DEVELOPMENT OF CLASSIFICATION PROCEDURES FOR AUTONOMOUS SHIPS

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Abstract

This is a report on the Smart City Ferries project under the Work Package 2: Smart Passenger Ferry, Task 2.2, The Safety of an Unmanned and Automated Ferry. The part discussed here is called “Development of Classification Procedures for Autonomous Ships”.

The idea was to discuss and look into ways of developing and defining classification procedures, as they are scarce at the moment. Lloyd’s Register was involved as class representative in the project.

The main findings were clear. The classification procedures have to be developed extensively. Goal-based procedures are to be used, but with some basic rules of prescriptive character. FSA – Formal Safety Assessment methods have to be implemented. Ship requirements are to be based on intended sea area and ship type and primarily on existing equipment, sensors etc. In some applications, new equipment/sensors have to be introduced. Overall, simple redundancy is required, to be enhanced by using diverse systems.

The report is prepared by senior lecturer Magnus Winberg at Novia University of Applied Sciences.
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## Terminology, abbreviations and acronyms

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<th>Explanation</th>
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<tr>
<td>Aboa Mare</td>
<td>Aboa Mare Academy and Training Center, see <a href="http://www.aboamare.fi">www.aboamare.fi</a></td>
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<tr>
<td>AIS</td>
<td>Automatic Identification System</td>
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<td>AL</td>
<td>Autonomy Level</td>
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<td>AI</td>
<td>Artificial Intelligence</td>
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<td>COG</td>
<td>Course Over Ground</td>
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<td>DIMECC</td>
<td>Digital, Internet, Materials &amp; Engineering Co-Creation</td>
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<td>DP</td>
<td>Dynamic Positioning</td>
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<td>ECDIS</td>
<td>Electronic chart and display system</td>
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<td>FSA</td>
<td>Formal Safety Assessment</td>
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<td>GMDSS</td>
<td>Global Maritime Distress and Safety System</td>
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<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<td>IACS</td>
<td>International Association of Classification Societies</td>
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<td>IMO</td>
<td>International Maritime Organization</td>
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<td>INS</td>
<td>Inertial Navigation System</td>
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<td>LIDAR</td>
<td>Light Detection And Ranging</td>
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<td>LR</td>
<td>Lloyd’s Register</td>
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<td>MASS</td>
<td>Maritime Autonomous Surface Ship</td>
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<td>OOW</td>
<td>Officer of the watch</td>
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<tr>
<td>R &amp; D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>SDME</td>
<td>Speed and Distance Measuring Equipment</td>
</tr>
<tr>
<td>TRAFI</td>
<td>Finnish Transport Safety Agency</td>
</tr>
<tr>
<td>UAS</td>
<td>University of Applied Sciences</td>
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<td>UMS</td>
<td>Unmanned Marine System</td>
</tr>
<tr>
<td>VDR</td>
<td>Vessel Data Recorder</td>
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<td>WG</td>
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1 Introduction

The Smart City Ferries (ÄlyVESI) project is an R&D innovation project including a few cities, technology companies and universities. The goal is to look into new solutions and services for intelligent sea transportation. The project also gives companies an opportunity to develop new business in marine technology and ICT. Currently Novia University of Applied Sciences, Turku University of Applied Sciences, Aalto University and City of Turku are cooperating on the project. The financing is mainly based on ERDF/6.Aika, with additional financing from the Finnish Transport Safety Agency and the cities of Helsinki and Espoo. More information is available at http://www.aboamare.fi/About-ÄlyVESI.

1.1 Background and motivation

Work Package 2 (WP2) in the Smart City Ferries project ÄlyVESI was called “A Smart Passenger Ferry”. This is a report on one part of that WP, i.e. on task 2.2. “The Safety of an Unmanned and Automated Ferry”; and more specifically on one part of that task: “Development of Classification Procedures for Autonomous Ships”. This part of the work package was assigned to Novia UAS.

1.2 Objectives and scope

In task 2.2 the safety of an autonomous ferry will be evaluated and a risk analysis of the vessel operation will be carried out. Previous surveys will be studied and reviewed in cooperation with experts, authorities and technology companies. The aim is to create a method with a new approach for similar projects in the future. In this part of the project the development of classification procedures for autonomous ships is studied. Lloyd’s Register is the classification society involved.

2 Realization method

In this chapter the background, planning and working methods are described.

2.1 Timetable

This part of the project was initiated in late 2017. In November, a kick-off meeting was convened, in which Lloyd’s Register, Novia UAS, Finnish Transport Safety Agency (TRAFI) and Digital, Internet, Materials & Engineering Co-Creation Ltd. (DIMECC) participated. This meeting resulted in an exhaustive list of suggestions for topics to be used further on in the project.

