figure 1: Timeline DIWA SuAc 3.3* was agreed upon during the kick-off in December 2021.

	Dec 2021	Jan 2022	Feb 2022	Mar 2022	Apr 2022	May 2022	June 2022	July 2022	August 2022	Sept 2022	Oct 2022
Kick-off	x										
Inventory by each		x	x								
Inventory review				x	x						
Feedback from other SuAc's					x						
Process feedback						x	x	x			
Draft report									x		
Feedback loop										x	x
Finalizing report											x

Figure 1: Timeline DIWA SuAc 3.3

In the course of this SuAc, meetings were held to fill in the objectives set beforehand. One of these important objectives was to draw up an inventory for the sensors and PNT systems. This was the first step taken. Therefore, some time had to be spent in order to arrive at a complete inventory. All members contributed to this.

After compiling the inventory, the report from Activity 2 was reviewed. This was done in the following subsection (3.2 Relation with sub-activities).

At the end of the process, a draft report for SuAc 3.3 was drawn up. This report was prepared in several steps and reviewed by the different participants from all countries.

The final development of this SuAc did not follow the predetermined timeline. Finalisation and drafting of the draft report were carried out only in August and September. The final version was not distributed until the end of October.

3.2 Relation with sub-activities

In activity 2 of the Masterplan DIWA project a number of IWT business developments were investigated. In addition, the results of SuAc 3.1 New Technologies were studied and used as input for this report. Although PNT and sensoring are not often mentioned explicitly in the resulting reports, the services required by the aforementioned business developments in the upcoming years are to a large extend dependent on high quality PNT and sensoring technology.

The use of AIS as a synonym for vessel position data (see also 7.1 regarding the Difference between AIS and PNT) features heavily in the activity 2 reports, especially regarding the topic of Smart Shipping. Apart from facilitator related issues (e.g. sharing of AIS data & expanding the AIS carrying obligation) there are several technology-related issues brought forward in the reports:

- Data quality of vessel position related data.
  This concerns not only basic accuracy of the position and assuredness of data integrity, but also completeness and accuracy of transmitted additional data. What is mentioned as important is not especially the absolute accuracy of a data value, but that data is accompanied

by an indication of its reliability. Of course, malicious attempts to subvert the data are expected to be swiftly detected and acted upon by authorities.

- Use of AIS technology to transmit and receive non-position related information (e.g. traffic restrictions, low bridge clearance, etc.).
  Primarily driven by the current situation where there is no internet coverage of sizeable areas of fairways, this is proposed as an alternative solution for getting certain data on board of a vessel.

The need for smart sensor technology (again mainly from the smart shipping community) can be attributed to:

- Sensors which are part of the vessel
  This covers an array of sensors; RADAR, LiDAR, height detection, cameras, depth sounding, etc. Intended usage is often to augment/verify data from other sources. Main concerns are interoperability with other systems and from a fairway authority point of view, reliability and cyber resilience (especially when used to operate a vessel without people on board).
- Sensors which are part of the IWT infrastructure
  Most movable objects (e.g. locks and bridges) are already equipped with sensors, necessary for their operation. Fairway users and industry would like the data generated by these sensors made available together with additional sensors for actual bridge clearance. Again, intended usage is to augment/verify data from other sources and being able to feed it into systems for planning and navigating (track/auto pilot). Concerns from a fairway authority point of view are accuracy/reliability (in light of liability) and cyber resilience since these sensors are connected to vital infrastructure and deliver their data via internet).

In SuAc 3.3 these conclusions from activity 2 were used as a basis for investigating possible technological solutions that could be within the scope of fairway authorities.

4 Objectives of SuAc 3.3: Smart sensoring & PNT

4.1 Objectives

The objective of this SuAc is to describe the new technological developments on Smart Sensoring including Positioning, Navigation and Timing (PNT) which will contribute to the digital transformation with focus 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.

4.2 Tasks

Following tasks were identified in order to meet the objective of SuAc 3.3:

- Make an inventory and study on recent technological developments in Smart Sensoring including PNT. Furthermore, the changing user needs and requirements in IWT in the coming decade will be identified.

- Define the integral and harmonised technical services that can be facilitated by implementing Smart Sensors. Define the pre-conditions for the application of these Smart Sensors related to the digital transition of inland Waterways.

- Define the requirements on the application of PNT systems and the consequences in relation to the digital transition of Inland Waterways related to the business development as specified in activity 2.

- Draft the report (study) on Smart Sensoring including PNT in IWT inventory. Assess the requirements and consequences for application of adequate Smart Sensoring including PNT systems as input for the Masterplan Digitalisation of inland Waterways.

4.3 Expected results

First of all, this SuAc aims to elicit a inventory that presents the current available smart sensors and PNT systems as well as smart sensors and PNT systems that will become available in the future. Secondly, this SuAc aims to produce an overview of the business developments from activity 2 that could potentially be covered by a technology from the inventory. And finally, the findings will be compiled in a report.

5 Smart sensor explained

It is good to know what a smart sensor is, before building an inventory. According to different sources a smart sensor is the combination of a base sensor and a microprocessor and has communication capabilities and some form of onboard diagnostics. This signal will be converted into a digital one, processed and transmitted.

Definition according to Techtarget [1]:
A sensor is a device that would create an electrical signal which is related to the quantity that is measured by it. So this device would measure the physical quantity and the measurement will be displayed by using an instrument.

In very general terms a Smart Sensor has a base sensor, a microprocessor, is communication-capable, and has some form of onboard diagnostics.
Smart Sensors are capable of a variety of functions and options. Smart Sensors can perform self-assessments and self-calibration.

A smart sensor or an intelligent sensor is a device that has integrated electronics, and it is able to perform certain functions like, logic functions, two-way communications, and are capable of making decisions. These sensors are capable of measuring the environmental data more accurately with less noise. Smart sensors are used for monitoring and as a controlling mechanism in many industrial applications. Mostly a smart sensor has three important parts: element sensing, signal processing, and microprocessor. The major difference between smart sensors and a conventional sensor is that the smart sensor is faster and more accurate in data acquisition and processing than the conventional sensors. Smart sensors are smaller in size than a normal sensor and they also consume less power.

Smart Sensors can detect issues such as sensor contamination, switch failures, and open coils.

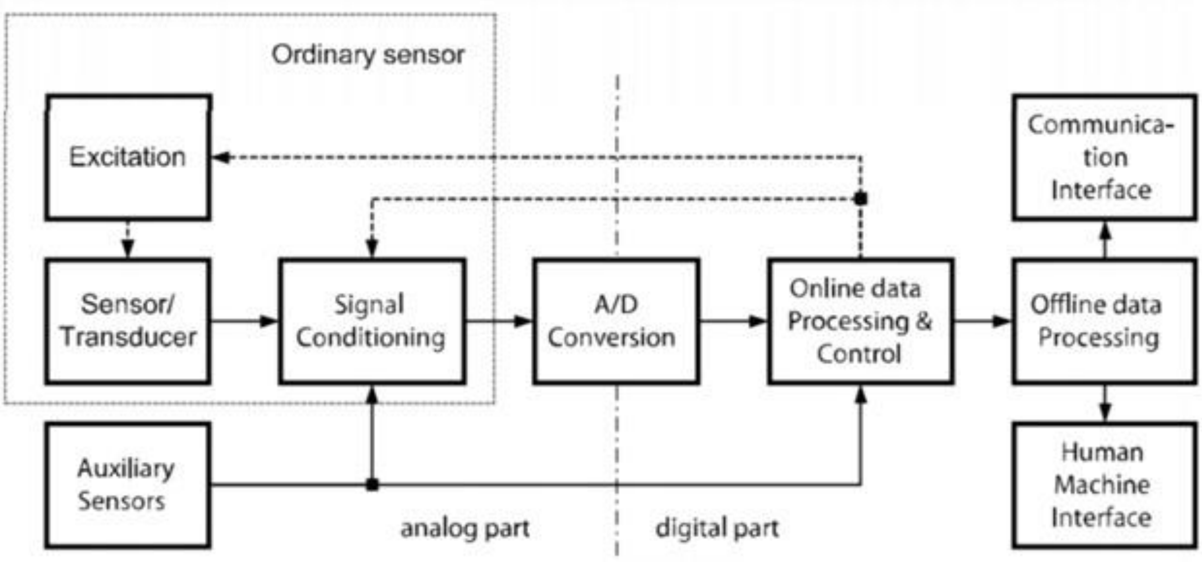


Figure 2: Intelligent sensor structure (Automationforum.co)

5.1 How do smart sensors work?

In general, smart sensors would measure certain physical quantities like pressure, temperature, humidity, flow, etc. So, these sensors would convert the analogue input that they receive to a digital input with the help of an analogue to digital converter. This converter would pass the converter value to the processor. Smart sensors have memory to store data and programs.

[1] What is a Smart Sensor and How Does It Work? - Definition from TechTarget.com

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So, these sensors tie a raw base sensor to integrated computing resources that enable the sensor's input to be processed.

The base sensor is the component that provides the sensing capability. It might be designed to sense heat, light or pressure. Often, the base sensor will produce an analogue signal that must be processed before it can be used. This is where an intelligent sensor's integrated technology comes into play. The onboard microprocessor filters out signal noise and converts the sensor's signal into a usable, digital format.

Smart sensors also contain integrated communications capabilities that enable them to be connected to a private network or to the internet. This enables communication to external devices.

Smart senors play a very important role in Internet of Things! Data is measured, converted, checked and moved to the cloud where it will/can be used.

5.2 What are different types of smart sensors?

Smart sensors can be classified according to the purpose of the sensors or measured parameters. According to Techtarget the wide range of smart sensors can be divided into five main types which are used in industrial environments.
Five main types [1]:

- **Level sensors.** A level sensor is used to measure the volume of space taken up in a container. A vehicle's fuel gauge might be connected to a level sensor that monitors the level of fuel in the tank.
- **Temperature sensors.** A temperature sensor is a sensor that can monitor a component's temperature so a corrective action can be taken if necessary. In an industrial setting for example, a temperature sensor can be used to make sure machinery is not overheating.
- **Pressure sensor.** Pressure sensors are often used to monitor the pressure of gasses or fluids in a pipeline. A sudden drop in pressure might indicate a leak or a flow control issue.
- **Infrared sensors.** Some infrared sensors, such as those used in thermal imaging cameras or noncontact infrared thermometers are used for temperature monitoring. Other infrared sensors are optical sensors tuned to a frequency that enables them to see light in the infrared spectrum. These types of sensors are used in medical equipment, such as pulse oximetry devices, and in electronic devices designed to be operated by remote control.
- **Proximity sensors.** A proximity sensor is used to detect the location of a person or object with relation to the sensor. In retail environments, proximity sensors can track customer movements throughout the store.

5.3 Conventional sensors smartly used

Besides the smart sensors which have the capability to process and transmit the outcome of the measurement, “conventional” sensors can be used in a smart way to get a more expanded result.

A conventional sensor is a device that can detect any change or determine the presence of any physical parameters. The sensor can be an electrical, mechanical or electronic device depending on the characteristic it detects.

There is a distinction between “active” and “passive”” sensors. Where active sensor requires a continuous input to get a required output from the sensing element, the passive sensor does not require any external input. The passive sensor continuously detect changes without the input of e.g. a power signal.

The output of a conventional sensor can be an analogue or digital result.

Examples of common known conventional sensors are temperature sensor, RADAR or light sensor.

The biggest difference between a conventional sensor and a smart sensor is the fact that the conventional sensor will not process the detected change and will not automatically calibrate itself. These are two important and additional advantages of a smart sensor.

However, using the conventional sensors in a smart manner, will allow other devices to register, to combine, to calculate and to make decisions based on the input of the sensors. In case of e.g. autonomous navigation, IWT shall not only rely on the smart sensors but will use the input of the conventional sensors as well.

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.

This means that not only smart sensors in the strict sense of the word will contribute to the (future) digitalisation of IWT but that also the conventional sensors will keep on playing an important role in the development of monitoring and registration systems for IWT.

For this reason, this report does not exclude the conventional sensors in the inventory and further descriptions.

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6 Inventory on smart sensors and PNT systems

To enable the SuAc to analyse smart sensors and PNT systems, the first task was to create an inventory of existing devices which could be interesting for the digitalisation of IWT. The result of the inventory is a table (see 10.1 Appendix 1 – Inventory smart sensors and PNT) which is also available as Excel file ('Appendix 1 – Inventory smart sensors and PNT'). For each sensor/PNT the following properties are described as much as possible:

- Name
- (Initial) Purpose
- Components
- Output
- Dependencies
- Issues/limitations
- Accuracy (if known)
- Possible link with IWT
- Advantages
- Fall back arrangements
- Source

The next chapters describe the different types of sensors according to different categories:

- the usage with the focus on PNT (6.1 Usage: position of vessel or navigation),
- data availability (6.2 Real-time data provided by sensors) and
- business developments (6.3 Business developments) of the Masterplan DIWA project which comprises 5 studies.

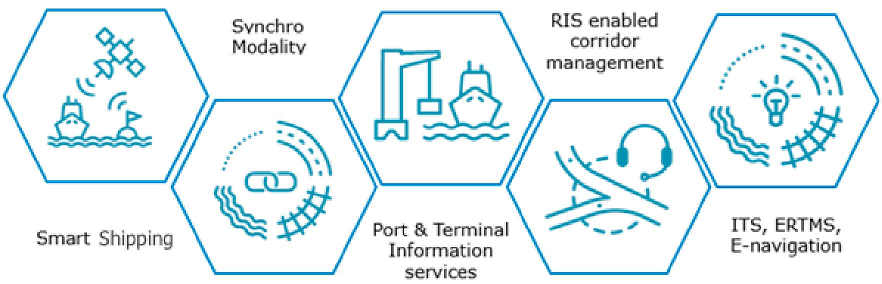

Figure 3: DIWA Activity 2 Sub-Activities

Chapters 6.4 and 0 will discuss in more detail the installation, and or configuration of the sensors and the fallback options.

6.1 Usage: position of vessel or navigation

Probably the most known and used sensor in IWT is the GPS on board of a vessel. This sensor will retrieve the position data of a vessel which will be used for navigation. Latitude, longitude, rotation, heading, all values can be calculated by using GPS in different setups.

