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Editors:
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Address: Børrestuveien 3
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PREFACE

These proceedings contain selected papers from the first International Conference on Maritime Autonomous Surface Ships (ICMASS), held in Busan, Republic of Korea, on November 8th and 9th, 2018. The first day of the conference had ten invited presentations from the international autonomous ship community, while the second day contained parallel sessions on industrial and academic topics respectively. A total of 20 industrial and 16 academic presentations were given. From the presentations, six full manuscripts are presented in these proceedings after peer review by two Korean and Norwegian experts.

ICMASS is an initiative from the International Network for Autonomous Ships (INAS, see http://www.autonomous-ship.org/index.html), an informal coalition of organizations and persons interested in autonomous ship technology. In 2018 it was organized by KAUS – Korea Autonomous Unmanned Ship Forum. The plan is to make this a yearly event in different places around the world. In 2019 it will take place in Trondheim, arranged by SINTEF Ocean AS and NTNU in cooperation with the Norwegian Forum for Autonomous Ships (NFAS).

The organizing committee would like to thank everyone who has helped with review of manuscripts, all those who helped to promote the conference and all authors who have submitted and presented their contributions.

Kwangil Lee & Ørnulf Jan Rødseth

KAUS Korea Autonomos and Unmanned Ship Forum

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Contents

HULL-TO-HULL CONCEPT SUPPORTING AUTONOMOUS NAVIGATION

Svein P. Berge[1*], Marianne Hagaseth[1], Per Erik Kvam[2], Arne Rinnan[2]
[1] SINTEF Ocean AS, Postbox 4762 Torgarden, NO-7465 Trondheim, Norway
[2] Kongsberg Seatex AS, Pirsenteret, Havnegata 9, NO-7010 Trondheim, Norway

* Corresponding author e-mail: svein.berge@sintef.no

Abstract

This paper presents the hull-to-hull (H2H) project where the concept of hull to hull positioning and uncertainty zones are used to assist navigators and operators to perform safe navigation of objects in proximity to each other. Data from position sensors and geometry (2D/3D) data will be shared amongst the H2H objects to calculate for example hull to hull distance to help avoiding physical contact (e.g. steel-to-steel contact). H2H will utilize a variety of positioning sensors, including the European GNSS systems Galileo and EGNOS. The H2H project aims to develop open interfaces such that any H2H compliant equipment provider or user can use the services provided in the planned standard. Data exchange protocols will be based on existing standards as the IHO S-100 standard for geometry and zone descriptions and for describing additional layers needed for ECDIS. Finally, a working methodology describing the needed steps from use case descriptions to implementation of the necessary services is presented.

Keywords: *Autonomous navigation, IHO S-100, Standardization, Interoperability, Digital twins, GNSS, Galileo.*

1. Introduction

Moving from manned to fully autonomous unmanned ship operations requires very accurate and reliable ship navigation systems. Normally, ship navigation is based on several onboard sensors like GNSS, echo-sounder, speed log and navigational radar, as well as electronic chart system (ECDIS) in addition to visual observations by the officer on watch. In manned operation, sensor fusion, situational awareness and control are all done by human in the loop. In absence of human perception and observation, there is a need for additional sensors and new intelligent sensor fusion algorithms applied for autonomous navigation. During maritime proximity operations, like simultaneous operation with several ships, automatic docking and manoeuvring in inland waterways, the relative distances and velocities between the different objects are of major importance.

The H2H (hull-to-hull) concept, initially proposed by Mr. Arne Rinnan at Kongsberg Seatex in a proposal under EU's H2020 program [8], will provide exchange of navigation data supporting both relative positioning and exchange of geometry data between objects using a secure maritime communication solution (e.g. maritime broadband radio system [9]). The H2H solution will be based on existing open standards like the IHO S-100 standard and being prepared to support autonomous navigation. The protocol will preferably be open, such that any H2H compliant system from any vendor can connect and start using the services provided in the standard.

2. The H2H project

The H2H project is funded by the European GNSS Agency under the Horizon 2020 programme. The project is coordinated by Kongsberg Seatex (NO), and participants are SINTEF Ocean (NO), SINTEF Digital (NO), KU Leuven (BE) and Mampaey Offshore Industries (NL). The project started in November 2017 and will run for three years. The project will develop the H2H concept, propose standardization and study safe and secure communication solutions. An H2H pilot will be built and demonstrated in three use cases: simultaneous operation, inland waterways and auto-mooring.