The Novia UAS researcher and project leader had an initial meeting in November 2017, where the broad strokes of the intended project were discussed. The deadline of the ÄlyVESI project was fixed to May 2018. It was decided that the classification society Lloyd’s Register (LR) should be approached for an initial meeting as soon as possible. The first meeting with LR was held in early January 2018.
2.2 Initial meeting with Lloyd’s Register

At the first meeting with Lloyd’s register, a group consisting of the Novia ÄlyVESI project manager, the researcher and two representatives for Lloyd’s register gathered to work out a preliminary plan for how to approach the study. As the starting point, the exhaustive list of suggestions for research topics from the kick-off meeting was presented. It was clear from the beginning that the study would have to focus on a selection of these topics.

During the brainstorming session, the structure for a proposal slowly emerged. The discussion focused to some degree on the companies and persons available in the reference groups available for Lloyd’s Register and Novia UAS. It was decided that selected companies, organizations and individual persons with special knowledge in the areas to be chosen should be approached and invited to participate in the project.

This decision thus turned the process of selecting the topics into one of identifying expert companies, organizations and persons available.

The end result was that three topics were selected to be studied further:

1) Redundancy and diversity requirements (AI, object detection and position reference systems, connectivity)

2) Requirements for vessel state monitoring systems (weather and sea state, vessel stability and loading situation, vessel capability prediction)

3) Recovery plans

2.3 Working methods

After the selection of topics was made, a discussion on how to proceed with the research followed. The Novia UAS researcher was given the responsibility of carrying the study onwards, to contact the companies/organizations/persons discussed in the planning group and to arrange for initial meetings. The choice of working methods was also given to the researcher.

The preliminary timetable called for workgroup initial meetings ASAP and having some preliminary results by mid-March, 2018.

3 Working groups

Based on the first meeting described in chapter 2.2, three working groups were formed.
3.1 Working group 1 (WG 1) on Redundancy and diversity requirements (AI, object detection and position reference systems, connectivity)

The planning group suggestion on the composition of WG 1 contained the following participants:
- Lloyd’s Register
- Novia UAS
- Navis Engineering
- Rolls Royce Marine
- Åbo Akademi

3.2 Working group 2 (WG 2) on Requirements for vessel state monitoring systems (Weather and sea state, Vessel stability and loading situation, Vessel capability prediction)

The planning group suggestion on the composition of WG 2 contained the following participants:
- Lloyd’s Register
- Novia UAS
- Navis Engineering
- NAPA
- Eniram
- Fleetrange

3.3 Working group 3 (WG 3) on Recovery plans

The planning group suggestion on the composition of WG 3 contained the following participants:
- Lloyd’s Register
- Novia UAS
- Arctia Icebreaking
- Rolls Royce Marine

3.4 Basic information on the suggested companies/organizations

This chapter contains, in brief, basic information on the suggested companies/organizations. The information is compiled from the public websites of the companies/organizations.

**Lloyd’s Register** - Started out in 1760 as a marine classification society. Today a provider of professional services for engineering and technology.

**Novia University of Applied Sciences** - is a Swedish-speaking UAS in Finland, with about 4000 students and a staff of 300. Novia has campuses in Vaasa, Turku, Raasepori and Pietarsaari.
**Arctia Icebreaking** - is a limited company established in 2010 and owned by the state of Finland. The company’s line of business is the provision of icebreaking services.

**Eniram** - provides the maritime industry with energy management technology to reduce fuel consumption and emissions. In July 2016, Eniram was acquired by Wärtsilä Corporation.

**Fleetrange** - was founded in 2016 with the vision of creating smarter, simpler and more cost-efficient real-time situational awareness solutions for the maritime industry.

**NAPA** - NAPA Group is a software house providing solutions for ship design and operation with the mission to improve safety and eco-efficiency of the global maritime industry.

**Navis Engineering** - designs and manufactures manoeuvring control systems for different types of the ships - offshore vessels, cruise and ferry, workboats and special ships, super and mega yachts.

**Rolls Royce Marine** - employs technologies that deliver clean, safe and competitive solutions to meet the planet’s vital power needs.

**Åbo Akademi** - Established 100 years ago, Åbo Akademi University operates currently in Turku and Vaasa. In the capacity as the only Swedish-speaking University in Finland, ÅA offers a wide range of educational options. Research in many fields is conducted, special focus areas being minority research, drug development and diagnostics, molecular process and material technology, and the sea.

### 4 The working groups in action

This chapter describes the main proceedings of the working groups.

#### 4.1 Working group 1

WG 1 first met at the very end of January.

#### 4.1.1 The proceedings

The participants represented the companies/organizations suggested earlier (see chapter 3)

The participants introduced themselves. It was noted that everybody had a clear connection to the topic at hand.

The ÄlyVESI project was then introduced to give the participants the general idea of what to expect and what to, possibly, produce.
The timetable was also discussed. The main point was that the time allocated for the working group is about one month; some results should be ready by the end of March.