A reliable knowledge of a vessel's position and movement in relation to other traffic participants and obstacles is a fundamental requirement for navigation, and for avoiding collisions and groundings. This holds true for maritime navigation as well as for shipping on Inland Waterways. The provision of Position, Navigation, and Timing (PNT) data is required to enable safe and efficient navigation, especially in congested areas such as traffic separation areas, harbour entrances or busy Inland Waterways.

GNSS (especially GPS) has become the primary PNT source for maritime and inland waterways navigation. The GNSS position is used both, for vessel navigation and as the position source for other onboard equipment such as Inland ECDIS and AIS.

A typical GNSS position receiver will provide the calculated position in latitude, longitude and height. Furthermore, it can derive Position, Velocity and Time (PVT) data. For many applications, further navigation data are required to support the navigation of a vessel and to enable emerging applications like driver assistance functionalities or future smart shipping (automated/autonomous). Here especially navigation parameters like heading, Rate Of Turn (ROT), Course Over Ground (COG) are essential. The provision of such data in addition to the position are defined as position, navigation and time data (PNT).

The following application grades could be used to define different requirements on the amount and types of PNT data:

- Grade A supports the description of position and movement of a single onboard 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 onboard 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.

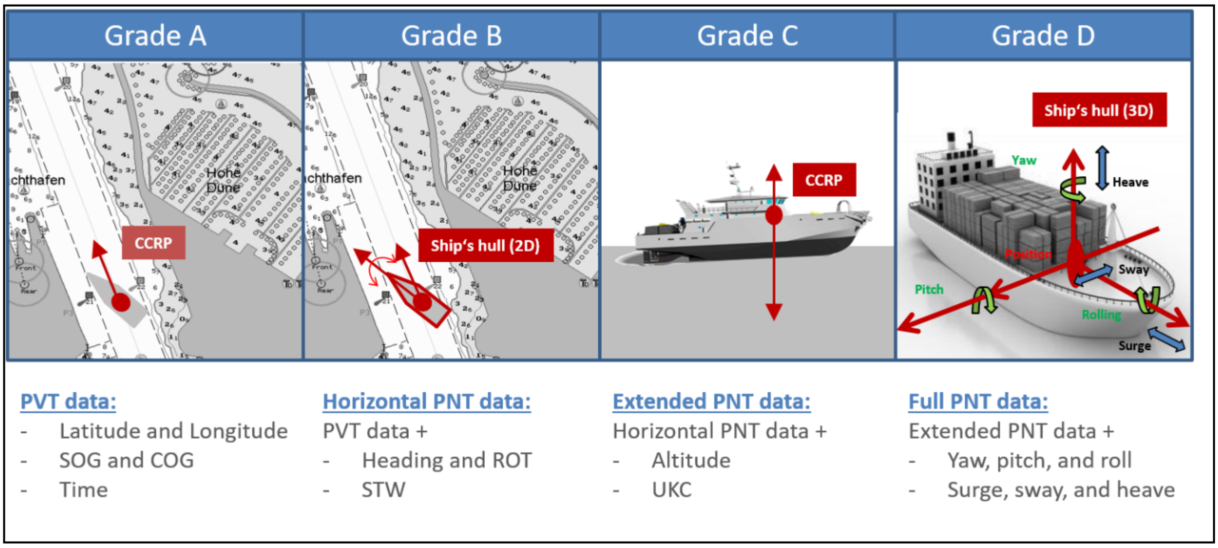

*Figure 4: Application Grades of PNT-DP [2] (*provided with improved accuracy)*

Main goal is to enhance the safety and efficiency of navigation by improved provision of position, navigation and timing (PNT) data to future automated shipboard applications. The shipborne provision of resilient PNT data and associated integrity (I) and status data (S).

To enable integrity and status evaluation of the PNT data various dissimilar inputs are required which can be used from different sensors, services and sources (see Figure 4: Application Grades of PNT-DP (*provided with improved accuracy)).

[2] IMO MSC.1/Circ.1575, "GUIDELINES FOR SHIPBORNE POSITION, NAVIGATION AND TIMING (PNT) DATA PROCESSING", June 2017

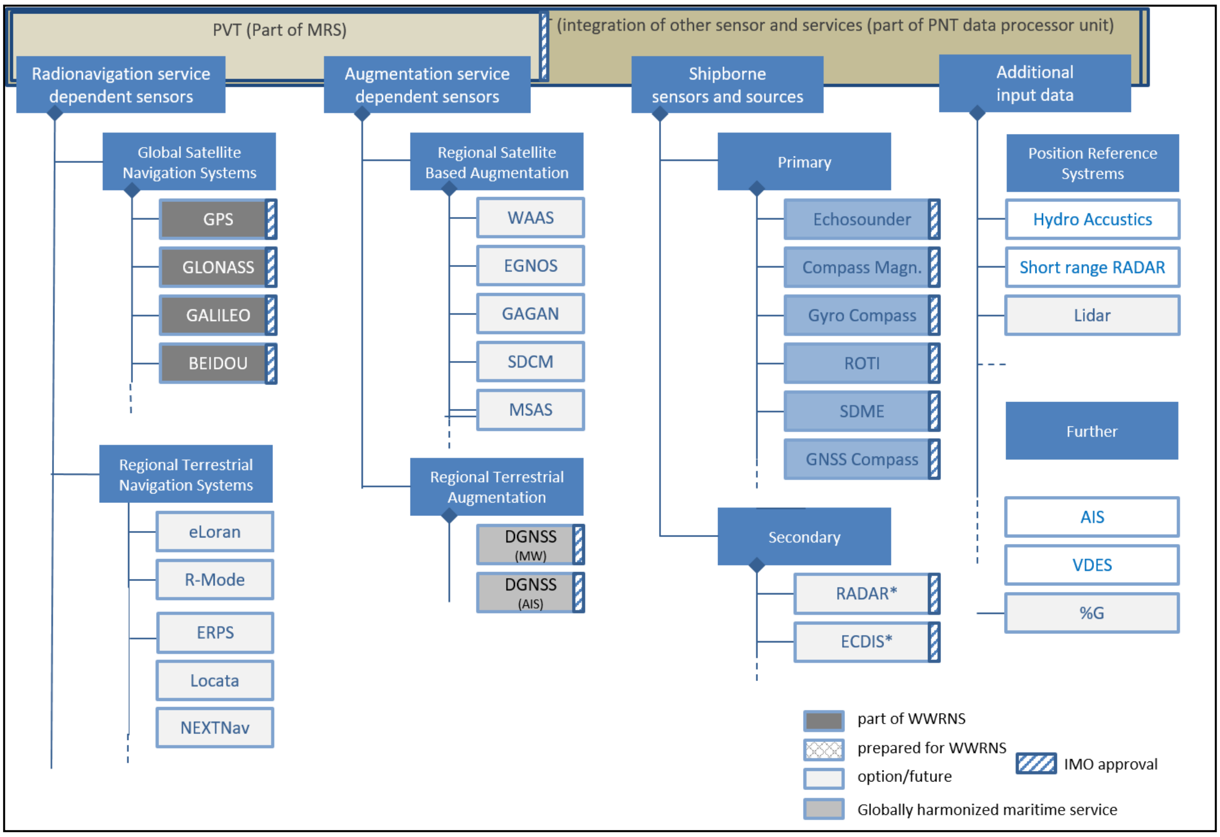

Figure 5: Sensors Services and sources to Provide PNT on board vessels [2]

The sensors and services shown in Figure 5: Sensors Services and sources to Provide PNT on board vessels [2] are mainly used in the maritime domain. Some of them have global and regional coverage. Nevertheless, most of the sensors and service could also being used for PNT determination of inland vessels.

The above services can be classified by grade/type as follows:

- Radionavigation services provide navigation signals and data which enable the determination of the vessel's position, velocity and time (PVT).
- Augmentation services are other services that provide additional correction and/or integrity data to enable improvement of radionavigation-based determination of the vessel's position, velocity and time (PVT).

Furthermore the services can be classified regarding its geographical coverage:

- Global services are characterized by their worldwide coverage. They may have limitations regarding usability for different phases of navigation due to signal disturbances reducing the availability or performance of transmitted signals and/or provided data.
- Regional services (and maybe local services) are only available in dedicated service areas. They may be used to improve the performance of the vessel's navigational data in terms of accuracy, integrity, continuity and availability even in demanding operations when, for example, higher accuracy and integrity level is required during coast and port navigation.

The type-approved sensors and data sources are distinguished into the following categories:

- Service-dependent sensors rely on any service from outside the vessel provided by human effort. They cannot be used on board without at least a satellite-based or terrestrial communication link to the service provider (shown in figure 2, mainly used to provide data of the vessel's position, velocity and time).

- Shipborne sensors and sources:

- Primary sensors use a physical principle, e.g. earth rotation or water characteristics and are independent of any human applied service provision (shown in Figure 5: Sensors Services and sources to Provide PNT on board vessels [2] , mainly used to provide data of the vessel's attitude and movement)

- Secondary sensors and sources may be used to provide additional data for the verification of PNT data (see Figure 5: Sensors Services and sources to Provide PNT on board vessels [2]), e.g. water depth at known position from an ENC.

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6.2 Real-time data provided by sensors

The following section discusses data that can be generated (almost) in real-time by using the sensors that are included in the inventory (see 10.1 Appendix 1 – Inventory smart sensors and PNT). Some information was already available but can now be measured more easily or accurately with newer sensor technologies. Other information could not be determined in a suitable way until now, but new sensor systems are making it possible.
Previous sub-activities noted in their findings the demand for new real-time data that has not been provided yet. These data are labelled as NEW in the following.

6.2.1 Fairway- related information

For the most parts there is already enough information about the waterway provided to the skippers and the traffic management. New sensors can provide better ways of measurement or enable to be in line with future innovations. Additional provision of information enable to create a Holistic Digital Twin of the waterway network. A higher accuracy and for relevant passages also real-time data is essential for Smart Shipping.

Data:	**Water level**	
Possible data provider:	Authority, Vessel, Infrastructure	
This information shows the level of the water surface in relation to zero point of gauge (ZPG). The Sea level is often used as the reference height (ZPG) but some countries also are using different ZPG. The water level is an indicator of the required height of the river for transport activities. The numerical value of the water level can be calculated with measurements of distance at reference objects with the help of floats, RADAR and ultrasound devices. It has been common practice for many years to provide the water level values to skippers and other stakeholders. In Smart Shipping the information should be as accurate and as up-to-date as possible to help autonomous vessels figure out where they should sail. Accurate distances can be measured by using sensors like Laser Distance Sensor, Ultrasonic Sensor or measuring surfaces by using the LiDAR technology.		
Applicable Sensors:	Laser Distance Sensor, Ultrasonic Sensor, LiDAR, GNSS	

Data:	**Water depth**	
Possible data provider:	Authority, Vessel, Infrastructure	
This information describes the distance between the water level and the riverbed. Like the water level, the water depth is an indicator of the required height of the river for transport activities. Using the depth information, the boundaries of the fairway can be identified. A common sensor for measuring water depth is the echo sounder. The bathymetric information is provided via Inland ECDIS charts. Like levels, this information is particularly important for the safe operation of smart shipping concepts. To measure water depth, smart sensors such as Smart Echosounder and Smart Buoy are available to measure depths and provide immediate (pre)processed data to users or authority. The Echosounder can be installed on transporting vessels or on (floating) drones Smart buoys can also determine the water depth with appropriate sensors, but only at their respective location.		
Applicable Sensors:	Smart Echosounder, Smart Buoy	

Data:	**Discharge information**	
Possible data provider:	Infrastructure, Authority	

The discharge information of a river describes how much water flows through a certain cross-section of the river in a certain time. The amount is usually expressed in cubic meters per second. The discharge is closely related to the water level and the water depth. Time series of the discharge originally helped to predict flooding and water shortages. Currently, discharge monitoring helps in detecting climate and environmental changes. Today, there are different methods or devices to measure the discharge of the river section. A direct method is to measure velocity and flow area of the water.

The discharge is already provided in different river information systems. New sensors can provide better ways to measure the current amount of water.

The Smart Buoy and the Acoustic Doppler Current Profiler have the ability to measure the discharge. A Smart Buoy equipped with specific sensors can perform the measurement of the water flow speed in the waterway. The Acoustic Doppler Current Profiler using sound waves to measure the speed and direction of the flowing water can be installed on vessels or at convenient points on infrastructure.

Applicable Sensors:	Acoustic Doppler Current Profiler, Smart Buoy

Data:	**Currents information**	**NEW**
Possible data provider:	Authorities, Infrastructure	
Need of SuAc:	3.1 New Technologies	

This information is related to the discharge information. The river current varies spatially as well as temporally within the stream, depending on the flow volume of water, stream gradient, and channel geometry.

The information about the currents is an information need expressed in the results of the SuAc 3.1 New technologies. Within a smart infrastructure, the dynamics of the fairway could be provided by smart sensors.

For the measurement of the river currents the same sensors or devices like for measuring the discharge can be used. The Acoustic Doppler Current Profiler can measure the current velocity and the direction. This device can be installed on the vessel, on the infrastructure or even as a part of a Smart Buoy.

Applicable Sensors:	Acoustic Doppler Current Profiler, Smart Buoy

Data:	**Continuous weather/ temperature information**	
Possible data provider:	Authority, Infrastructure	

This information is needed to produce weather forecasts. The skippers are interested in knowing the weather conditions before they start their voyage. The weather information can include the general weather conditions, temperatures, quantity of rainfall, humidity, wind direction and speed and even more data. The various information have to be measured by different sensors.

Weather information are usually provided by meteorological institutes. On individual locations it can be necessary to gather further and more accurate data.

Some devices or technologies like a Smart Buoy, multi-purpose sensor and the BJT-Based CMOS Smart Temperature Sensor have the capability to measure the temperature, to e.g. warn of ice conditions. The multi-purpose sensor can also measure e.g. the humidity. Based on the measurements of current and historical weather parameters, models can be created that are used to forecast future weather events.

Applicable Sensors:	Smart Buoy, multi-purpose sensor, BJT-Based CMOS Smart Temperature Sensor

6.2.2 Network infrastructure information

The waterway network contains various infrastructures like bridges and locks. The space available there can be very limited and therefore affect the safety of navigation. Some fairway information about the network infrastructure is already provided on different river information platforms.
Accurate and sometimes real-time data about the infrastructure is particularly important for Smart Shipping. Making fairly exact estimations of durations at specific passages of a voyage can be crucial within a synchromodal transport. The following information contains also important elements for the creation of a Holistic Digital Twin of the waterway network in the future.