3. The H2H Concept

The core functionality of H2H is to provide hull to hull distance between vessels, and to use the concept of uncertainty zone to visualize the uncertainty of the distance calculation.

To calculate the hull to hull distance it is required to know the location of a vessel's hull relative to the hull of other nearby vessel(s). The basic idea in H2H is to calculate hulls' locations on basis of geometric vessel models in combination with position sensors. The vessel models will be automatically exchanged on digital radio between nearby vessels. Additionally, to provide relative position measurements, sensor data might also be exchanged on the same radio link.

The geometric vessel models will be used to generate digital twins representing the vessels, and then the position sensor data will allow positioning the digital twins relative to each other. Hence, each H2H vessel will be represented by a digital twin implemented in H2H.

In addition to hull to hull distances, the hull to hull velocities are essential navigation information. H2H will therefore also estimate the relative motion between the digital twins, and from this derive hull to hull velocities.

The position sensors can be different types, including systems providing two- and three-dimensional positions (for example GNSS) and systems providing range measurements and angle measurements, as well as inertial systems. In the H2H pilot we will include the European GNSS systems Galileo and EGNOS. Galileo will be used in relative mode providing high accuracy relative positions between vessels, whereas EGNOS will provide an added level of integrity.

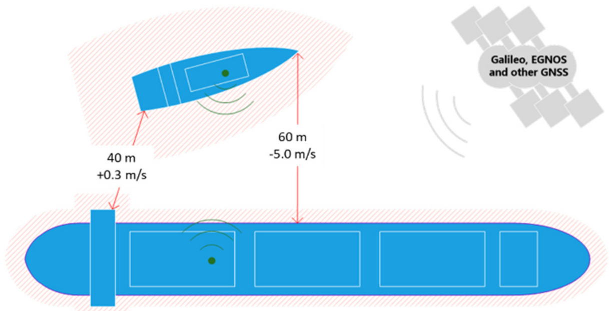

Figure 1. Uncertainty zones surrounding estimated hull location.

As shown in Figure 1, the uncertainty zone will surround the estimated hull location, and hence represent the uncertainty in the calculation of the hull's location. The size of the uncertainty depends upon the accuracy of the estimation of hull location. Therefore, the uncertainty zone will be derived on basis of the accuracy of the positioning sensors and the accuracy of the geometric model.

The concept is extended to not only providing hull to hull distance, but also distance between hull and static objects, for example a quay. Therefore, also the static objects might be represented as digital twins.

As shown in Figure 2, the H2H system has two external interfaces: 1) The H2H Engine User Interface and 2) The H2H Vessel-to-vessel Interface. Both interfaces will be based upon existing standards as far as possible such that different vendors can connect their own proprietary applications and systems following the H2H framework.

3.1 *H2H Engine User Interface*

The H2H Engine User Interface allows external applications to connect to H2H and obtain navigation information, for example hull to hull distances and velocities and uncertainty zones. Typical output data will be motion measurements, uncertainty zone, relative distances/velocities between different objects and support for ECDIS or other systems.

Real-time motion data for control applications (e.g. auto-docking, auto-mooring) will also be provided in the interface and necessary Quality of Services (QoS) measures (latency, data-rate etc.) will be supported.

3.2 *Example of display system – ECDIS*

ECDIS provides continuous position and navigational safety information. The system generates audible and/or visual alarms when the vessel is in proximity to navigational hazards. For inland waterway operations there is an own Inland ECDIS Standard [1] based on edition 4.0 for the Product Specification for Inland Electronic Navigation Charts (IENC). For inland waterway operations, the bathymetric data are of special interest. Inland ECDIS provides also the basis for other

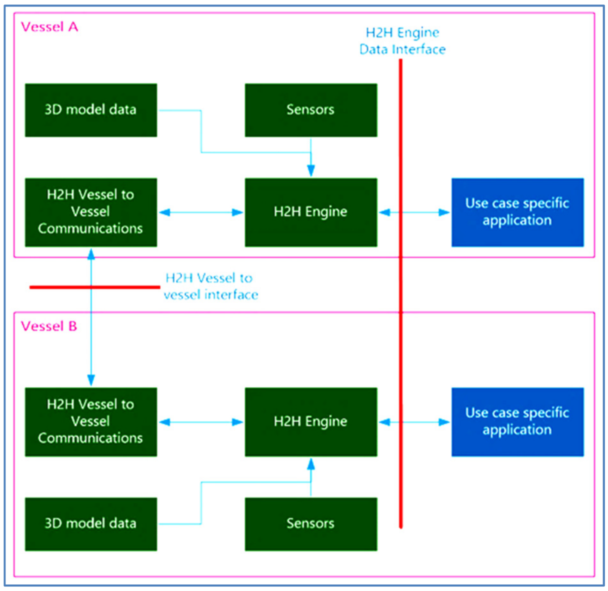

Figure 2. H2H Basic Modules (green boxes) and connection to external applications (blue boxes).