The supposed goals/outcomes were discussed briefly. The main outcome are written reports, which are prepared by Novia UAS. The results will be presented at the ÄlyVESI final seminar on May 22nd, 2018.

A document from IACS ([http://www.iacs.org.uk/media/3785/iacs-class-what-why-how.pdf](http://www.iacs.org.uk/media/3785/iacs-class-what-why-how.pdf)) was used to clarify the modern way of doing class regulations, which is goal - based as compared to the older prescription - based way. Some input from the group also clarified the difference. The main idea of the goal-based approach is to establish goals and principles. It is then up to the end user, in this case the ship owner / charterer to figure out how to achieve the required level. The Polar Code, which entered into force on January 1st, 2017, is an example of a recent goal-based IMO code.

A simple analogy is the problem “how to stop people from falling over the edge of a cliff?”

- A prescriptive rule would say: “erect a one-meter high fence at the cliff edge”
- A goal-based rule would state: “prevent people from falling off the cliff”

The next thing to be discussed was the IMO guidelines on FSA - Formal Safety Assessment ([http://www.imo.org/en/ourwork/safety/safetytopics/pages/formalsafetyassessment.aspx](http://www.imo.org/en/ourwork/safety/safetytopics/pages/formalsafetyassessment.aspx)) which are a good starting point for a risk analysis.

Next, the Lloyd’s Register document “Design Code for Unmanned Marine Systems” was presented. The idea was that this document could possibly be used as a basis to improve existing rules. The Lloyd’s representative stated for the record that this document is on completely unmanned vessels, not autonomous vessels of a lower AL class, which are addressed in the document “Cyber-Enabled ships”.

In this document, a design code for Unmanned Marine Systems (UMS) is presented. Without delving into too much detail, the following are the main points of this Code:

“*The purpose of this Code is to provide a framework for the assurance of safety and operational requirements for UMS.*

*The implementation of this Code is dependent upon defining the operational requirements that will determine applicable safety and operational risks.*

*The Code is goal-based providing a set of Performance Requirements that support design innovation.*”

The Code also defines six levels or “hierarchy of tiers” as shown in the hierarchy triangle in picture 1.

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In the document, the first four hierarchy levels are described and defined. (Please note that the numbering in the triangle and the numbering in the rest of the document differ; Tier 0,1,2,3 as opposed to tier 1,2,3,4. The text designations are similar.)

Tiers 4, Solutions and 5, Justification and Guidance, are not included in the document (or tiers 5 & 6 depending on which one you use)

As defined in the original task, a pragmatic approach to flesh out existing regulations would be preferable. It thus seems quite practicable for the working group(s) to focus on tier 4, Solutions, to find some usable information to be considered by Lloyd’s Register.

4.1.2 The facilitation method and results:

The facilitation method chosen is called the Me-We-Us method. The idea is to bring out different views and thoughts without too much interference between the participants. It has been used successfully in high level, demanding commercial courses delivered at Novia UAS simulator center.

The steps are presented below in picture 2.
Me-we-us group facilitation method

Phases explained

ME = EVERYONE ALONE
- In this phase everyone thinks in silence about the topics important to him/her
- Ideas, general topics are written on a piece of paper
  - Simple bullet list
  - No topic is too small
- Phase duration: 5 minutes

ME WE US
- ME = EVERYONE ALONE (5 min)
  - Silent thinking, list on paper
- WE = TWO PERSONS TOGETHER (5 min)
  - Two persons discuss together
  - Three ideas / topics
- US = ALL TOGETHER
  - Discussion on results, putting topics / ideas on whiteboard etc.

To find all needs and wishes:
ME-W-E-US Group facilitation method

- For successful outcome all participants should share a common goal
- In a group sometimes
  - Only easy and simple questions are tackled
  - Not all views are heard
  - Goals and targets remain unclear
- Group facilitation methods can improve goal setting and outcomes
  - Me-we-us is a proven, simple tool for facilitation

Phases explained

ME WE US
- ME = EVERYONE ALONE (5 min)
  - Silent thinking, list on paper
- WE = TWO PERSONS TOGETHER
  - Two persons compare and discuss their topics/ideas
  - They select together three (3) MOST INTERESTING OR DEMANDING TOPICS
  - These topics / ideas are written down
- Phase duration: 5 min

LET’S GROUP THE TOPICS ON THE WHITEBOARD

US
ALL TOGETHER

Picture 2: Me-we-us facilitation method. (Aboa Mare)

The result as written on the whiteboard is shown in picture 3 below.

Picture 3: Me-we-us facilitation method results, WG 1. Photo by Magnus Winberg
The procedure yielded the following:

- It is extremely important not to state requirements that will become obsolete quickly. Given the area we are discussing, development can be expected to be very swift.

- Redundancy and diversity should also be handled using a goal-based approach.

- Software and hardware are two completely different domains. Software does not as such “break down” but hardware does.