Data:	**Vertical clearance at bridges, cables/pipes or other special constructions**	
Possible data provider:	Infrastructure, Authority	
This information is particularly relevant for the comparison with the air draft of the vessel. The vertical bridge clearance is defined as the height between the underside of the bridge and the surface of the water which flows underneath the bridge. There should always be enough space between the bridge and the vessels to ensure safe shipping traffic. The values of the bridge clearances have been made available to the skippers for years. Although there are no new sensors for this measurement, the measuring devices could be used more intelligently or provide the information to the users more directly and in real-time. The distance can be measured by using Laser Distance Sensors or Ultrasonic Sensors and are to be attached on the bridge at suitable points.		
Applicable Sensors:	Laser Distance Sensor, Ultrasonic Sensor	

Data:	**Structural conditions of locks/bridges**	**NEW**
Possible data provider:	Infrastructure, Authority	
Need of SuAc:	3.1 New Technologies	
Continuous measuring of conditions of locks/bridges can provide insight into their “health”. Traditional sensors like strain gauges am(pere)meters, vibration sensors, temperature sensors and the like provide data that, when collected over time and analysed by (automated) processes can indicate whether elements within the lock/bridge have, or are about to malfunction. Often when these malfunctions are found they can be fixed before they cause another element to fail and eventually render the lock/bridge inoperable. Typical examples are supportive appliances that use no power when expected or do use power when not expected, pumps that exhibit an unusual amount of vibration due to debris obstructing the inlet and engines that are overheating just to just below the signalling threshold. Preventing extended blockage of bridges and locks reduces waiting times and/or having to take detours for vessels.		
Applicable Sensors:	”traditional” sensors e.g. strain gauges am(pere)meters, vibration sensors, temperature sensors. (not in inventory)	

6.2.3 Vessel dynamics

Some vessel-related data is already provided to the users in real-time on charts or different information platforms. The information on vessel movements ensures safe navigation within a small area. The integration of Smart Shipping concepts requires reliable object detection in the vessel’s environment including the projection of the next movements of vessels nearby. This enables the upcoming sailing line of the surrounding vessels to be taken into account in one's own manoeuvres.

As a major support of traffic management, the relevant information shall be provided via a (multimodal) Data Exchange Platform.

Data:	**Absolute vessel position**	
Possible data provider:	Vessel, Authority	
This information helps to track the vessel on the waterway and enables to create an image of the current traffic situation on the waterway. It is also used for the automatic identification of the vessels and the collected data enables the calculation of ETA information for the individual transports. There are already various technologies or systems to calculate the position of a vessel. For the usual waterway traffic, the data is sufficient, but accurate positioning plays a key role in the navigation of autonomous vessels. Nowadays, newly developed sensor systems provide more accurate and reliable position information. Especially Smart Shipping relies on very accurate positions and distances to other vessels or objects. The developments of Global Navigation Satellite Systems (like GALILEO) and access to it in the future are going to provide highly accurate Precise Point Positioning including correction mechanisms through the signal and by terrestrial means. On the other hand, the multi-sensor data fusion technique used in the MEMS-IMU/GPS Integrated Navigation System also enables a very high level of accuracy in determining a location. Systems with comparatively lower accuracy are RADAR or multi-purpose sensors using common GPS.		
Applicable Sensors:	GNSS, MEMS-IMU/GPS Integrated Navigation System, multi-purpose sensor	

Data:	**Relative position information of vessel**	**NEW**
Possible data provider:	Vessel	
Need of SuAc:	2.1 Smart Shipping	
This information indicates the distances to other moving or stationary vessels or objects. It helps to avoid collisions with other users of the waterway or the infrastructure. As well, it enables to get the vessel into the right position or angle relative to a specific object. The relative position can already be determined reasonably well by certain sensors and solutions Currently, the relative position of vessel isn't provided to users or other stakeholders in shipping. The results of the SuAc 2.1 Smart Shipping show the importance of the relative position of the vessel. With the integration of smart or autonomous vessels, this information will very quickly become extremely relevant. Accurate distances to other vessels are needed to keep the necessary gap between the vessels. This can be assisted by sensors such as LiDAR, Stereo Camera or RADAR (also used in the RangeGuard). LiDAR in particular, with the very precise laser scanning method, seems to be a highly suitable sensor system for this purpose.		
Applicable Sensors:	LiDAR, Stereo Camera, RangeGuard, RADAR	

Data:	**Vessel dynamics information**	
Possible data provider:	Vessel, Authority	
This information provides some details about the current and imminent movement of a vessel. Interesting real-time data of a vessel are e.g. speed, heading and rate-of-turn (ROT). The speed can be calculated via the current and previous positions of the vessel. The heading and the ROT can be directly determined by sensors. The speed and heading information already get collected and are displayed on different river information platforms. The ROT, as well as speed and heading, is measured to make it visible to the skipper and crew on the vessel. There are already many good technologies to determine the position or the speed. The position sensors or devices are already described in the section of absolute position information. In addition, certain multisensors offer the possibility to measure the approximate speed directly on the vessel with the help of a paddlewheel. The heading of a vessel can be measured by modern compasses such as GPS Compass Magnetometer, Gyro Compass. The turning of the vessel or degrees of heading change can be determined by the use of a Ring Laser Gyro or a Fibre Optic Gyro sensor.		
Applicable Sensors:	Speed: GNSS, MEMS-IMU/GPS Integrated Navigation System, multi-purpose sensor, multisensor Heading: GPS Compass Magnetometer, Gyro Compass ROT: Ring Laser Gyro, Fibre Optic Gyro	

Data:	**Air draft of vessel**	**NEW**
Possible data provider:	Vessel	
Need of SuAc:	3.1 New Technologies	
This information defines the distance from the surface of the water to the highest point on a vessel. The air draft indicates if a vessel can pass safely under a bridge or installations such as cables and pipes. The counterpart to this is the draught of the vessel, which is influenced by the net weight and the loading. Vertical movement due to wave action is also a factor to be considered. The static air draft can be calculated by means of hull data and cargo information. The calculation for the dynamic air draft is considering more factors like squat, heel, draft tolerance, siltation, wave response and some more. The SuAc 3.1 New technologies would like to have a traffic management using a Data Exchange Platform to increase the user-friendliness of Inland waterway transport. A comparison of the air draft and the bridge clearance gives a quick indication about the remaining vertical distance between vessel and bridge for safely passing a bridge. An inland cargo vessel could equally be limited by temporary bottlenecks in the waterway due to draught. If the vessel dimension to highest point is known, the determination of the air draft can be made using distance sensors on the side of the vessel to measure the distance to the water. Distance sensors, like the Laser distance Sensors and the Ultrasonic sensor, need to be at multiple points of the vessel (e.g. at bow and stern).		
Applicable Sensors:	Laser distance Sensor, Ultrasonic sensor	

6.2.4 Smart Shipping

In Smart Shipping the ability of situational awareness is fundamental. There is a need for reliable and accurate detection of other objects and their movements to ensure safe traffic of autonomous vessels on the waterway in the future. For the permanent real-time estimation of traffic status and decision-making, the usage of artificial intelligence could become of key importance. It is certainly good to use existing (static or dynamic) data that is made available, but it is sometimes advantageous to capture the circumstances for the own individual situation exactly.

Data:	**Movement of other users on the waterway, in locks, berths or at bridges**	**NEW**
Possible data provider:	Vessel	
Need of SuAc:	2.1 Smart Shipping	
This information informs about the detection of objects in the surrounding of a vessel. The aim is to recognise and monitor the movements of other vessels in order to avoid potential collisions by appropriate response without human intervention or to automatically circumnavigate obstacles. There are different sensor systems available to perceive the environment and detecting an object. The SuAc 2.1 Smart Shipping stated the importance of a reliable detection of other objects and their movements. Similarly, exact distances in locks, moorings or when passing through bridges are of great concern. The area around the vehicle can be captured with different sensors or with combinations of sensors. The RangeGuard is specially developed for scanning the surroundings and the detection of objects. But other sensors such as LiDAR, a Stereo Camera, RADAR or highly accurate Global Navigation Satellite Systems can also be used to detect other vessels or infrastructure buildings on the waterway.		
Applicable Sensors:	RangeGuard, LiDAR, Stereo Camera, Electro-optical Sensor System, RADAR, GNSS	

Data:	**Detection of bridge shape and bridge clearance**	**NEW**
Possible data provider:	Vessel	
Need of SuAc:	2.1 Smart Shipping	
This information includes the detection of a bridge shape or the distance of the bridge pillars and especially the clearance in the area of the bridge crossing. The height and the shape of a bridge is already available and provided to the waterway users, but redundancy creates more safety for self-steering vessels. The SuAc 2.1 Smart Shipping also covered the requirement of situational awareness capabilities of autonomous vessels. Like the surrounding traffic, the infrastructure can also become a dangerous obstacle for autonomous vessels. For the detection of the shape of the bridge you can use the same sensors like for the capturing of movements of other vessels. Together with other known variables (e.g. actual air draft), the autonomous vessel can then make decisions for the next manoeuvres.		
Applicable Sensors:	Shape and Clearance: RangeGuard Shape: LiDAR, Stereo Camera, RADAR Clearance: Electro-optical sensor system, BridgeScout, GNSS	

6.2.5 Environmental impact related information

Since inland navigation also contributes to climate change through its emissions, it would be important to provide appropriate data. As stated in the result of SuAc 2.2 Synchromodality, (real-time) environmental data can be a decision-making factor for a future synchromodal transportation of

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freight. The ecological footprint in logistics shall help to find the best mode of transport for a shipment. The SuAc 2.4 RIS enabled Corridor Management identified environmental information as possible new services in the future to find the greenest route in addition to the shortest and fastest route. Also, future opportunities for inland terminal logistics are being investigated on the basis of the carbon footprint, pricing, and/or duration. Consequently, the measurement of the carbon footprint in real time is being further explored.

Data:	**Fuel consumption**	**NEW**
Possible data provider:	Vessel, Logistics	
Need of SuAc:	2.2 Synchromodality, 2.4 RIS enabled Corridor Management	
The fuel consumption describes the energy efficiency of a vessel. It is given as the ratio of distance travelled per unit of fuel consumed or the consumed fuel for travelling 100 kilometres. It is dependent on factors like engine efficiency, transmission design and driving style. The direct assessment of consumption is the permanent measurement of the fuel used for propulsion. The availability of appropriate sensors or measuring devices is rather limited. The Fuel Flow meter FUELTRAX offers the possibility to measure the flow of the fuel in a pipe. The fuel management solution provides the opportunity to adjust the speed of the vessel to reduce vessel operating costs and annual fuel spend. The throttle optimisation provides the options with best speed or maximising fuel savings. In the optimisation process, AI can probably be very helpful.		
Applicable Sensors:	Fuel Flow meter FUELTRAX	

Data:	**Produced emissions/ carbon footprint**	**NEW**
Possible data provider:	Vessel, Logistics	
Need of SuAc:	2.2 Synchromodality, 2.4 RIS enabled Corridor Management	
In general, this information includes any particles, substances or radiation that are released into the atmosphere caused by the propulsion of a vessel. In addition to natural emissions, there are also anthropogenic emissions, such as particulate matter, carbon dioxide and fluorinated greenhouse gases from traffic and heat and power generation. Such emissions are among the driving forces of global warming. Inland waterway transport presents itself as an extremely environmentally friendly mode of transport. In fact, it is one of the most CO_2-efficient modes of transport per tonne of cargo transported. Increasing the shift of freight transport to shipping is a way to reduce CO_2 emissions in transport. Emissions can be calculated most efficiently by measuring the amount of fuel used which automatically considers variability in both the vehicle and driving skills. Another method is to analyse the produced gases approximately at the end of the exhaust. Devices available on the market for measuring emissions include ABB's CEMcaptain and Norsk Analyse's Emission Monitoring System. Both systems can measure CO_2 emissions and also a few other substances. Opportunities for optimising the exhaust gas emissions are in the modernisation of the propulsion technology used on the vessel or to make changes to the skipper's driving style. Here as well, the use of artificial intelligence could possibly leverage further potential for improvement.		
Applicable Sensors:	CEMcaptain, Emission Monitoring System	

6.2.6 Location-related information

Some voyage information on times and duration of waterway sections is already provided on different information platforms. It relies on the position data of the vessels. Today, there are new or developed Sensor systems on the market to get more reliable positional data. In the meantime, the systems are able to achieve higher accuracy. This enables to identify a vessel more precisely at prominent waypoints or determine the entering and the leaving of a section.

Data:	**Actual Passage Time (timestamp) at a specific waypoint of a stretch (e.g. river km)**	
Possible data provider:	Authority	
This information describes the timestamp when a vessel passes a specified point of the waterway. In this case, the end of a section is defined at a very specific waypoint where the time of passing is of interest. The information of the time stamp for passing a waypoint of the waterway is already provided for certain sections. In order to identify a vessel at prominent waypoints, for example, a Smart Buoy can be utilised to this end. However, the more common method of detecting the passing of a vessel is probably more simply done by the position of a vessel and reaching defined coordinates on the fairway. Otherwise there are localisation sensors such as a Global Navigation Satellite System (also used in Behrtech's MYTHINGS Smart Sensor) or the MEMS-IMU/GPS Integrated Navigation System.		
Applicable Sensors:	Smart Buoy, GNSS, MEMS-IMU/GPS Integrated Navigation System, multi-purpose sensor	

Data:	**Actual passage duration (hh.mm.ss) required for navigating through a specific stretch or section (e.g. between two locks) considering the actual traffic situation (density)**	
Possible data provider:	Authority	
This information describes the time a vessel needs for passing a defined section of the waterway. The section may consist of a part of the waterway or be bounded by waterway infrastructures such as locks or bridges. Traffic planning tries to improve the passage duration on a fairway or transport corridor for users by providing information on the state of the passage time of the fairway and passing times at locks and bridges. Especially, for voyage planning the information is important as the logistic sector has the opportunity to optimise the travel time and fuel consumption of their vessels. The information on passage duration of waterway sections is already provided. Different sensor systems are available to determine the position of the vessel.		
Applicable Sensors:	GNSS, MEMS-IMU/GPS Integrated Navigation System, multi-purpose sensor	

Data:	**Duration at harbours / ports / terminals**	**NEW**
Possible data provider:	Authority	
Need of SuAc:	2.2 Synchromodality, 3.1 New Technologies	
This information indicates the time a vessel needs to be in a harbour, port or terminal area. In Maritime it is called the Vessel Turnaround Time and it is defined as the total time that a vessel spends at a harbour, port or terminal from its arrival to departure. The logistics sector tends to keep a vessel's stop as short as possible and to decrease the Average Turnaround Time (ATT). A large part of the success of containerisation is due to time economies, particularly the reduction in the duration of port calls. Although vessels now spend a smaller amount of time in port, it is still a cost factor. In the results of SuAc 2.2 Synchromodality it is stated that these information would be very meaningful. According to the roadmap of SuAc 3.1 New Technologies, in the future this information shall be offered in a Holistic Digital Twin in terms of a multimodal information system. Consequently, a relatively accurate multimodal ETA (estimated time of arrival) can be calculated with it.		