River Information Services (RIS), e.g. Inland AIS. Inland ENC must be produced in accordance to the bathymetric Inland ENC Feature Catalogue and the Inland ENC Encoding Guide. Typical information needed for the Inland ECDIS are;

- Position of own vessel including uncertainty zone
- Bathymetric data
- Navigational hazards (operational zones)
- Inland AIS
    - River Information Services (RIS)
    - NMEA data

Typical standards that are supported in ECDIS systems are;

- **IEC 61174 Ed.4.0** Maritime navigation and radiocommunication equipment and systems – Electronic chart display and information system (ECDIS) – Operational and performance requirements, methods of testing and required test results
- **IMO Resolution A.817 (19)**, Performance Standard for Electronic Chart Display and Information Systems
- **IEC 60945 Ed.4.0** Marine Navigational equipment, General Requirements. Methods of Testing and Required Test Results
- **IEC 61162-450/460** Digital interfaces for navigational equipment within a ship – Multiple talkers and multiple listeners.
- **IEC 61162-1,2,3.** Single talkers and multiple listeners (NMEA 0183, NMEA 2000)
- **IEC 529 Second edition (1989-11)**, Degrees of protection provided by enclosures (IP code)
- **AIS interface** is compatible with ITU-R M.1371 and IEC 61993-2

3.3 *Vessel-to-vessel interface*

The vessel-to-vessel interface is used for data exchange between H2H objects. The basic types of data to be exchanged is sensor data and geometric models, complemented with other navigation related data. The communication channel could be any wireless system providing required performance (bandwidth, latency, reliability etc.). Different communication solutions will have different bandwidth capacity and latency performance needed to be taken into account in the framework. To avoid cyber-attacks on an open wireless communication protocol, reliable mechanism to reduce cyber risk must also be implemented. IMO has in 2017 initiated the Guidelines on maritime cyber risk management to raise awareness on maritime cyber risk threats and vulnerabilities [2]. Typical, new signature and encryption systems for digital data and use of a public key infrastructure can protect against cyber-attacks on critical safety and operational information. There is currently no functionality or registry in the S-100 standard supporting cyber-security issues. Due to limited bandwidth, data can be serialized with less overhead using for example the **Google Protocol Buffer** to support a variety of programming languages (Java, Python, Objective-C and C++).

3.4 *Standardization*

As a starting point, we will investigate if the **IHO S-100 standard** could be used for the data exchanges in H2H. The S-100 standard is based on several ISO 19100 Standards covering spatial and temporal schema, imagery and gridded data, profiles, portrayal, encoding and so forth. For the H2H project, additional information about the vessel's geometry data (3D and 2D data), uncertainty zone (position uncertainty) and other operational zones will be proposed as amendments to existing standards.

Exchange of GNSS data supporting relative positioning might be done according to the RTCM standard [6], whereas the NMEA standard [7] is a good candidate for navigation information.

4 Uncertainty Zone

The concept of uncertainty zone was introduced above as a zone around the vessel which represents the uncertainty in the outer boundary of the geometry of vessels or objects of interests, as shown in Figure 1.

The uncertainty zones will be calculated by H2H, based on the accuracy of geometric vessel models and accuracy of the position sensors. The extent of the uncertainty zone from the hull would then represent this accuracy. The integrity requirement for the uncertainty zone will in the baseline application be expressed as the probability that actual position of a point on the hull will be inside the uncertainty zone with a probability of 95%. The probability of 95% has been chosen on basis of common standards for expressing accuracy for safe state in the maritime domain [10], [11]. However, specific applications could select other confidence levels for the uncertainty zone, adapted to their use case.

Uncertainty zone can be modelled as a polygon in either 2D or 3D. A polygon is defined as a plane figure (2D) or volume (3D) that is bounded by a finite chain of straight-line segments closing in a loop to form a closed polygonal chain or circuit. Each corner (edge) is defined by its coordinate including position uncertainty which can be modelled by a parametrized ellipsoid or a sphere.