- Sensor requirements and AI should be based on operational area.

- Data communications and cyber security should be based on operational area and have to be considered very carefully.

- The use of shore based support has to be considered at all levels.

It was seen as clear that the rules have to be goal-based because of widely different applications; different types and sizes of ships (dry cargo, tanker, and passenger) and different sea areas (short ferry crossings of a few hundred meters, one kilometer, archipelago, Baltic, Atlantic). Every selection of equipment and/or procedures has to be accompanied by a risk assessment (type IMO FSA).

It was also clear that in determining the operational areas one has to consider the available communications. One analogy would be the GMDSS (Global Maritime Distress and Safety System)

The working plan onwards was agreed on and the next physical meeting was suggested for the end of February.

4.2 Working group 2

WG 2 first met at the very end of January.

4.2.1 The proceedings

The participants represented the companies/organizations approached earlier (see chapter 3)

The introduction, discussion on basic classification terminology and practices, Design Code for Unmanned Marine Systems etc. were similar to the first meeting of WG 1, thus that explanation is omitted in this chapter.

The original focus for the working group(s), tier 4, Solutions, to find some usable information to be considered by the classification society, was also seen as the best way to work.
4.2.2 The results

The Me - We - Us procedure was used, and, of course, yielded different results, as the topic was different.

The result on the whiteboard is in picture 4.

- Exactly as in WG1, the sea/operating area is one of the first considerations which influences restrictions, loading states etc.

- Continuous monitoring of the state of the ship is required, parameters are e.g. trim & list, hull stress and draft.
- Capability prediction and the ability to react and respond to changes in ship’s behavior (dynamic control). This can be modeled e.g. on existing DP systems of similar performance, with capability prediction based on a mathematical model.

- The redundancy in DP systems of propulsion etc. are, however not necessary, existing merchant ships do not necessarily have them either.

- The systems can use existing sensor technology, many ships already have them installed and installing new sensors to measure ship movements is fairly easy and inexpensive. The data needed is, to at least some extent already used and recorded, for example in VDR.

- Sensor redundancy was discussed and also not seen as a problem. It is easy to duplicate sensors.

- Wave height measuring was seen as not necessary, this can be extrapolated from ship movements by movement sensors.

- Adjusting the ship route according to weather predictions was seen as not a part of this discussion, this applies to all ships already.

At this point, it was also clear that most of the points discussed in the WG 1 meeting were directly applicable to this subject as well, see below.

- **It is extremely important not to state requirements that will become obsolete quickly, given the area we are discussing, development can be expected to be very swift.**

- **Also redundancy and diversity should be handled with a goal-based approach**

- **Software and hardware are two completely different domains. Software does not as such “break down” but hardware does.**

- **Sensor requirements and AI should be based on operational area.**

- **Data communications and cyber security should be based on operational area and have to be considered very carefully.**

- **The use of shore based support has to be considered at all levels.**

At several points in the discussion it was stressed that by employing a system with “total transparency”, better results can be achieved by all interests.

It was decided, like in WG 1, to plan the next meeting at end of February.
4.3 Working group 3

Working Group 3 had a totally different run of things. The topic was “Recovery plans”, i.e. how to get the autonomous vessel up and working again after a breakdown in the systems or other anomalies affecting the functions of the ship.

The planning group suggestion for participants for this group was:

- Lloyd’s Register
- Novia UAS
- Arctia Icebreaking
- Rolls Royce Marine

There were also suggestions on further participants representing operators of smaller passenger vessels engaged principally in local traffic schemes, but this was ultimately not successful.

However, it soon became clear that coordinating a first meeting was difficult. The preliminary plan was to have all three working groups meeting initially at the end of January, which worked well for WG 1 and WG 2. WG 3 could not find a suitable date. First indications were positive, but some of the intended participants withdrew at quite a late stage. The efforts continued, but as no solution was forthcoming, the focus was kept on WGs 1 and 2.

From time to time, attempts to gather WG 3 were done, but without success. In mid-March, the project leader encouraged a last all-out effort to get at least some group work done. The presumptive participants were approached again, and, as a new opening, it was decided to approach a company that had not been involved before. Sadly, that company declined.

Eventually, a meeting was convened on May 3th, in which the following companies/organizations were represented:

- Novia UAS
- Rolls Royce Marine
- Arctia Icebreaking Oy

4.3.1 The proceedings

The agenda at this meeting was somewhat different, since it was clear that it would become the only meeting possible within the timeframe.

The first items were the same as in the WG 1 & WG 2 meetings, and the rest was arranged so that maximum effort could be put into the brainstorming phase. The Me-We-Uss method was again utilized.
4.3.2 The results

The result of the Me-We-Us discussion is in picture 5.

Picture 5: Me-we-us facilitation method results, WG 3. Photo by Magnus Winberg

- The predictability of system breakdowns or service needs is important. By using big data principles, it is possible to predict what will happen to components and/or systems.