There are different possible sensor systems for localising a vessel's position such as Global Navigation Satellite Systems, RADAR or smart measuring devices.	
Applicable Sensors:	GNSS, RADAR, MEMS-IMU/GPS Integrated Navigation System, multi-purpose sensor

6.2.7 Cargo/Vehicle-related information

These voyage information support the planning of the transportation and enables to monitor the freight. The results of the SuAc 2.2 Synchromodality show that reliable real-time positions of (push) barges or transport units are not always available. Equally, actual information about the transported freight or free cargo space is needed. The research in SuAc 2.3 Port & Terminal Info Services revealed the occasional use of proprietary GPS transponder solutions for vessel position tracking. Some real-time data about the cargo and free cargo space along the transport chain would also be very useful for cargo operators and their customers. Logistics companies and their customers have an interest in always being able to track the condition of the cargo being transported. The roadmap of SuAc 3.1 New Technologies mentions the provision of various logistical information in the multimodal information system within the Holistic Digital Twin.

Data:	**Position of barges**	**NEW**
Possible data provider:	Authority, Logistics	
Need of SuAc:	2.2 Synchromodality, 2.3 Ports & Terminals Information Service	
This information provides the position of individual (non-motorised) barges. These vessels are without its own drive, used for the transport of solid, bulk or liquid (tank barge) cargo. Barges are vessels that are towed or pushed by tug boats to get from one place to another. Barges are sometimes left in one place for a long period of time, or the many changes of location make it difficult to reliably track the position of a barge. Therefore, it makes sense to provide the position information available to authorised bodies, if necessary. Usual sensors or systems can be used to determine the position. Simple and inexpensive sensor systems that offer reasonably good accuracy can be sufficient for this area of application. A cost-effective variant of Global Navigation Satellite Systems can be used, or a localisation sensor in a smart device, such as in multi-purpose sensor (e.g. Behrtech's MYTHINGS Smart Sensor).		
Applicable Sensors:	GNSS, multi-purpose sensor	

Data:	**Tracking of cargo**	**NEW**
Possible data provider:	Authority, Logistics	
Need of SuAc:	2.2 Synchromodality, 2.3 Ports & Terminals Information Service, 3.1 New Technologies	
This information provides the positions of individual freights being transported. The different types of goods also require different transport equipment in order to be handled in a suitable manner. Depending on what it is transported with, it can be tracked in different ways. Regardless of, whether it has to be transported in a container or in a tank, the sharing of cargo data can be rather disadvantageous sometimes. Especially, if the transported freight is a dangerous good. In cases of sensitive information, it is probably advisable not to provide any information or to really make sure that only authorised persons can see it. It would certainly support creating good berthing predictions, cargo handling plans and berth schedules. Sensors on containers seem to be the only reasonable way to accompany the cargo throughout its journey. The goods transported in a Smart Container can be easily monitored with the technological equipment of the container. Whereas the goods transported directly in the vessel or in a barge can		

only be tracked via the position of the transporting vessel or barge. Finally, predictive and reliable ETA data for freight should be received for logistics.	
Applicable Sensors:	Smart Container

Data:	**Information about transporting cargo (quantity, temperature, humidity, ….)**	**NEW**
Possible data provider:	Logistics	
Need of SuAc:	2.2 Synchromodality, 3.1 New Technologies	
This information shows the status of cargo that are being transported. New or smart technologies make it possible to observe many different conditions of the goods and improve the visibility and management of the cargo. Subsequently, it increases the efficiency and resilience of the supply chain. Depending on the type of cargo, there are different sensor systems to measure the status of the cargo. A Smart Container provides the opportunity to monitor the position, the door openings, the humidity, the amount of gases in the air and some other conditions in the container, for example, to more accurately predict shelf life of the freight (i.e. food products). However, not all goods can be transported in containers. When the cargo is transported on barges, LiDAR can be used to measure the quantity or volume.		
Applicable Sensors:	Smart Container, LiDAR	

Data:	**Information about free cargo space**	**NEW**
Possible data provider:	Logistics	
Need of SuAc:	2.2. Synchromodality, 2.3 Port & Terminal Information Services, 3.1 New Technologies	
This information indicates the availability and extent of free cargo space on the vessel/barge. The cargo space is defined as any space on a vessel designated for carriage of cargo. The availability of cargo space is an essential information for shippers and forwarders. However, the remaining capacity to further load the vessel is not only determined by the total cargo space, but also by the water level of the waterway. Both information have to be taken into account. The amount of available cargo space again depends on the type of goods. In the case of a bulk load, the loaded volume can be measured using LiDAR and the space still available can then be calculated directly. If containers are being transported, the number loaded can only be counted and compared with the maximum possible number. However, everything is performed in consideration of the water level or the draught of the transporting vessel.		
Applicable Sensors:	LiDAR	

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Data:	**Number of containers on board**
Possible data provider:	Vessel, Logistics

This information states the number of containers on board of a vessel. Only a small share of total inland waterway transport is accounted for by container transport. There are significantly fewer container vessels on the European rivers compared to maritime transport and they are also much smaller and can carry less cargo. However, standardised containers are very advantageous for intermodal or international transport chains. Simplicity through standardisation causes increasing diversity of cargo in the containers. The supply chain management already provides a system of tracking the way of freight on their shipment.

Counting the containers is not new information that is to be made available now, but new sensor technology shall simplify and even automate the processes.

The use of Smart Containers, together with the variety of their possible equipment, can make counting and tracking of their location much more convenient through smart applications.

Applicable Sensors:	Smart Container

Data:	**Type of container on board**
Possible data provider:	Vessel, Logistics

This information describes the types of the container on board of a vessel. There are different types of containers that are suitable for transporting different cargo. In addition, with TEU (Twenty-Foot Equivalent Unit) and FEU (Forty-Foot Equivalent Unit), two essential units of container sizes are to be considered. With the knowledge of the container type, the type of content can also be quickly ascertained, at least to the extent that it is required.

A listing of the containers loaded on the vessel is certainly available in some format. The potential for more simplification of processes can be further exploited.

By utilising Smart Container, the relevant data (e.g. type of cargo) can automatically be sent in real-time and very accurate at the beginning of the transportation. The reliably transmitted information supports to create more convenient cargo handling plans.

Applicable Sensors:	Smart Container

6.2.8 Object-related information

Traffic Information at specific objects or waterway sections are already gathered and provided as well as displayed on river information systems. Further developments in Inland Shipping and future information services will require higher accuracies (especially position of autonomous vessels) but may also create new opportunities. There is potential to make object-related data more reliable and accurate or measured in real-time by using more comfortable sensor systems. Measuring something twice in narrow areas or during difficult manoeuvres can lead to significantly more safety.
Better real-time data enable better real-time decisions in traffic planning. Just like mentioned in the results of SuAc 2.2 Synchromodality it can improve the planning of voyages or the preparation of additional options for possible changes of transport modes. The traffic situations, especially congestions, can strongly affect the ETA of the respective transport mode. The SuAc 2.3 Port & Terminal Information Services points out that it would be very beneficial for their scheduling to know the current traffic situation at locks, bridges or other relevant passage points.

Data:	**Exact location of vessel at berth (public/private) – anonymised**
Possible data provider:	Authority

This information provides an accurate position of a vessel within the berth area. In Inland Waterway Transport a berth is a place for the mooring of vessels and floating bodies outside a port. It is located near or directly on the riverbank of a waterway. A berth usually consists of several moorings. The

precise positions of the vessels can be used to calculate the "Percentage of occupied berth space". Consequently, the degree of utilisation of a berth can be provided to the users. To do so, the vessels must be localised or detected by means of sensors. Some new or developed Sensor systems now provide a more simple or precise localisation. Global Navigation Satellite Systems or the MEMS-IMU/GPS Integrated Navigation have an improved accuracy. This enables to get precise position data of the vessels in the berth area. Other sensor systems such as LiDAR, RADAR or Electro-optical sensor systems can also be used to detect objects in the berth area. For very challenging mooring or docking manoeuvres, the use of a Laser-based Aid System is a reasonable solution.

Applicable Sensors:	LiDAR, Stereo Camera, RADAR, GNSS, MEMS-IMU/GPS Integrated Navigation System, Electro-optical Sensor System, Laser-based Aid System

Data:	**Vessel/convoy dimensions, respectively occupied berth space**	
Possible data provider:	Authority	
This information states the area of a vessel and/or the used space of the vessel in the berth area. A continuous berth allocation can be described as an efficient placement of vessels (replaced with rectangles) on the two-dimensional space of the berth. For this purpose, it is necessary to measure the vessels on their size, mainly the horizontal dimension. Currently, the vessel size is determined by the information of the vessel owners. Since the vessel dimensions provided by AIS are sometimes subject to errors, more precise vessel dimension values are needed to calculate the occupied berth space. Ideally, a vessel is accurately measured once using 3D laser scanning to map a vessel, resulting in a 3D hull model. A very accurate measurement can be achieved by using LiDAR. This sensor system can measure the vessel and create a 3D point cloud of it. However, vessel sizes do not always remain the same, this is especially true for pushed convoys. The horizontal dimensions can also be measured at favourable points, e.g. at the entrance to locks or when passing bridges. Other suitable sensors for this application would be a stereo camera and an electro-optical sensor system.		
Applicable Sensors:	LiDAR, Stereo Camera, Electro-optical Sensor System	

Data:	**Positions of all vessels in the lock chamber**	
Possible data provider:	Infrastructure, Authority	
This information shows the distribution of the vessels to be locked in the given area in the lock chamber. The locks vary in size and can usually host several vessels. The sensor systems for tracking the position don't need a long range but have to be pretty accurate. In general, the position in locks is monitored with Global Navigation Satellite Systems. So far, the accuracy has been sufficient for the previous use cases. For the exact determination of the position of the vessels in the lock, the already known sensor systems for object detection can be used, such as LiDAR, Stereo Camera or Electro-optical Sensor System. When used correctly, they can detect the positions of the vessels and their distances between each other and the walls of the lock chamber.		
Applicable Sensors:	LiDAR, Stereo Camera, Electro-optical Sensor System	

Data:	**The remaining available length and/or width (in lock chamber)**	
Possible data provider:	Infrastructure, Authority	
This information provides the amount of space that can still be used for additional vessels in the lock chamber. The size of locks depends greatly on the size and draft of design vessel, traffic projections and difference in water levels. The dimensions of the lock chamber should be kept		

optimal to ensure sufficient lock capacity and appropriate operating time. To obtain the information discussed here, sensor systems are needed that can detect the space between the vessel s.

So far, the free space in the lock has not been measured. Although the position of vessels in locks are usually prepared with lock planning, an actual representation of reality is beneficial for the safe movement of (autonomous) vehicles in the locks. It may also be possible to optimise the spontaneous lockings of smaller vessels with the automatic detection of free space.

The determination of the free space in the lock can be carried out in the same procedure as the precise detection of the vessel's positions. The detection of the vicinity at a short distance can be carried out quite accurately with sensor systems such as LiDAR, Stereo Camera or Electro-optical Sensor System.

Applicable Sensors:	LiDAR, Stereo Camera, Electro-optical Sensor System

Data:	**Traffic situations / densities at strategic locations**	**NEW**
Possible data provider:	Authority	
Need of SuAc:	2.2 Synchromodality, 2.3 Port & Terminal Information Services	

This information indicates the number of vessels occupying a strategically important area of the fairway at a given instant of time. It signals whether an area is affected by high or low vessel traffic. This in turn puts the responsible authorities to carry out risk assessments, improve transport planning and enhance overall vessel safety. Traffic density is generated from the position signal of the vessels' automatic identification systems (AIS). The system signals the position also to other vessels. Positioning sensors are used for tracking of the vessels to determine the traffic density.

The determination of the traffic density just utilises the positions of all vessels in a specific area. For measuring density, it is not necessary to have a sensor system with the highest accuracy. A standard GNSS, RADAR and multi-purpose sensor can be used for it. A useful monitoring of traffic situations requires highly accurate GNSS or the MEMS-IMU/GPS Integrated Navigation System.

Applicable Sensors:	GNSS, RADAR, MEMS-IMU/GPS Integrated Navigation System, multi-purpose sensor

Data:	**Overview of affected vessels (by incidents, accidents, …)**	**NEW**
Possible data provider:	Authority	
Need of SuAc:	2.5 ITS, ERTMS, e-Nav	

This information provides a listing of fairway users affected by various events that negatively impact the traffic flow. These events can be e.g. disruptions to the infrastructure, accidents like collisions with bridges or locks as well as other obstacles on the fairway. The affected waterway users should be informed of these events as soon as possible in order to be able to adjust to the new circumstances. This information provision requires a more complicated concept in order to be able to provide users with reliable information. In addition to the position data of the vessels, the use of Big Data and Artificial Intelligence is necessary to recognise the coming development of traffic from the sum of the collected data.

The outcomes of SuAc 2.5 ITS, ERTMS, e-Nav reveal that notification of vehicles whose journey is affected by events along the route would also be a useful information in inland waterway transport.

The position data, which does not require the highest accuracy, can be determined with sensor systems such as Global Navigation Satellite Systems, RADAR or a Smart Sensor. The position information in combination with Big Data technology can provide prediction about the coming traffic situations and it can lead to increasingly better statements about affected vessels.

Applicable Sensors:	GNSS, RADAR, MEMS-IMU/GPS Integrated Navigation System, multi-purpose sensor

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6.3 Business developments

Based on the inventory and the feedback received from business partners (

Appendix 3 – Feedback business), an overview was created linking the different business developments from Activity 2 (see Figure 3) to the smart sensors listed in the inventory of this SuAc.

The same sensors can be used within different developments and therefore they can be repeated.