H2H will be a flexible framework that allows using all available position sensors. The position sensors will be fused into a position and orientation estimator. This will then be used to locate and orientate the vessel model in a chosen coordinate system, for example a geographical grid.

The achievable accuracy, and hence size of the uncertainty zone, depends upon the both the accuracy of the position and orientation estimator, as well as how close the geometric model is in representing the physical hull. Hence, the size of the uncertainty zone, being steered by the accuracy, depends upon the quality of the sensors and the geometric models. A vessel well equipped with high quality sensors, including relative GNSS, and a precisely calibrated geometric model, could achieve uncertainty zones down to meters or even decimeters level.

Finally, it should be noted that the uncertainty zone could be dynamic. In case improved accuracy of a position sensor, for example when there are more GNSS satellites in view, then the uncertainty zone would shrink. Adversely, in case a sensor input disappears, then the uncertainty zone will increase. In case of a fallback to inertial navigation, then the uncertainty zone will grow with time.

Additionally, the uncertainty zone represents the uncertainty of a snapshot of the location of the hull, and does not take into account other constraints, e.g. external forces or vessel maneuverability. Those other constraints will be represented by operational zones, which are discussed in the next section.

5 Operational zone

Operational zones are any other zones than the uncertainty zone which need to be taken into account when navigating. The H2H concept will focus on defining and providing uncertainty zones related to the position accuracy, whilst the use case applications will define and implement operational zones related to different aspects of safe navigation. Hence, the H2H concept includes exchange and display of operational zones, whereas the calculation of the operational zones will be done by external applications that are adapted to specific use cases.

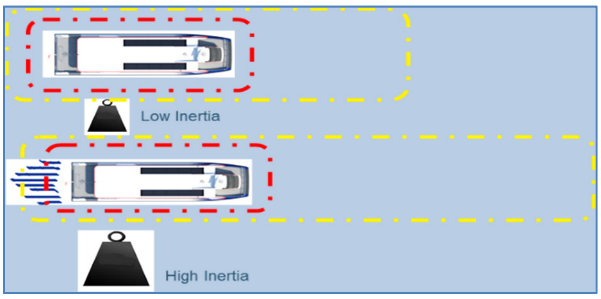

Figure 3. Examples of operational zones for inland waterways.

The uncertainty zone represents the uncertainty of the position of the hull at a given time. However, when it comes to safe distance between vessels and objects, also the vessel's dynamics and manoeuvrability need to be taken into account. Additionally, when navigating relative to a map, the map accuracy must be considered. Further, additional margins might be required to further reduce the risk of accident. As an example, if several H2H vessels are doing simultaneous operations, common safety zones or escape zones need to be transmitted to all interested H2H objects using the same zones for navigation. Safe navigation will also be different, depending upon type of operation and vessels involved, and could include distance, speed, course, maneuverability, etc. This will be included in the operational zones.

Other examples of zones are escape zones for offshore operations and different zones for inland waterways dependent on the vessel's ability to stop completely.

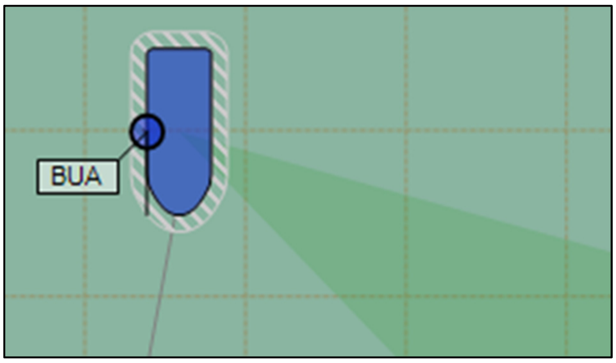

Figure 4. Escape Sector Zone.

Some of those zones are illustrated in Figure 3 and Figure 4. As a part of the next phase in the project, the H2H standardization work will define a format for representing the uncertainty zones and the operational zones.