- The design principle has to be considered and chosen carefully. A selection between predictability and redundancy has to be made. Predictability means that it is possible to know when a component/system will stop functioning and service or replace it in time. Redundancy means that the systems will be used with normal scheduled service/replacement. If and when a breakdown occurs, a redundant system will take over the functions until the primary system is re-established.

- The level of recovery has to be considered. Two levels of recovery were identified:
  1) Complete recovery to the same state as before the anomaly/breakdown/disturbance.
  2) Changeover to “safe state” and “limp home” operation, where total recovery is not attempted, rather taking the ship to a safe haven, where the total recovery can be done safely.

Selecting the recovery level depends on sea area, ship type and autonomy level. The need for human intervention was also discussed. Here it was felt that notifications had to be made to the Remote Operations Centre or equivalent, but these notifications do not necessarily have to be acknowledged before the ship proceeds with the recovery plan. Again, this depends on sea area, ship type and autonomy level.

- An important question, that has not been discussed so far, is the combination of onboard systems and shore systems. It was considered essential that both parts are included in
all planning, risk assessment and operations. The system must be seen and approached as an entity, with a holistic approach. Separating onboard and shore side is dangerous. Also, the mandate of classification societies to handle shore side classification was discussed. This was eventually seen as similar to existing classification of industrial systems and processes onshore, which are also handled by the same classification societies as at sea.

- The incidents that may necessitate recovery plans to be activated was divided into two main groups:
  
a) Maritime emergencies, i.e. grounding, collision, fire, stability issues etc. In principle, the same that might occur to a standard, manned ship.

b) Technical anomalies/breakdowns, i.e. disturbances in onboard systems, partly in existing systems in use today, such as radar, position fixing systems or navigation lights, or in new systems installed for autonomous operation.

In both cases, all the reasonably identifiable anomalies have to be assessed in a FSA and applicable recovery plans made.

- The testing of the recovery plans should be included in the normal testing procedures during building of the vessel, during outfitting and at sea trials.

Finally, a discussion on the topic of WG 3 ensued. It was felt that “recovery plans” was perhaps not the optimal term. Other terms such as “fallback plans”, “contingency plans” and “safe state” were discussed. Eventually, some consensus was reached that “contingency plans” might be a more suitable term. On the other hand, in some instances “fallback” and “recovery” might be more appropriate.

4.4 Second working group meeting, WG 1 and WG 2

Already during the first meetings in January and even more so during February, it became clear that WG1 and WG2 had a lot in common. It was decided that the second meeting would combine WG 1 and WG2, partly because Navis Engineering was represented in both groups and secondly because the meeting was to take place in Turku, which necessitated some traveling for the majority of participants.

The meeting came off as planned but the participant list changed radically. The companies represented at the meeting were:

- Novia UAS
- Navis Engineering
- Napa
- Rolls-Royce (2 persons)
- Guidance Marine (a Wärtsilä company)

Thus, Novia, Navis Engineering, Rolls Royce Marine and NAPA remained in the group, but some of the persons from the first meetings had changed. This made it somewhat challenging to create a group able to work, but it eventually came off acceptably. The basic ideas from the
previous meetings were discussed and were seen as justifiable. There was a somewhat heated argument on goal-based and prescriptive regulations, as some of the participants aired the thought that, in this case, the suggestion made was somewhat a hybrid between these two (which it was). Eventually, the matter was put to rest and the original ideas prevailed.

On the whole, most of the time the discussion circled around the same topics as the first meeting. The new composition of the group caused a lot of repetition, which was not necessarily negative, it also enhanced the relevance of the topics and decisions that had been made earlier.

Some new information was presented, such as thoughts on stability management and new sensor technology that can be used in the autonomous shipping context.

5 The ideas

In all working groups, a lot of ideas and thoughts were presented and discussed. All of them will not be discussed, but the basic ideas are presented here. As there was a lot of findings similar between the working groups, the findings will be presented as together.

5.1 Basic limitations

Some basic limitations are quite evident. It is not possible to create one set of rules and regulations to cover all shipping in the world. The field has to be divided in different ways to create a realistic rule set.

5.1.1 Prescriptive vs. goal-based

As the current development seems to favor goal-based regulations, it was seen as the only viable way of proceeding. Nevertheless, it was also pointed out that some classification societies have focused on a more prescriptive way of working; there is no clear-cut consensus on the subject. The working groups however recommend a goal-based approach. One motivator for this is the necessity of having an open-ended development possibility, to be able to employ new findings and new technologies as they emerge. A prescriptive system basically “freezes” the standard to a certain point in time.

5.1.2 Areas, ship types and level of autonomy

The demands of different sea areas, from inland rivers, canals and lakes to near-coastal and ocean areas are highly different. Thus, rules have to be laid down depending on sea-area.