	Smart Shipping	Synchro Modality	Port & Terminal Information services	RIS enabled corridor management	ITS, ERTMS, E-navigation
LiDAR (feature recognition, distance)	X	X	X	X	X
Stereo Camera (feature recognition, distance)	X	X	X	X	X
RangeGuard (distance)	X				
AIS (position)	X	X	X	X	X
VDES (position)	X	X	X	X	X
GNSS (position)	X	X	X	X	X
RADAR (feature, distance)	X	X			X
Maglev porous nanogenerator	X				
Smart echosounder (depth)	X		X	X	
Electro-optical sensor system (distance)	X		X		
Accurate BJT-based CMOS smart temperature sensor with duty-cycle-modulated output (temperature)			X	X	
MEMS-IMU/GPS Integrated navigation system	X	X	X		X
Smart embedded passive acoustic devices for real-time hydroacoustic surveys					
Laser based aid system (distance)	X				X
Smart container		X	X		
Multi-purpose sensor	X	X		X	X
Laser distance sensor (distance)	X				X
Ultrasonic senor (distance)	X		X		
IR sensor (distance)	X		X		X
Capacitive proximity sensor	X	X	X		X
GPS Compass (heading)	X				X
Magnetometer (heading)	X				X
Gyro compass (heading)	X				X
Ring laser gyro (ROT)	X				X
Fibre optic gyro (ROT)	X				X
Fule flow meter FUELTRAX		X		X	
Emission sensors (ABB CEMcaptain, Norsk Analyse Emission Monitoring System)		X		X	

6.4 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). Further Installation guidelines are published which provide recommendations for installation of electronic equipment (e.g. Installation of the inland Automatic Identification System (Inland AIS Station, Appendix to CESNI/TI (22) 6 rev. 2 = CESNI/PT (22) 18 rev. 2 = CESNI/TI/VTT (22) 1 rev. 2).

Equivalent requirements must also be developed for evolving sensors and PNT equipment used for automatic/autonomous vessels.

If such equipment will be connected to the on-board RADAR or Inland ECDIS, the connected sensors need a type approval according to the relevant international minimum performance standards. The example below shows the appropriate standards of external sensors connected to an inland AIS device.

Sensor	Minimum performance standard (IMO)	ISO/IEC standard
GPS	MSC 112(73)[3]	IEC 61108-1, 2003
DGPS/DGLONASS	MSC 114(73)[4]	IEC 61108-4, 2004
Galileo	MSC 233(82)[5]	IEC 61108-3, 2010
Heading/GPS Compass	MSC 116(73)[6]	ISO 22090-3 Part 3 “GNSS-Principles”, 2014

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. This could be typically the conning position of the bridge. In the maritime domain such point is defined as Consistent Common Reference Point (CCRP).

The configuration of sensors and PNT equipment shall be realised by the system integrator before commissioning to ensure compliance between the shipborne sensors and PNT equipment available and the operational environment as well as the intended application grade including the required accuracy and integrity level. The configuration should further include the specification of thresholds and value ranges used for integrity evaluation and system controlling (e.g. in relation to operational and technical accuracy levels as well as applied integrity evaluation techniques.

[3] MSC.112(73) adopted on 1 December 2000 - Revised Performance Standards for Shipborne Global Positioning System (GPS) Receiver Equipment

[4] MSC.114(73) adopted on 1 December 2000 - Revised Performance Standards for Shipborne DGPS and DGLONASS Maritime Radio Beacon Receiver Equipment.

[5] MSC.233(82) adopted on 5 December 2006 - Performance Standards for Shipborne Galileo Receiver Equipment.

[6] MSC.116(73) adopted on 1 December 2000 - Performance Standards for marine transmitting heading devices (THDs).

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6.5 Fall back option

GNSS (e.g. GPS, Galileo, GLONASS, BeiDou) have become the primary source onboard PNT data provision. Furthermore, PNT data is used by many applications on vessels, like AIS (Automatic Identification System), ECDIS (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. Safe navigation, the protection of the environment and the efficiency of access to ports are today highly dependent on the availability, continuity, accuracy and integrity of GNSS based positioning and timing. However, it is well known that the radio navigation signals from GNSS are provided at very low power levels. Thus, the signal propagation is vulnerable to jamming and natural interference[7]. As a result, the provision of PNT data as needed may be corrupted or interrupted. Unavailable PNT data, even for short periods, limits the situation assessment and results in numerous alerts raised by multiple systems on the bridge. Much more critical are hazardously misleading information as result of position errors that are large enough to have a severe impact on navigation safety but small enough to remain undetected.

Within the Strategic Implementation Plan of e-Navigation the IMO has identified the user need on improved reliability, resilience and integrity of bridge equipment and navigation information as one of the five prioritised e-Navigation solutions. It is foreseeable that this holds also true for future navigation applications on inland waterways.

A variety of technological solutions provides the potential to fulfil this backup requirement (such as R-Mode or enhanced RADAR positioning, see Figure 4, chapter 6.1). Within the radio frequency (RF) domain existing maritime radio infrastructure can facilitate ranging information to a user receiver. Beside the technical upgrade possible impacts on the existing system and its band have to be evaluated. While these existing signals currently are not primarily intended for positioning, a future navigation receiver may attempt to exploit them as such. Specifically, if each signal can provide a (pseudo-)range to the receiver from a known location, thus a trilateration position solution is available, if at least three (pseudo-)ranges are known. The use of such ranging signals from maritime radio infrastructure is known as "R-Mode" (ranging mode). Even if it is impossible to derive an R-Mode based position solution (e.g. due to insufficient number of received pseudoranges), the available pseudorange information, combined with measurements from other positioning systems or vessel sensors, can provide a position solution. Furthermore, any R-Mode pseudorange can be used to improve PNT data integrity. Maritime radio infrastructure, suitable for R-Mode usage, are the maritime Medium Frequency (MF) radio beacon services and the Very High Frequency (VHF) transmissions as used with the existing Automatic Identification System (AIS) or the future VHF Data Exchange System (VDES) which is under development at the time.

The IMO opened up the usage of multiple position fixing systems with the adoption of the Performance Standards for Multi-System Shipborne Radionavigation Receivers[8] and the associated DP-GUIDELINES[9]. These recent performance standards allow the combination of any recognised IMO World-Wide Radionavigation System (WWRNS) with terrestrial position fixing systems as well as wide area augmentation systems. The rising numbers of available ranging signals from any source support the determination of position accuracy and associated integrity.

[7] J. A. Volpe, Vulnerability Assessment of Transport Infrastructure Relying on the GPS, Final Report, 2001

[8] IMO, "Radionavigation Receiver Performance Standard", (MSC.401(95))

[9] IMO, "GUIDELINES FOR SHIPBORNE POSITION, NAVIGATION AND TIMING (PNT) DATA PROCESSING", (MSC.1/circ.1575)

7 Issues/considerations

7.1 Difference between AIS and PNT

Class A shipborne mobile AIS stations on maritime vessels have to use an external shipboard EPFD (Electronic Position Fixing Device, mainly GPS L1 C/A code) for its position reports. It is mandatory that this EPFD - in the case of GPS receiver - conform to IEC 61108-1 ed. 2[10]. This also holds true for the AIS internal GPS receiver, mainly used to provide timing signal for the slot allocation. Thus, the main purpose of AIS is communication and not acting as the main position sensor.

On inland vessels, where we currently do not have a mandatory carriage requirement for a positioning receiver in Europe, the internal GPS receiver is in many cases also used as a positioning source, providing PVT data input to other onboard equipment (e.g. IENC). Because the internal GPS board is just using GPS L1 C/A code measurements, typically without any correction data (to improve integrity and accuracy), the quality and reliability does not fulfil the demands for emerging smart shipping applications.

7.2 Privacy

7.2.1 General - New technologies introduce new privacy risks [11]

With the desired future increase in automation, the use of additional and redundant information sources will continue to grow. Sensors will consequently be increasingly used to create a larger and thus redundant data collection. As a result, data management is becoming more and more complex and control is becoming increasingly difficult. The potential risk of data being misused through cyberattacks consequently increases significantly. This poses a major problem, especially in the case of sensitive data. Thus, the role of privacy of data collected by sensors will also increase significantly in importance in the future.
Consequently, this chapter takes a closer look at privacy related to the most common sensors and examines potential issues in more detail.

7.2.1.1 Legal framework

The legal framework for privacy in the EU is mainly defined by the General Data Protection Regulation (GDPR). Concrete "Guidelines on the Protection of Privacy and Transborder Flows of Personal Data" [12] were developed by the OECD, among others, which establishes various principles for privacy: collection limitation, data quality, purpose specification, use limitation, security safeguards, openness, individual participation, accountability. Taking such principles into account enables the actors who process (sensitive) data to do so in a manner that complies with privacy requirements.

7.2.2 Location data – GNSS

In navigation, location data is primarily used for safe navigation on the waterway and, in a broader sense, for extended planning by shipping operators, logistics companies and authorities.

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[10] IEC 61108-1 ed.2 "GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)", Performance standards, methods of testing and required test results, 2004

[11] European Commission, Joint Research Centre, Bargiotti, L., Gielis, I., Verdegem, B., et al., *Guidelines for public administrations on location privacy : European Union location framework*, Publications Office, 2020, https://data.europa.eu/doi/10.2760/546158.

[12] OECD (2013): OECD Guidelines on the Protection of Privacy and Transborder Flows of Personal Data. https://www.oecd.org/sti/ieconomy/oecdguidelinesontheprotectionofprivacyandtransborderflowsofpersonaldata.htm

In principle, location data according to the GDPR is not sensitive data, as no individual identity can be directly derived from it or is revealed. According to the e-Privacy Directive [13], location data is defined as "any data processed in an electronic communications network, indicating the geographic position of the terminal equipment of a user of a publicly available electronic communications service". However, the combination of location data with other data can lead to the disclosure of an individual's identity.

The European Commission (2020) defines personal location data in its Guidelines on location privacy as "any location data directly or indirectly linked to a living individual or that can be directly or indirectly used to identify a living individual. (…) In taking this broad approach it is important to draw a distinction between data that has location information and data that could have personal location information when combined with other data. It may be that in the combining of datasets the location data becomes personal information." [14]

In navigation, the transmission of the vessel's position not only reveals the position of the vessel, but also the location of the crew, passengers and, if applicable, the vessel's owner. In particular, if the vessel operators live on the vessel - sometimes even with their family - GNSS constantly transmits information on the location of the family and their household. Furthermore, information on identity and personal life can be derived by combining different data sources.

Thus, location data also indirectly represent personal data that should be subject to special protection, since incorrect management or use of the data, for example through unauthorised access to the data, could lead to privacy problems. Accordingly, data protection also plays an essential role in navigation location data and should not be neglected.

According to the European Commission (2020), location data privacy is: "the individual's right not to be subjected to unauthorised collection, aggregation, processing and distribution (including selling) of his location data. It is the right to be protected by the ability to conceal information of whereabouts, which can be derived from personal location data." [15]

Potential protective measures intended to ensure the privacy of the data through their processing are discussed in chapter 7.2.7 Protective measures / legal obligations when processing (personal) data and 7.3 Cybersecurity.

7.2.3 AIS (VDES)

The situation is similar with AIS systems. Again, no personal data per se, i.e. information that can be used to identify a private individual, is transmitted. However, AIS data can be linked to other sources of information, e.g. crew or passenger lists, so that the position of crew members or passengers can be disclosed.

As AIS is an open source system that transmits data on VHF channels, AIS information is at high risk of cyberattack as the systems can be hacked relatively easily, allowing unauthorised access to the data. Further information on cybersecurity and potential threats to AIS data can be found in chapter 7.3 Cybersecurity.

7.2.4 Cameras

Optical cameras are used in navigation for different purposes. On the one hand, permanently installed to monitor waterway objects such as locks or movable bridges, and on the other hand, they are already interacting with waterway users within in the context of apps that make it possible to take pictures of defective infrastructure and report them to the authorities. It can also be assumed that the use of optical cameras will continue to increase with increasing automation and autonomous navigation.

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[13] DIRECTIVE 2002/58/EC https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0058&from=DE

[14] European Commission, Joint Research Centre, Bargiotti, L., Gielis, I., Verdegem, B., et al., *Guidelines for public administrations on location privacy : European Union location framework*, Publications Office, 2020, https://data.europa.eu/doi/10.2760/546158

[15] European Commission, Joint Research Centre, Bargiotti, L., Gielis, I., Verdegem, B., et al., *Guidelines for public administrations on location privacy : European Union location framework*, Publications Office, 2020, https://data.europa.eu/doi/10.2760/546158.

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Images or videos taken by cameras can capture facial data and other identifying information of individuals. Of course, the recording of persons is not the actual purpose of the recording in the context of waterway management, but it cannot be prevented that there are persons on the recordings from time to time. Consequently, cameras and the recording of images with cameras are relevant in terms of privacy. The recordings should therefore be given special protection. On the one hand, access to the data should be particularly well protected. On the other hand, the anonymisation of the persons on the recordings plays an important role that can contribute to increased privacy. For example, an algorithm could be used that automatically blurs faces so that people in the recordings are rendered unrecognisable.

7.2.5 Active sound monitoring

Waterway authorities also use active noise surveillance to monitor certain areas along the waterway such as lock chambers. In the event of an incident, the relevant authorities can react quickly. However, the noise recordings can also contain private conversations, so noise monitoring is also relevant in terms of privacy.
A reduction in the amount of data would contribute significantly to privacy. The authorities should therefore ask themselves whether the recordings should also be stored and, if so, for how long.

7.2.6 Other sensors

Other sensors, such as LiDAR and RADAR, do not collect personal data and are therefore not relevant under privacy law.

7.2.7 Protective measures / legal obligations when processing (personal) data

"The protection of personal data is a fundamental right. New technologies introduce new privacy risks and a more privacy-aware and assertive society requires fully fledged control measures to protect private life. Policy makers and standardisation organisations are responding to this by updating data protection legislation and guidelines." [16]
The European Commission has also developed a guideline ("Guidelines for public administrations on location privacy" [16]) with the most important data protection obligations that should be observed when processing (personal) data. Although the guidelines were drawn up in the context of processing location data, they can also be applied to the processing of other (personal) data.