Each zone can also be related to a specific contextual meaning, e.g. the **colour** is representing level of a warning or an alarm. It can be used to give guidance to the ship master or the control system on which navigational actions to take. Operational zone can be defined on top of a uncertainty zone or in some cases independent of a uncertainty zone. Operational zones are calculated by the Use Case Specific Applications and has specific semantics related to it as defined by the Use Case Specific Applications, for instance:

- **Warnings** to be raised when two zones are over-lapping or are in close contact, or when an object is entering a zone.
- **Recommendations** to specific actions to be taken by autonomous systems related to a zone, for instance for auto-mooring, where a new phase starts when an overlap is identified.
- **Access restrictions** to the zone, also linked to specific time periods, vessel types, vessel sizes and geographical areas. This can be used to indicate locks (including closing/opening times), quays or VTS areas. Another example is to use this zone to indicate fixed obstacles that must be passed on a certain distance, for instance the riverbank or navigation marks.
- **Navigational zones** to ensure that vessel keeps safe distance to other vessels and obstacles during navigation. Examples are the Waypoint Operational Zone defined for inland waterways passages indicating that the vessel should stay within this zone to ensure safe passage and the safe zones defined for two vessels approaching on a passage (collision avoidance).
- **Safe zones** and other zones related to safe operations that are used to indicate safe operations for vessels in close proximity with each other or to a fixed object, or escape zones, no-go zones, stand-by zones and responsibility zones.
- **Communication zones** can be an area of interest/first communication zone defining that a vessel moving into this zone should be made known to the object that has defined this zone and should start communication with this object in the cases where both objects are H2H compliant and able to communicate. This type of operational zone can be used to define what information to be exchanged at what time. This can be defined based on how several operational zones relates to each other or based on an object entering or leaving an operational zone.
- **Regulations**: Operational zone can be defined based on requirements given in maritime regulations for instance related to piloting, tug usage, reporting and VTS areas.

Each operational zone can be defined by a set of parameters that are listed in the following:

- **Shape:** This is the geometrical shape of the operational zone (polygon, circle etc.) and whether it is 2D and 3D. The shape (circle, ellipse, square, polygon) is determined by the Use Case Specific Application. The shape of an operational zone for a certain vessel can change during the different phases of an operation or navigation action. An example is a situation where two vessels are approaching and passing in close distance: When the relative distance between the vessels is large, having a circular or rectangular shape, or just a point, may be enough. When the vessels are moving in closer proximity, the shape of the operational zone may be based on the shape of the hull.
- **Size:** This is the size of the operational zone. The size of the shape must be determined, either by the diameter, length of the sides or by other means.
- **Time:** This is the time period when the operational zone is valid in case of time-varying information, for instance in the case of opening hours for locks and quays, bridge opening hours and mooring gear availability.
- **Information:** This is the information that is related to the OZ and is described by the following dimensions:
- **What information is transferred?** This can be information related to the vessel or fixed object: position data, geometric model, vessel dimensions, intended routes, already calculated uncertainty zones

and operational zones, among other kinds of information needed by the Use Case Specific Applications. It can also be operational information, as for instance warnings, recommendations, information about restricted waters or related to regulatory requirements.

- **When the information is transferred?** For an operational zone, the trigger for exchanging information can be defined to be for instance the time when two operational zones meet or when they intersect. It can also be when an object or vessel enters an operational zone. Further, it can be when a uncertainty zone meets or intersects with an operational zone. The timing of the operational zone information can be defined by the Use Case Specific Application user.

6 Development Methodology

Next phase in the H2H project is to work on the H2H framework defining the needed services for the two interfaces defined in Section 1.

Based on the work in the MUNIN [4] and MiTS project [5], we use the 3 layers model defining the conceptual, logical and technical layer, see Figure 5. Following this methodology, it is possible to break down the use cases into programmable interfaces (APIs) and data models for implementation.

As the modelling tool, we use the Enterprise Architect (EA) software from Sparx Systems. The EA is a visual and design tool based on the OMG UML. Typical work flow is to start defining the use cases where the interaction or activities between different actors and systems are visualized by simple symbols.

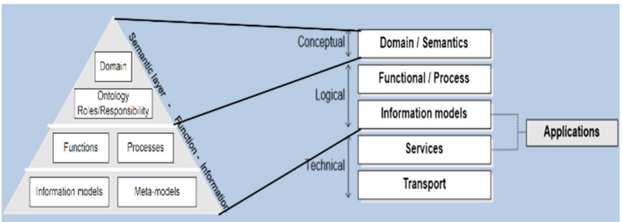

Figure 5. MiTS Architecture [5].