The same thing can be said about different ship types. Inland ferries, riverboats, coastal tankers, huge container vessels and crude oil tankers or specialized ice-breaking vessels, have quite different characteristics.

This is not to say that a river crossing with a train ferry is “easier” than proceeding in the open ocean with a product tanker, it might be quite the other way around!
It was also perfectly clear, that the level of autonomy is extremely relevant, as they differ drastically, see table 1 below.

Table 1: Autonomy Levels (AL) - Adapted from the Lloyd's Register Cyber Enabled Ships – Draft ShipRight Procedure

<table>
<thead>
<tr>
<th>AL</th>
<th>Description</th>
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<tbody>
<tr>
<td>0</td>
<td>Manual: No autonomous function. All action and decision-making performed manually (n.b. systems may have level of autonomy, with Human in/ on the loop.), i.e. human controls all actions.</td>
</tr>
<tr>
<td>1</td>
<td>On-board Decision Support: All actions taken by human Operator, but decision support tool can present options or otherwise influence the actions chosen. Data is provided by systems on board.</td>
</tr>
<tr>
<td>2</td>
<td>On &amp;Off-board Decision Support: All actions taken by human Operator, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off-board.</td>
</tr>
<tr>
<td>3</td>
<td>‘Active’ Human in the loop: Decisions and actions are performed with human supervision. Data may be provided by systems on or off-board.</td>
</tr>
<tr>
<td>4</td>
<td>Human on the loop, Operator/ Supervisory: Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human Operators the opportunity to intercede and over-ride.</td>
</tr>
<tr>
<td>5</td>
<td>Fully autonomous: Rarely supervised operation where decisions are entirely made and actioned by the system.</td>
</tr>
<tr>
<td>6</td>
<td>Fully autonomous: Unsupervised operation where decisions are entirely made and actioned by the system during the mission.</td>
</tr>
</tbody>
</table>

A higher Autonomous Level (AL) system may use a lower AL system as part of its reversionary control and a complex system may be a combination of multiple systems at different levels

5.1.3 Existing sea area classifications

By doing a literature search, basically on the web, some examples of sea area classifications were found.

One of them, well known to mariners, is the GMDSS sea areas, see picture 6.
The GMDSS sea areas have another bearing on the autonomous ships, namely the connectivity, as these areas are defined by the available communication solutions in each area. However, these are a product of the 1980-1990s, and, as such, probably won’t be a very good solution.

Another sea area classification can be found in the UK Maritime Publication “Being a responsible industry; An Industry Code of Practice - A Voluntary Code “, Version 1.0 as of November 2017.

This Code addresses Maritime Autonomous Surface Ships (MASS) up to 24 metres in length. It can thus be construed as an acceptable approximation for larger vessels of the same type.

The following tables can be of interest:

Table 2: Areas of operation. (UK Maritime 2017)
Table 3: Design Categories. (UK Maritime 2017)

<table>
<thead>
<tr>
<th>Design category</th>
<th>Wind force (Beaufort scale)</th>
<th>Significant wave height (HS, metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - ‘Ocean’</td>
<td>Exceeding 8</td>
<td>Exceeding 4</td>
</tr>
<tr>
<td>B - ‘Offshore’</td>
<td>Up to, and including, 8</td>
<td>Up to, and including, 4</td>
</tr>
<tr>
<td>C - ‘Inshore’</td>
<td>Up to, and including, 6</td>
<td>Up to, and including, 2</td>
</tr>
<tr>
<td>D - ‘Sheltered waters’</td>
<td>Up to, and including, 4</td>
<td>Up to, and including, 0.5</td>
</tr>
</tbody>
</table>

The ship owner has to select desired ship type and sea area, and then, by using a risk assessment (type IMO FSA) when selecting of equipment and implementing procedures.

5.2 Sensors and redundancy

The main information needed to run an autonomous ship safely can be divided into two groups:

- Ship internal information
- Ship external information

5.2.1 Ship internal information

To be able to operate the ship safely, at least the following information concerning the ship is needed:

- Position
- Heading
- Course over ground
- Speed

This information can be obtained by using sensors already existing on the ship. The basic premise will thus be that no new sensor technology is needed.

The working group discussions clearly showed, that **Position, Heading, COG and Speed** has to be determined by at least two independent systems that work on different principles/methods.

In the case of position, these could be, e.g. a satellite system (GNSS) or an Inertial Navigation System (INS). On a very short route (river crossings etc.) it could be e.g. LIDAR and GNSS.

The idea is to have enough diversity in the systems. Using e.g. two GNSS systems, (even of different types) does not work satisfactorily. If the satellite segment for some reason stops working or is degraded, by spoofing or jamming, all the GNSS receivers will be rendered unusable.
The same principle, two independent systems of different types, should be used in all internal applications. All selections must always be verified by a goal-based risk assessment. Please also note, that even more redundancy might be needed in some applications/areas.