1) Appoint a responsible individual for data protection
2) Ensure lawful processing of personal location data
3) Apply data protection by design and default
4) Apply data minimisation
5) Perform periodic privacy risk assessments
6) Secure data processing activities
7) Comply with data subjects' rights
8) Notify data breaches to data subjects and relevant bodies

According to the ITS directive, "Anonymisation as one of the principles of enhancing individuals' privacy should also be encouraged." [17] However, Golle and Partridge (2009) point out that "anonymity is a useful, but imperfect tool for preserving location privacy" since "ostensibly anonymous location data may be tracked back to personally identifying information with the help of additional data sources". [18]

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[16] European Commission, Joint Research Centre, Bargiotti, L., Gielis, I., Verdegem, B., et al., *Guidelines for public administrations on location privacy : European Union location framework*, Publications Office, 2020, https://data.europa.eu/doi/10.2760/546158.
[17] DIRECTIVE 2010/40/EU https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0040&from=EN
[18] P. GOLLE, K. PATRIDGE, "On the Anonymity of Home/Work Location Pairs", in Y. TOBE (ed.) H. TOKUDA, M. BEIGL et al., Pervasive Computing, Springer, 2009.

However, anonymisation of location data is difficult and even impossible for AIS data, as some vessels are so unique that the vessel can still be identified by experts based on other characteristics, despite anonymised ID.

More detailed information on how to deal with existing or possible data protection problems of sensors as well as possible protective measures are discussed in SuAc 4.2 legal & regulatory.

7.3 Cybersecurity

DIWA SuAc 4.3 addresses cybersecurity in detail. Therefore, this section will be limited to a short introduction on cybersecurity risks concerning PNT and (smart) sensors.

7.3.1 Cybersecurity & PNT

PNT is quite vulnerable to cyberattacks. Because of the open nature of the technologies used, signals can be jammed, spoofed (fake signals) or devices hijacked[19].

Jamming is technically not within the scope of cybersecurity[20] and technical mitigation measures are available or being developed (see 6.5 Fall back option).

Spoofing entails fake signals being injected into the (primarily AIS) system, indicating that vessels are at another position than their actual position or that the same vessel is at several different positions at the same time. This can be done for military/political reasons, concealing smuggling operations or illegal fishing[21]

The open nature and use of the NMEA protocol[22] in different types of systems on board of a vessel causes vulnerability to hijacking. This is not limited to the PNT device (primarily AIS) itself but extends to e.g. propulsion, pumps and steering systems[23]. Extortion or military/political motivations seem likely for these types of attacks.

7.3.2 Cybersecurity and (smart) sensors

Interfering with a sensor used to require manipulation of its immediate environment (e.g. jamming) or physical tampering with the sensor (e.g. covering a camera lens with spray paint). Today however, sensors are often connected to computer networks and increasingly exchange data via remote connections over the internet. This makes them vulnerable to cyber-attacks. Large scale cyber-attacks can be launched with relatively low effort from any location[24].

Possible attacks include:
Shut down: sensors are forced to shut down or stop working causing connected appliances or machines to malfunction.

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[19] https://safety4sea.com/easy-hacking-on-the-ais-system-puts-global-shipping-at-risk/
https://en.wikipedia.org/wiki/Automatic_identification_system#Security

[20] Jamming concerns the deliberate use of radio noise or signals in an attempt to disrupt communications whereas a cyberattack is any offensive maneuver that targets computer information systems, computer networks, infrastructures, or personal computer devices (both en.wikipedia.org). Jamming pre-dates the computer era and does not require computer involvement while cyberattacks do.

[21] Androjna, A., Perkovič, M., Pavic, I., & Mišković, J. (2021). AIS data vulnerability indicated by a spoofing case-study. *Applied Sciences*, *11*(11), 5015

[22] https://en.wikipedia.org/wiki/NMEA_0183

[23] https://www.pentestpartners.com/security-blog/crashing-ships-by-hacking-nmea-sentences/

[24] https://www.automationworld.com/products/data/article/13320007/battle-for-cybersecurity-spreads-to-sensors
https://en.wikipedia.org/wiki/Internet_of_things#Security

Data manipulation: data captured by the sensor is changed before it is transmitted to its intended recipient.
Data theft: data captured by the sensor is re-routed or copied to unintended recipients. Depending on the data this may lead to privacy related data leaks (see 7.2 Privacy).

Attacks may be politically motivated, be part of extortion schemes, industrial espionage or common vandalism.

Vulnerabilities are mainly caused by software bugs and exacerbated by the fact that many sensors have not been designed for cybersecurity[25]. Process sensors often do not even require passwords to change configuration settings[26]. Factory passwords are often not changed by buyers of devices, whilst these passwords are known in the hacker communities[27].

Because of processing limitations of small devices like sensors and cost (many devices like IP cameras are built for the larger consumer market), mainstream IT security measures are impractical at the level of the sensor/device itself[28].

7.3.3 Awareness and risk mitigation

The use of PNT devices and ("smart") sensors on (inland) vessels must take cyber vulnerability into account in conjunction with connected systems on board. Because of the extensive lifetimes of vessels these connected systems have been found to struggle to keep up with defensive measures against cyberattacks[29]. Also, devices and sensors should not be considered cyber secure out-of-the-box. Therefore, cyber security measures should be added "on top of" and around these devices and sensors to mitigate risk (see also[30]). This is especially important when employed on (semi)autonomous vessels since there is most likely no one on board to take manual control of the vessel when equipment is compromised by cyberattacks.

Fairway authorities often own PNT shore-based infrastructure and/or deploy sensors in and around fairway infrastructure such as locks and bridges. They are subject to the same vulnerabilities as vessel based PNT and sensors and should therefore also work to mitigate the effects of cyber-attacks. Not only to ensure safety of navigation but also to protect fairway infrastructure from indirect damage.

Since the majority of the on-board systems are installed by external contractors and because not all the systems have to be certified, the skipper and his crew are not always informed as needed and not always aware of the (cybersecurity) risks related to these systems. They should at least be instructed by the installer on what the risks are and the consequences could be. Safety related sensors could always be certified before use.

Raising awareness both among the fairway authorities and among the vessel operators is recommended.

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[25] https://www.automationworld.com/products/data/article/13320007/battle-for-cybersecurity-spreads-to-sensors
https://www.cybersecurityintelligence.com/blog/process-sensor-cyber-security-is-a-vital-issue-6063.html
[26] https://www.controlglobal.com/blogs/unfettered/a-vulnerability-worse-than-log4j-and-it-can-blow-up-facilities-and-shut-down-the-grid/
[27] https://www.csoonline.com/article/2844283/peeping-into-73-000-unsecured-security-cameras-thanks-to-default-passwords.html
[28] https://en.wikipedia.org/wiki/Internet_of_things#Security
[29] Bolbot, V., Theotokatos, G., Boulougouris, E., & Vassalos, D. (2019, September). Safety related cyber-attacks identification and assessment for autonomous inland ships. In *International Seminar on Safety and Security of Autonomous Vessels (ISSAV)*.
[30] https://www.pentestpartners.com/security-blog/tactical-advice-for-maritime-cyber-security-top-10/

7.4 Safety of navigation

Due to the increasing automation of navigation, more and more (redundant) data and complementary systems are required. Sensors and systems provide a wide variety of data to increase or guarantee the safety of navigation.

However, the increasing amount of data can lead to users being overwhelmed or overloaded, thereby reducing the awareness of the importance of the data. This can lead to the accuracy of the data being misjudged, for example. In addition, due to the large amount of data, there is an increased risk that manipulated data (e.g. through spoofing or jamming: see chapter 7.3 Cybersecurity) will not be recognised. This in turn increases the vulnerability to cyberattacks, as the probability that the cyberattack or the manipulation of the data will be detected at an early stage is low.

The past has shown that human intervention is essential to ensure the safety of navigation due to failures of systems or sensors. There are currently still too many sources of errors or vulnerabilities to enable fully autonomous navigation. However, there is great potential to increase the safety of navigation by improving the data quality of the data generated by sensors. Important quality parameters are:

- Availability
- Completeness
- Accuracy
- Timeliness
- Resilience
- Integrity

Since the representation of reality can never be exact, it is advisable to provide the data with an additional indication of reliability respectively with a reliable estimate of the accuracy[31]. Only in this way can the data be reliably interpreted by both users and systems. In addition, the data must be protected against external influences (see chapter 7.3 Cybersecurity).

The goal of data generation by sensors should be a "resilient provision of (…) data including associated integrity and status data" [32].

In principle, however, it can be assumed that greater data availability will lead to greater redundancy, which is desirable, if not necessary, in the case of autonomous navigation. The additional use of multiple and different sensors and systems on the vessel as well as on the shore infrastructure will bring navigation one step closer to autonomy.

7.5 Issues in the logistics sector

A smart sensor ecosystem would bring many benefits to the logistics sector: from real-time data of vessel position and movement to better and more economical (route)planning, to information on the current status of cargo.

However, creating such an environment "requires significant investment in product software and hardware, security tools, networking, storage, and systems integration" [33]. In addition, a "number of enabling technologies are required to create value through a smart sensor strategy" [34]. Furthermore, countless new surfaces for cyber-attacks are created when sensors are added to the supply chain.

Despite countless advantages for the logistics sector, it seems rather reluctant to embrace the new technological achievements that could be achieved through the use of sensors. Besides the investments on the one hand, the limited internal functional expertise and technical skills on the other hand, both in terms of implementing a new smart sensor environment and in terms of the ability to

[31] International maritime organisation, Guidelines for shipborne position, navigation and timing (pnt) data processing, London, 2017.

[32] International maritime organisation, Guidelines for shipborne position, navigation and timing (pnt) data processing, London, 2017.

[33] Deloitte Development LLC (2018): Using smart sensors to drive supply chain innovation. A series exploring Industry 4.0 technologies and their potential impact for enabling digital supply networks in manufacturing, https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-cons-smart-sensors.pdf

[34] Deloitte Development LLC (2018): Using smart sensors to drive supply chain innovation. A series exploring Industry 4.0 technologies and their potential impact for enabling digital supply networks in manufacturing, https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-cons-smart-sensors.pdf

protect against the resulting new cyber-attacks, are often a major obstacle for the logistics sector. [35] This can hinder technological innovation on IWT.
On the other hand, for the logistics stakeholders, there is no reason (yet) why the existing and especially functioning systems should be replaced by new and more complex systems based on smart sensors. Accordingly, there is a lack of will and flexibility to redesign or replace the internal processes.

7.6 Usage of sensors

In shipping, sensors are used for safety of navigation, situational awareness and logistic purposes as described before in this document. For these purposes the usage of sensors depends on the goal to be accomplished with the sensors. When using sensors their dependency on other systems connected or remotely connected should be taken into account. Sometimes multiple sensors are needed or recommended for accomplishing the same or better data. Factors to keep here in mind are described in paragraph "7.4 Safety of navigation" as quality parameters.

Next to the quality parameters of sensors also the following list of requirements should be considered:

- Verifiability
- Maintainability
- Repairability
- Evolvability
- Reusability
- Portability
- Interoperability

But most of all users should understand what the sensors are doing and where they are needed for. You could call it system thinking. Not all sensors but a lot of sensors are time related. A central time system between sensors and the systems using these sensors is necessary. Sometimes just for logging but mostly for synchronising.

For instance, for timing several systems could be used nowadays like PNT systems terrestrial and satellite based but also other available systems in a certain area like mobile networks and a central timing system like DCF-77 where one station is in Frankfurt (Germany). All systems have pro and cons but using more than one could make the result (central timing) more reliable and robust.

For positioning (knowing where you are) sometimes the same sensors/systems can be used as for timing but also other systems could be used like RADAR in combination with shore infrastructure (eRACON) or detailed electronic charts. For instance, be aware that the electronic charts provided by authorities or other parties don't have the required quality.

These where just two examples but depending on the use there could be dozens of them.

[35] Deloitte Development LLC (2018): Using smart sensors to drive supply chain innovation. A series exploring Industry 4.0 technologies and their potential impact for enabling digital supply networks in manufacturing, https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-cons-smart-sensors.pdf

8 Recommendations and conclusions

8.1 Recommendations

Listed below are the recommendations from this SuAc. These can be directed to stakeholders as well as to the follow-up activities of the DIWA project.

REC 1: When using data from sensors, GDPR guidelines should always be taken into account by all parties. (cfr. 7.2.2 Location data – GNSS)

REC 2: Camera recordings should be given special protection. They are also subjected to the GDPR rules (Rec 1). (cfr. 7.2.4 - Cameras).

REC 3: Recordings of sound are also subjected to GDPR regulation and therefore should be considered. (cfr. 7.2.5 - Active sound monitoring)

REC 4: 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. (It's proposed to consider this in SuAc 4.3) (cfr. 7.3 - Cybersecurity)

REC 5: 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. (cfr. 7.3.3 - Awareness and risk mitigation)

REC 6: When different sensors give different values, it becomes difficult to ascertain the correct value. Investigate the amount of sensors needed to get accurate data in order to create redundancy. (It's proposed to consider this in SuAc 4.1 and SuAc 4.4) (cfr. 7.4 Safety of navigation)

REC 7: Raise awareness among the logistics industry to plan modifications to their vessels to ensure technical innovation. (cfr. 7.5 - Issues in the logistics sector)

REC 8: Raising awareness both among the fairway authorities and among the vessel operators is recommended. (It's proposed to consider this in SuAc 4.3) (cfr. 7.3.3 Awareness and risk mitigation)

REC 9: When different sensors and vessels start working together (autonomously), a central timing system is needed. Investigate central timing systems for deployments. (cfr. 7.6 - Usage of sensors)

REC 10: All sensors compiled in the inventory are cross checked with the business developments from Activity 2. Investigate on the possibility to implement (cfr. 6 – Inventory on smart sensors and PNT systems)

REC 11: Investigate the need of a cybersecurity policy for vessel operators (do's and don'ts regarding IT and Data). This could also be demanded by authorities.

REC 12: Safety related sensors could be certified before use.

REC 13: Requirements must also be developed for evolving sensors and PNT equipment used for automatic/autonomous vessels. (cfr. 6.4 Installation and/or configuration of sensors)

REC 14: The usage of a sensor should be well thought trough and should be according to the supplier guidelines and/or the applicable certification process if available/needed. (e.g. cfr. 7.1 Difference between AIS and PNT)

REC 15: It is a necessity to implement fall back options in case of using smart sensors and sensors in general. (cfr. 6.5 Fall back option)

REC 16: Ensure high data quality of data generated by sensors. Investigate the data quality parameters to be met, in function of smart sensors. (It's proposed to consider this in SuAc 4.4) (cfr. 7.4 Safety of navigation)

REC 17: Add metadata describing the accuracy or uncertainty of the measured data of the sensor in accordance to the technical specifications of the sensor.