6.1 Use case specifications

Figure 6 presents the activity diagram for the simultaneous operation case in the H2H project. The text boxes show the system boundaries, while the oval shapes define the activities. Each use case has also a textual description based on a template which defines the goal, short summary, different actors, preconditions, triggers and successful scenario.

6.2 Main components

The right part of Figure 5. shows the main components of a proposed architecture as described in [4,5]:

1. **Domain and Semantics**: This is the definition of facts **about** what the architecture covers, including the definition of the area of interest: The domain model. This also includes business models: "Why a function is implemented". This layer is described by a domain model, an ontology and roles and responsibilities.
2. **Functional and process:** This layer describes **what** and **how** functions are implemented. This layer will focus on the minimum and generic aspects of the required functionality. This is described by use case diagrams.
3. **Information models:** This is the definition of the **required information** elements, including an exact definition for each element, its context, meaning and representation.
4. **Services:** Functions are implemented as a **number of services defined** in this layer. It also includes definitions of **information requirements for the services**. These are defined by APIs.
5. **Transport:** One also needs to consider the data transport mechanisms available to the services that needs to be covered by the communication solutions.

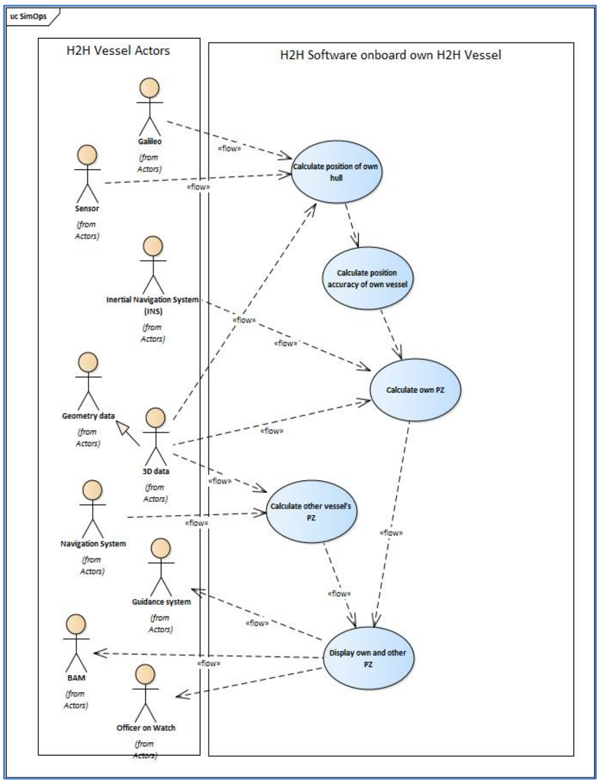

Figure 6. Activity diagram in EA.

7 Conclusion

This paper describes the initial concept of the H2H project defining the uncertainty zone as a measure of monitoring the physical distances between two or more objects, movable or fixed. This concept can be used to assist navigators and later being included into control systems for autonomous navigation. The H2H project supports the process moving from manned to fully unmanned autonomous navigation. The uncertainty zone calculation is based on exchange of 3D/2D models between H2H compatible objects and by use of GNSS Galileo or other positioning sensors if needed.

The operational zones are also defined and will be exchanged during maritime operations to provide necessary and additional information for safe navigation. The H2H project also propose open APIs both for internal communication on the ship itself and external communication from ship to ship using wireless IP network. The open API defines both the public data and services. Data security is obtained using authentication, authorization and encryption mechanism.

Three pilots will be developed within next year and used to demonstrate three different operations from open sea operation (simultaneous operations), inland waterways operations with hard constraints, and auto-mooring (ship-to-shore operation) by use of the H2H concept. Based on the user requirements for these three pilots, we will use the Design Methodology defined in Section 6 to derive the initial API including necessary services for all the three pilots.

As earlier mentioned, **the H2H concept does not yet focus on unmanned operations. Safety and risk are still managed by the operators.** Even if the overall goal of the project is to increase safety of close proximity operations, failures in the H2H system might give undesired consequences and reduced safety. The safety aspect should therefore be the backbone in further development of autonomous navigation when there is no human in the loop. **A safe design rule is to develop new autonomous navigation systems with at least the same level of safety as for the dynamic positioning (DP).** A fully unmanned, autonomous H2H navigation system will require an extensive safety analysis and may be divided into different classes like DP systems with different levels of redundancy in both hardware and software.

Acknowledgements

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This paper is a part of the dissemination activities for the H2H project and has not yet been published at any other conference.

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