A further discussion on the different sensors and data is presented in chapter 5.2.4.

5.2.2 Redundancy

The question of how high redundancy is required has to be addressed. Clearly, there has to be redundancy, but how much? DP and ECDIS applications suggest simple redundancy. If a system or some part of it breaks down, you can switch to the other system, i.e. a duplicated system. This, however, raises the problem of how to ensure which system is actually working correctly?

An analogy could be the quite ordinary principle at sea to run two (all) hydraulic rudder systems in restricted waters, to ensure steering capability. There is a risk in this, however. If (when) you have a breakdown (eg. hydraulic fluid loss due to ruptured pipe) in either system, you have to shut down the malfunctioning system to avoid more damage. If you then, by mistake in the commotion, shut down the still functioning system, you will lose steering altogether.

It can be argued, that by running only one system instead of two, you eliminate this risk. An alarm going off means that the operating system is damaged, whereby you shut it off and start the other, undamaged one. You eliminate the risk of mistakes.

A short explanation of redundancy definitions is in order to ensure usage of the correct nomenclature.

- One system = No redundancy.
- Two systems = Simple redundancy.
- Three systems = Double redundancy.
- Four systems = Triple redundancy.

The question of cost is clearly highly important. A DP vessel with redundancies is quite expensive, and it will probably not be feasible to have a very high redundancy level because of...
the cost. A triple-module system would be very good, but in the end this is simply not feasible, so a minimum of simple redundancy (two systems) should be required, but this needs to be enhanced by using diverse systems (different types).

**5.2.3 Ship external information**

The ship also has to be able to ascertain what is happening outside the vessel, namely detecting other vessels (regardless of size), their movements, speeds etc., to be able to avoid close-quarters situations and eliminate the risk of collision. Also hydrographic data has to be taken into account, to avoid groundings. A third important parameter is the weather; wind speed and wind direction, visibility, waves and currents.

The sensors for these applications can also, but only partly, be those already existing. The marine radar is good for detecting targets at long and medium ranges (1-24 nautical miles) and can track and calculate the movements of multiple targets. This could be further improved, especially on short ranges, by employing broadband radar techniques, which, are not currently in use on merchant ships.

Another important part of the external information is the visual. This is now done by the OOW, using visual observations and no equipment for this is installed. Also the auditory observations are done by the human being on the bridge, the OOW. In these cases, special optical and audio equipment has to be installed. It is, however, logical that the same principle of simple redundancy, two different (diverse) systems, should be employed. In the case of visual observations, e.g. one system for visible light and another for infrared (heat) wavelengths would work. Another possibility is light intensification technologies.

The weather information is not a big problem. It is quite straightforward to do weather-based route planning and it has been used for over fifty years. The route planning is not seen as a function for the autonomous ship to perform, but it is rather done externally on the shore.

Observing wind speed and direction is already done; sensors for those exist and are commonly in use. Normally, though, they are not particularly reliable due to aerodynamic effects created by the ship’s hull. Nevertheless, this information can easily be supplemented by using movement sensors to measure the ship’s movement in six degrees of freedom (roll, pitch, yaw and heave, surge, sway).

These movement sensors are widely used on board ships, so also in this case, no further equipment installation is necessarily needed.

**5.2.4 Sensors**

Deciding which sensors should be required or recommended can be done using existing frameworks. The working groups identified three that could be used as a starting point.

- Voyage Data Recorder (VDR)
- Dynamic Positioning (DP)
- Automatic Identification System (AIS)

See tables 3, 4 and 5 below.
Table 3: VDR requirements, IMO A 861(20) (IMO 2017)

<table>
<thead>
<tr>
<th><strong>A.861(20) REF</strong></th>
<th><strong>DATA ITEM</strong></th>
<th><strong>SOURCE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4.1</td>
<td>Date &amp; time</td>
<td>Preferably external to ship (e.g.GNSS)</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Ship’s position</td>
<td>Electronic Positioning system</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Speed (through water or over ground)</td>
<td>Ship’s SDME</td>
</tr>
<tr>
<td>5.4.4</td>
<td>Heading</td>
<td>Ship’s compass</td>
</tr>
<tr>
<td>5.4.5</td>
<td>Bridge Audio</td>
<td>1 or more bridge microphones</td>
</tr>
<tr>
<td>5.4.6</td>
<td>Comms. Audio</td>
<td>VHF</td>
</tr>
<tr>
<td>5.4.7</td>
<td>Radar data- post display selection</td>
<td>Master radar display</td>
</tr>
<tr>
<td>5.4.8</td>
<td>Water depth</td>
<td>Echo Sounder</td>
</tr>
<tr>
<td>5.4.9</td>
<td>Main alarms</td>
<td>All mandatory alarms on bridge</td>
</tr>
<tr>
<td>5.4.10</td>
<td>Rudder order &amp; response</td>
<td>Steering gear &amp; autopilot</td>
</tr>
<tr>
<td>5.4.11</td>
<td>Engine order &amp; response</td>
<td>Telegraphs, controls and thrusters</td>
</tr>
<tr>
<td>5.4.12</td>
<td>Hull openings status</td>
<td>All mandatory status information displayed on bridge</td>
</tr>
<tr>
<td>5.4.13</td>
<td>Watertight &amp; fire door status</td>
<td>All mandatory status information displayed on bridge</td>
</tr>
<tr>
<td>5.4.14</td>
<td>Acceleration &amp; hull stresses</td>
<td>Hull stress and response monitoring equipment where fitted</td>
</tr>
<tr>
<td>5.4.15</td>
<td>Wind speed &amp; direction</td>
<td>Anemometer when fitted</td>
</tr>
</tbody>
</table>