8.2 Conclusions

8.2.1 Fallback, recommendation regarding necessary integrity levels

Every sensor can malfunction and when this happens there should be measurements 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:

1. Implement/activate the fall back;
2. Go to a "Gracefully shutdown"

When implementing a fallback solution, it usually starts operation when the primary sensor or system fails. It happens that the backup or fall-back also fails at start-up. Therefore, when implementing sensors and/or a system, although it will cost more, the backup or fallback system should be checked regularly or should be running with or next to the primary system. Increasing the integrity level of sensors and the system depends on the setup of the fallback system.

Even if sensors and systems are setup carefully "Murphy's Law" will always arise sooner or later. Therefore, next to redundancy and fallback a way of "Gracefully shutdown" could be implemented. This will mean that in time sub-sensors/systems will fail and stop working. This might influence the situational awareness and thereby the safety of navigation as well as the logistic planning. But due to a "Gracefully shutdown" process bigger problems/costs could be minimised.

8.2.2 Guidelines concerning setup 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.

A list of questions to consider while selecting and setting up sensors and/or the system:

1. What do I want to accomplish/detect with this/these sensor(s)?
2. What are the quality parameters that the sensors must give?
3. Do I need multiple sensors?
4. Do the sensors used for one goal have the same characteristics or do I need the same kind of sensors with different characteristics?
5. Are the sensors dependant on other system/infrastructure? And what could be the impact on the sensor?
6. Can I use the sensors everywhere I need them?
7. Can the sensors be unintentionally or on purpose tampered with and can I detect that? And take mitigating actions.

8.2.3 Accuracy indication and protection

Sensor data will be used to make tactical and/or strategic decisions. Depending on usage and purpose of the data these decisions will be taken by a human or a machine. In both cases it will be important to know the accuracy of the data. Not only the length, width or position but also the completeness or timeliness are important indicators.
To enable the different systems to use data in a correct and intended way, some kind of indication has to be provided by the sensor. This indication should be preferably a single number that tells the user of the data the accuracy value. This could be an absolute figure or a descriptive number.
Since sensors can be influenced by external hacks, the data could be corrupted and therefore the smart sensors should be protected.

8.2.4 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: the user should know which the related risks and consequences are and should know how to deal with these for the safety of navigation as a primary goal.

9 Feedback from the business and reference groups on this topic

On 29/08/2022 two interviews took place with Mr Marc Persoons from Periskal and with Mr Jo Jacobs from Tresco. The main conclusions of these interviews are:

The sensor inventory list was considered as good and solid base. Mr Marc Persoons emphasized on the affordability of sensors, the installation cost, the accuracy and e.g. the mean time between failure of the used sensors. The accuracy was also mentioned by Jo Jacobs concerning the missing calibrations in the inland waterway domain. Expensive sensors can and will most likely be considered if the usage lead to reduced staffing and if the usefulness is clearly described and promoted. Another main concern is the availability of backup technologies.

The details of the two interviews can be found in

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Appendix 3 – Feedback business. You can read more details on e.g. the need for a very accurate GPS, what is considered to be essential for remote controlled and autonomous inland waterway vessels.

10 Appendices

10.1 Appendix 1 – Inventory smart sensors and PNT

In a first phase of this project, an inventory of existing sensors and PNT systems was build. During this process new information was amended but not always available for all elements. Therefor some cells are left blank.

#	Sensor name (description)	(Initial) Purpose	Components	Output	Dependencies	Issues / limitations	Accuracy (if known)	Possible link with IWT	Advantages	Fall back arrangements

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1	LiDAR	Imaging	Multiple lasers or channels (8 – 128)	Pointcloud	Heavy rains and low hanging clouds High sun angles and reflections Skilled data analysts Low operating altitudes (500-2000m)	Expensive (small areas) Ineffective in the heavy rains and low hanging clouds (refraction) Degraded at high sun angles and reflections Inaccurate/unreliable in water depth and turbulent breaking waves Collection of large datasets that require a high level of analysis & interpretation Requires skilled data analysts No international protocols Inability to penetrate very dense forests/vegetation Powerful laser beams can potentially affect the human eye Low operating altitudes (500-2000m)	Range accuracy of 0.5 to 10mm relative to the sensor Mapping accuracy of up to 1cm horizontal (x, y) and 2cm vertical (z)	Feature recognition: 1. Realtime Inland ECDIS 2. Traffic management 3. Automated navigation	Quick and highly accurate data collection High sample density High penetrative abilities Independence of daylight No geometry distortions Integration with other data sources Minimum human dependence Not affected by extreme weather conditions Mapping of inaccessible and featureless areas Cheap (for large areas)	Old data
2	Stereo camera	Imaging	Multiple lenses with separate image sensors	3D images 3D point clouds	Requires skilled data analysts Shooting distance Inter-camera distance Camera focal length Viewing angle	Correction of artifacts (holes, edge erosion) Distance measurement less accurate (than e.g. RADAR)		Feature recognition: 1. Realtime Inland ECDIS 2. Traffic management 3. Automated navigation	Stereovision allows the perception of depth High resolution High azimuth resolution Precise object localization	Combination with radar Stereo vision can act as validation tool

3	AIS	Collision avoidance and identification. Also small data transfer	GPS, VHF receiver	NMEA 0183: Messages according to ITU.R-M1371, IEC and VTT standards	Accuracy of sensors used GNSS Vessel type Vessel speed GNSS antenna position and configuration Bandwidth	Incorrect input from skipper Vulnerable for hacking Small coverage range (--> increased by repeater stations) Can be turned off manually System mal function Coverage gaps between terrestrial stations Sensitive to radio frequency interference	Indication of positional accuracy transmitted by AIS	1. Traffic management 2. Automation	No human intervention Not affected by rain/sea Good propagation Possible to "seearound bends" Additional safety at night	Information fusion with shore sided-camera Supplements RADAR information
4	VDES	Data transfer (extension to AIS)	AIS ASM VDE	NMEA 0183: Messages according to ITU.R-M.2092, IEC and VTT standards				Traffic management, Logistic purposes		
5	GPS	Positioning, Timing and Navigation	Receiver Receiver-processor unit Control/display unit	NMEA 0183/NMEA 2000 standard	# receiving satellites	Low transmission power by satellites vulnerable for spoofing and jamming Obstacles (buildings, trees, mountains) and extreme atmospheric conditions (geomagnetic storms) lower accuracy	500-30 cm	iENC	Weather independent Cheap Global coverage	
6	Radar	Navigation	Antenna Diplexer Transmitter Phase-Lock Loop (PLL) Receiver	reflected radio-frequency electromagnetic signal	Atmospheric phenomena (e.g. precipitation (echo signals))	Atmospheric phenomena Ducting Interferences from nearby RADARs/other transmitters				

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7	Maglev porous nanogenerator (MPNG)	To power wireless smart sensors. self-powered by vibration energy, integrating triboelectric nanogenerator (TENG) and electromagnetic generator (EMG)		Energy (AC or DC, up to 3.3V)	Vibrations			Power for wireless smart sensors; Can charge various supercapacitors and Li-ion battery		
8	Smart echosounder	Accurate measurement of water depth	Sensor, embedded microelectronics	Depth information in the range of about 0.4 m to 200 m; sensors feature embedded microelectronics that process depth and temperature inside the sensor that can be instantly displayed on any device that accepts NMEA (National Marine Electronics Association) data	Distance, operating temperatures (-5C to +60C)		max. 0.03m difference	Hydrographic surveying of harbours, waterways and coastal water areas Dredging management operations Mobile field work		
9	Electro-Optical (EO) sensor system	Detection of objects and threats	Microbolometer detectors equipped with fast IR optics; Automatic image processing on a central computer	Image data alarm data automatic image processing enabling detection of threats	Contrast of Environment			Panoramic view of the surroundings Collision avoidance		
11	Accurate BJT-Based CMOS Smart Temperature Sensor with Duty-Cycle-Modulated Output	Temperature measurement	BJT-based temperature sensor implemented in standard 0.7µm CMOS technology, continuous-time duty-cycle	Temperature information			±0.1°C (-20°C to 60°C) and ±0.3°C (-45°C to 130°C)	Prediction of ice conditions		

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			modulator, microcontroller								
12	MEMS-IMU/GPS Integrated Navigation System	Positioning	MEMS inertial sensor, GPS, Signal processing board (CPU), Navigation computer, EMI filter board, vibration isolator	Position information			Accuracy of about 0.5 ~ 3.5 m	Realtime Inland ECDIS - Traffic management Automated navigation			
13	Smart embedded passive acoustic devices for real-time hydroacoustic surveys	Real-time hydroacoustic surveys: Noise statistics (including EU MSFD Indicators) Mammal detection (PAMguard)	Dual-channel compact, low-power digital hydrophone Digital passive acoustic transducer hydrophone array Multiplatform interoperability	Sound and noise Directional sound source information, Storage of relevant raw data in internal memory			Within the 1/3 octave bands of 63 and 125 Hz (centre frequency)	To protect endangered wildlife and habitats, especially those that are dependent on rivers			
14	Laser based Aid System	Measurement of distance between objects and a vessel (precise docking manoeuvre, collision avoidance)	Combining multiple sensors: laser distance sensors, Ultrasonic distance sensor, Ultrasonic 3D sensor, ZigBee to SIO module, Cameras	Distance				Evaluate stage of manoeuvre and vessel dynamics when vessel is docking or in the port area			

15	Smart Container	Alert operators to any potential issues with the cargo Regulate the internal conditions (e.g. temperature) Provide real time GPS tracking Enhance security Provide condition information	Internet of Things (IoT) technologies, sensors, GPS tracking and solar panels, maybe batteries to enable energy storage	Real-time data about position, temperature, humidity, door status, …..,	Energy, quality of data transmission,	Cybersecurity		Up-to-date tracking and can better predict arrival times at ports to enable optimized unloading of containers (Information provided is consistently outdated, which makes it difficult to accurately predict the containers arrival time at the port)		
16	MYTHINGS Smart Sensor	Multi-purpose industrial wireless sensor for long-range, robust and power-efficient IoT networks sensor allows you to capture critical data points; The smart sensor is integrated with the MYTHINGS Library – a hardware independent, small-footprint and power-optimized library of code, featuring the MIOTY (TS-UNB) low-power wide area network protocol.	Wireless self-contained multi-purpose sensor, External antenna, Rechargeable battery with USB,	GPS, acceleration, temperature, humidity, pressure Output Power: 14dBm (Europe) 20dBm (North America)		Operating frequency: 868 MHz (Europe) or 915 MHz (North America)			AES 128 network security layer	
17	Laser distance sensor	Distance		Distance	Detection range: 10cm - 3000m		1 mm			

18	Ultrasonic Sensor	Distance, Anemometer, Fluid detection		Distance	Detection range: up to 8 m	High-frequency ultrasonic range; through the conversion of electrical energy, Not able to measure the distance of Soft objects or ones with extreme textures	3 mm			
19	IR Sensor	Distance, Item counter, Burglar alarms		Distance	Detection range: 10 – 80 cm; Affected by environmental conditions and hard objects Performance dips over longer distances	Detects the presence of an object by emitting a beam of infrared light				
20	Capacitive Proxomity Sensor	Count objects, Distance, Moisture Control		Distance	Detection range: up to 2,5 cm	Low range				
21	Smart Buoy	Land based AtoN management On-line monitoring of oceanographic data Radio link for data transfer Offshore location reference	LED lantern, datalogger, battery, GSM-modem, several sensor, sinker	Temperature Conductivity Dissolved oxygen Turbidity Height of Tide Wave height Current speed Current direction Oil Spill And many more possible		Temp.: -5°C to 50°C Cond.: 0 to 100 mS/cm Oxygen: 0 to 50 mg/l Turbidity: 0 to 1000 NTU Height of tide: 0 to 20 m Wave height: 0 to 20 m Current speed: 0 to 300 cm/s Current direction: 0 to 360° oil spill:	Temp.: 0,15°C Cond.: 0.5% Oxygen: 2% Turbidity: 0.3 NTU Height of tide: 0.02% Wave height: 0.02% Current speed: 0.15 cm/s Current direction: 5° Oil spill:			

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22	GPS Compass Magnetometer	Heading	Accurate triaxial fluxgate magnetometer Triaxial accelerometer Dual antenna GPS system	GPS true north heading Latitude Longitude Magnetic heading X, Y, and Z axis magnetic field Declination (deviation) Inclination (dip) Magnetic vector Magnitude Magnetic field strength (N, E, V)	An antenna spacing of 0.5m Â±5mm is necessary. The "fore" antenna resides 0.5 meter ahead of the "aft" antenna on a line parallel to the x axis of the sensor package					
23	Acoustic Doppler Current Profiler (ADCP)	Uses sound waves to measure the speed and direction at which water moves across an entire water column	Doppler velocity log device (DVL) (acoustic transducers), communication device	2-D representation of true current velocity [m/s] and direction with respect to depth	Frequency of the sent sound wave	Higher frequencies, for example 300 kiloHertz (kHz), are useful in providing high-resolution data near the surface to a depth range of around 70 meters (230 feet). Lower frequency ADCPs, such as 38 kHz, will provide lower-resolution data to a depth range of up to 1,300 meters; If the water is very clear, as in the tropics, the pings may not hit enough particles to produce reliable data	Measurement Range: 0,6m - 150m; 0.015m/s	Measurements: Water depth, Current speed and direction	Measures small scale currents Measure the absolute speed of the water Measures a water column up to 1000m long	
24	Ring laser gyro (RLG)	Rotation detection, Heading, Inertial Navigations Systems (INS)	Laser beams, High reflective mirrors, Partially transmitting	Rotation rate		High price	Very high	Accurate ROT, heading for Smart Shipping	No external aiding required	

			mirrors, Laser cavity, Detector							
25	Fiber optic gyro (FOG)	Rotation, Heading	Laser source Beam splitters Detector Fiber optic coil	Rotation rate		Lower-cost technologies compared to RLG	High	Accurate ROT, heading for Smart Shipping	No external aiding required	
26	Gyro compass	Heading	Master compass, Repeater compass, Course recorder, Control panel, Voltage regulator	Direction of North	Detects true North by directly measuring Earth's angular rate as it spins on its axis once a day	Requires a particularly low-noise sensor with superior bias stability	Max. 0.5 ° heading error		o external aiding required	
27	Fibre Optic Sensor	Monitoring the physical health of structures in real time						Measurement of physical properties such as strain, displacement, temperature, pressure, velocity, and acceleration in structures of any shape or size Monitoring the physical health of structures in real time Buildings and Bridges: Concrete monitoring during setting, crack (length, propagation speed) monitoring Dams: Foundation monitoring, spatial displacement measurement, leakage monitoring, and	Easy integration into a wide variety of structures, Inability to conduct electric current Immune to electromagnetic interference and radio frequency interference. Lightweight Robust, more resistant to harsh environments High sensitivity. Remote sensing capability. Multifunctional sensing capabilities such as strain, pressure, corrosion, temperature and acoustic signals.	

								distributed temperature monitoring		
28	AIRMAR DST810 Smart Multisensor	Speed measurement	DST810 sensor, display devices	Vessel speed Speed-through-water Water temperature Water depth		Speed: 0.3 knots to 45 knots Temperature Sensor Range: -10°C to 40°C	Temperature Sensor Accuracy: ±0.5°C			
29	(Wireless) Fuel flow meter FUELTRAX	Fuel consumption monitoring	Coriolis Smart Meter Data transmission device (password-protected, fully SSL secured and encrypted)	Mass-flow of fuel			+/-0.5%	Optimisation of fuel consumption Optimise speed of vessel		

30	ABB CEMcaptain GAA610-M	Emission Monitoring	Analyser modules (i.e. Uras26 non-dispersive IR gas analyser) Sample handling components in a standalone cabinet	CO_2, SO_2 (also see Carbon intensity index (CII))		CO_2: 0 to 20 Vol.-%, SO_2: 0 to 500 ppm, SO_2 /CO_2 ratio: calculated, O_2 (option): 0 to 25 Vol.-%, CO (option): 0 to 500 ppm		Emission monitoring	Guarantee compliance with latest IMO regulations Certified system for emission monitoring in marine industry Digitally enabled for smart services	
31	Continuous Emission Monitoring System by Norsk Analyse	Emission Monitoring	Sample conditioning system Analyser cabinet	CO_2, SO_2 optional: NO_x, O_2		CO_2: 0 to 15 Vol.-%, SO_2: 0 to 1000 ppm		Emission monitoring	automatic analyser calibration Low-cost maintenance Long service lifetime Measures on a dry basis	
32	CyScan AS	Local position reference sensor		Interfaces to all known DP systems						
33	RadaScan	Local position reference sensor	Frequency Modulated Continuous Wave (FMCW)	Interface			0.25m (1σ) up to 600m 0.5m (1σ) up to 1000m	Long range sensoring and positioning		
34	RadaScan View	Vessel position and heading		Interface			0.25m (1σ) up to 600m			
35	RangeGuard	proximity sensor	Frequency Modulated Continuous Wave (FMCW) Dynamic Positioning Sensors based on laser and RADAR technology can provide both local position information	Vessel position relative to its surroundings	Detects objects within 300m Faster turnaround time Reduce risk of collision All weather operation	±2cm + 0.1% of Range	±2cm + 0.1% of Range, -25°C to +55°C	Detect objects nearby		
36	RS24		FMCW K-band dome RADAR	Images to dashboard or third party applications						
37	SceneScan									
38	Smart VS Level	Sensor to detect flooding		Serial interface (RS485 HD) using standard Modbus protocol				Detect flooding in vessels		

39	Smart EP Level	Measure pressure in liquid tanks						Liquid transport vessels		
40	Echo sounder									
41	DST810 Smart™ Multisensor	Temperature								
42	DST810 Smart™ Multisensor	Depth								
43	DST810 Smart™ Multisensor	Speed								
44	EchoRange™ 20 0 kHz Smart™ Sensor	Temperature & depth	Sensor	EchoRange™ transfers NMEA 0183 data in real time to a computer via RS422			99.33%			
45	GALILEO	Positioning, Timing and Navigation primary but also small bidirectional data transfer	Receiver and transmitter	NMEA 0183/NMEA 2000 standard	# Receiving satellites	Low transmission power by satellites vulnerable for spoofing and jamming	Accuracy according to IMO performance standards so > 10 meter in open water and < 10 meter in harbour areas			
46	GLONASS	Positioning, Timing and Navigation	Receiver	NMEA 0183/NMEA 2000 standard	# Receiving satellites	Low transmission power by satellites vulnerable for spoofing and jamming	Accuracy according to IMO performance standards so > 10 meter in open water and < 10 meter in harbour areas			
47	BEIDO	Positioning, Timing and Navigation primary but also small bidirectional data transfer	Receiver and transmitter	NMEA 0183/NMEA 2000 standard	# Receiving satellites	Low transmission power by satellites vulnerable for spoofing and jamming	Accuracy according to IMO performance standards so > 10 meter in open water and < 10 meter in harbour areas			

48	EGNOS	Integrity and correction of PNT sensors				low transmission power by satellites vulnerable for spoofing and jamming	Accuracy according to IMO performance standards so > 10 meter in open water and < 10 meter in harbour areas			
49	WAAS	Integrity and correction of PNT sensors				Low transmission power by satellites vulnerable for spoofing and jamming				
50	DGPS	Integrity and correction of PNT sensors	MF receiver	RTCM SC-104		Terrestrial based smaller coverage. Not available in all countries				
51	e-LORAN	Positioning, Timing and Navigation		RTCM SC-104		Terrestrial based smaller coverage. Not available in all countries				
52	R-mode	Positioning, Timing and Navigation	MF and VHF receiver	RTCM SC-104		Terrestrial based smaller coverage. Not available in all countries				
53	mmWave technology	RADAR sensor to measure surge movement of docked vessels. The passing movements are measured at cm level and also transmit images and AIS data of passing vessels.		Real time visible through an online dashboard.			Cm level and range is 300m-500m		Tidal movements, passing vessels and wind cause sporadic dangerous situations during loading/unloading. Could serve as a true alternative to LiDAR	
54	BridgeScout	Bridge height detection system			Only works when there are no obstructing obstacles between vessel and bridge.					

10.2 Appendix 2 – Abbreviations

Abbreviation	Explanation
AC	Alternating Current
ADCP	Acoustic Doppler Current Profiler
AIS	Automatic Identification Systems
ASM	Application Specific Messages
AtoN	Aid to Navigation
ATT	Average Turnaround Time
BJT-based CMOS	Bipolar Junction Transistor-based Complementary Metal Oxide Semiconductor
CCRP	Consistent Common Reference Point
CESNI/PT	Comité Europaen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure/Prescription Techniques
CESNI/TI	Comité Europaen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure/Technologies de l'information
CESNI/TI/VTT	Comité Europaen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure/ Technologies de l'information/Vessel Tracking and Tracing
CII	Carbon intensity index
COG	Course over ground
CPA	Closest Point of Approach
CPU	Central Processing Unit
CyScan AS	CyScan Absolute Signature
DC	Direct Current
DGLONASS	Differential Global Navigation Satellite System
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential Global Positioning System
DIWA	Digitalization of Inland Waterways
DP systems	Dynamic Positioning systems
DVL	Doppler velocity log
DVW	De Vlaamse Waterweg
ECDIS	Electronic Chart Display and Information System
EGNOS	European Geostationary Navigation Overlay Service
eLoran	Enhanced Long Range Navigation System
EMG	electromagnetic generater

EMI	Electro-Magnetic Interference
ENC	Electronic Navigational Chart
EO	Electro-optical
EPFD	Electronic Position Fixing Device
eRACON	Enhanced RAdar beaCON
ERPS	Enhanced Radar Positioning System
ERTMS	European Rail Traffic Management System
ESTRIN	European Standard laying down Technical Requirement for Inland Navigation vessels
ETA	Estimated Time of Arrival
EU MSFD	European Marine Strategy Framework Directive
FEU	Forty-Foot Equivalent Unit
FMCW	Frequency Modulated Continuous Wave
FOG	Fibre Optic Gyro
GAGAN	GPS Aided GEO Augmented Navigation
GDPR	General Data Protection Regulation
GLONASS	Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
IENC	Inland Electronic Navigational Chart
IMO	International Maritime Organization
INS	Inertial Navigation Systems
IoT	Internet of Things
IP cameras	Internet Protocol Cameras
IR	Infrared
ISO/IEC	International Organization for Standardization/ International Electrotechnical Commission
ITS	Intelligent Transport Systems
IWT	Inland Waterway Transport
LED	Light Emitting Diode
LiDAR	Light Detection and Ranging
MEMS-IMU/GPS	Micro-Electro-Mechanical System-Inertial Measurement Unit/Global Positioning System
MF	Medium Frequency
mmWave	Millimeter Wave
MPNG	Maglev Porous Nanogenerator
MRS	Multisystem Radionavigation Receiver
MSAS	Multifunctional Satellite Augmentation System
MSC	Maritime Safety Committee
MW	Medium Wave
NMEA	National Marine Electronic Association
OECD	Organisaton for Economic Co-operation
PAMguard	Passive Acoustic Monitoring Guard
PLL	Phase-Lock Loop
PNT	Positioning, Navigation and Timing

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PVT	Position, Velocity and Time
RADAR	Radio Detection and Ranging
RF	Radio Frequency
RIS	River Information System
RLG	Ring Laser Gyro
R-mode	Ranging-Mode
ROT	Rate of Turn
ROTI	Rate of Total electron content Index
RTCM SC	Radio Technology Commission for Maritime Services
RWT	Rijkswaterstaat
SDCM	System for Differential Corrections and Monitory
SDME	Speed and Distance Measurement Equipment
SIO	System Input Output
SOG	Speed over ground
SSL	Secure Sockets Layer
STW	Speed Through Water
SuAc	Sub-Activity
TCPA	Time to Closest Point of Approach
TENG	Triboelectric Nanogenerator
TEU	Twenty-Foot Equivalent Unit
TS-UNB	Telegram Splitting – Ultra narrow Band
UKC	Under Keel Clearance
VDES	VHF Data Exchange System
VHF	Very High Frequency
WAAS	Wide Area Augmentation System
WWRNS	World Wide Radionavigation System
ZPG	Zero Point of gauge

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10.3 Appendix 3 – Feedback business

10.3.1 Interview with Periskal (Marc Persoons)

On 29/08/2022 an interview took place with Mr Marc Persoons from Periskal. During this interview, he gave his personal findings regarding the inventory that was drawn up during this SuAc. He also clarified the current evolutions and needs in the market.
This interview was used as input for this appendix being part of the report of this SuAc 3.3.

- In terms of communication, 4G and 5G are not always reliable. Starlink could be used as a back-up here. However, no mobile unit of Starlink is available yet.
    - Problems currently in DE (Germany) and FR (France) - in DE a large project is starting to develop 5G better along the inland waterways.
    - Congestion on 4G/5G networks and non-covered areas might slow done the usage of those networks in the inland waterway domain.

- In general, we have already an extensive inventory list of sensors. Sensors can certainly be grouped according to the type of sensor when they belong to the same family (position, heading, RADAR,...).

- Every Inland Waterway Vessel (IWV) should have a heading sensor (cfr. GPS compass).

- In Marc Persoons' opinion, not much will happen in terms of technological developments.
    - Emission-related sensors may become a more significant technology, especially since this is a hot-topic.
    - The Gyro compass currently is still made out of an old mechanical device, the market needs a cheap alternative.
    - One thing that can still change in order to move forward is to make the current sensors available at a more acceptable price and to commercialise them. In this way, more sensors can be used. As a result, more IWVs will start to install sensors and the price can come down.

- In terms of autonomous sailing, it is still necessary for sensors to be accurate to within a few centimetres. But this is absolutely not realistic to keep the sensors affordable.
    - Positions and accurate distances needed for:
        - Automatic docking
        - Automatic lock passage, …

- Affordability for sensors is currently a pain point. This together with the installation costs. The installation is more expensive as everything on an IWV is wired. There is no network available here. It should also be noted that there is a lack of space on board for the sensors and the used cabinets.
    - Limiting the staff on board (read: autonomous sailing, remote control) can lead to budgets for sensors.

10.3.2 Interview with Tresco (Jo Jacobs)

On 29/08/2022 an interview took place with Mr Jo Jacobs from Tresco. During this interview, he gave his findings regarding the inventory that was drawn up during this SuAc. He also clarified the current evolutions and needs in the market.
This interview was used as input for this appendix being part of the report of this SuAc 3.3.

- Jo does not consider the problem of the cost price as high as Marc Persoons from Periskal. The order of magnitude was also different for a GPS compass (3000 to 4000 for Marc and 1200 for Jo).
- Jo was always talking about new vessels being built, unlike Marc, who was talking about fitting sensors to current vessels.

- It is already being attempted for some time to make GPS with compass standard on newly built vessels.
- Jo indicated that there is still a problem with the calibration of devices, resulting in inaccurate data. In maritime navigation, it is compulsory to do this every year for a bending meter, but this is not the case for inland navigation. This could be considered as an new rule for certain sensors but this cost price of this should be kept low.
- Important sensor: bending speed, for feedback to the autopilot.
- VHF has gained a foothold and is considered reliable.
- RTK (Real Time Kinematic) solution for GPS with compass is in progress.
- LiDAR for accurate mooring supported by lasers for measuring distances. Collisions with bridges could also be avoided.
- LiDAR uses point cloud, which is insufficient for real-time measurements/controls. An alternative could be an object-oriented output.
- Stereo cameras are currently being tested extensively; according to Jo, these are not yet sufficient if we compare this with stereo cameras in cars.
- Use of a load meter. How far has the IWV sunk due to its load?
- Height of the wheelhouse can be adjusted, not every vessel has a sensor to indicate height. Some manufacturers provide this, others do not. Some more information can be found on this topic (note of the redactor):
    - Regulations: https://www.arbo-binnenvaart.nl/arbo-handreiking/algemeen/hefbaar-stuurhuis
    - https://binnenvaart.org/toepassingen-ict/binnenvaart-ict/hoogtemeting/
    - https://www.schuttevaer.nl/nieuws/techniek/2013/01/16/brugalarm-voor-stuurhuizen/
- Finally, according to Jo, it's important to make the usefulness clear to the skipper/shipper. If this can be done, we can convince the skipper/shipper to make investments.

10.4 Appendix 4 – Table of figures

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