Table 4: DP system requirements, DP classes 0-2. (ABS 2014)

<table>
<thead>
<tr>
<th><strong>Subsystem or Component</strong></th>
<th><strong>Equipment</strong></th>
<th><strong>Minimum Requirements for each Classification Notation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DPS-0 (^{(1)})</td>
</tr>
<tr>
<td><strong>Power System</strong></td>
<td>Generators and Prime Movers</td>
<td>Non-redundant</td>
</tr>
<tr>
<td></td>
<td>Main Switchboard</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Bus-tie Breaker</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Distribution System</td>
<td>Non-redundant</td>
</tr>
<tr>
<td></td>
<td>Power Management(^{(2)})</td>
<td>No</td>
</tr>
<tr>
<td><strong>Thrusters</strong></td>
<td>Arrangement of Thrusters</td>
<td>Non-redundant</td>
</tr>
<tr>
<td><strong>Control System</strong></td>
<td>DP Control: Number of Control Computers</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Manual Position Control: Joystick with Auto Heading</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Manual Thruster Control</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Position Reference System</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sensors:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>MRU(^{(3)})</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Gyro</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>UPS</td>
<td>0</td>
</tr>
<tr>
<td><strong>Backup Control Station for Backup Unit</strong></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Consequence Analyzer</strong></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td><strong>FMEA</strong></td>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>
Table 5: AIS information requirements (US Coast Guard)

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Required Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Static</td>
<td>- IMO number (where available)</td>
</tr>
<tr>
<td></td>
<td>- Call sign &amp; name</td>
</tr>
<tr>
<td></td>
<td>- Length and beam</td>
</tr>
<tr>
<td></td>
<td>- Type of ship</td>
</tr>
<tr>
<td></td>
<td>- Location of position-fixing antenna on the ship (aft of bow and port or starboard</td>
</tr>
<tr>
<td></td>
<td>of centerline</td>
</tr>
<tr>
<td>2. Dynamic</td>
<td>- Ship's position with accuracy indication and integrity status</td>
</tr>
<tr>
<td></td>
<td>- Time in UTC*</td>
</tr>
<tr>
<td></td>
<td>- Course over ground</td>
</tr>
<tr>
<td></td>
<td>- Speed over ground</td>
</tr>
<tr>
<td></td>
<td>- Heading</td>
</tr>
<tr>
<td></td>
<td>- Navigational status (e.g. NUC, at anchor, etc. - manual input)</td>
</tr>
<tr>
<td></td>
<td>- Rate of turn (where available)</td>
</tr>
<tr>
<td></td>
<td>- Optional - Angle of heel (where available)**</td>
</tr>
<tr>
<td></td>
<td>- Optional - Pitch and roll (where available)**</td>
</tr>
<tr>
<td>3. Voyage related:</td>
<td>- Ship's draught</td>
</tr>
<tr>
<td></td>
<td>- Hazardous cargo (type)**</td>
</tr>
<tr>
<td></td>
<td>- Destination and ETA (at masters discretion)</td>
</tr>
<tr>
<td></td>
<td>- Optional - Route plan (waypoints)**</td>
</tr>
<tr>
<td>4. Short safety-related messages</td>
<td></td>
</tr>
</tbody>
</table>

Identifying the required sensors also created a lengthy discussion on the differences in sensor output in relation to the reference frame in use. This topic is highly important, but the timeframe does not allow for further digression into it.

6 Assessment of the study

The study was carried through between late December 2017 and mid-May 2018. The work started slowly in December but got into its stride in mid-January. After the meeting for establishing the basic presumptions, the working groups 1 and 2 had their initial meetings at the end of January. In these meetings, a lot of ideas and information was forthcoming, working methods were agreed on and file repositories were established. The next meetings were scheduled for the end of February.

When the next meetings were convoked, something that could be interpreted as disinterest could be discerned amongst the companies and persons involved. After a lengthy process, a combined meeting of WG 1 and WG 2 was scheduled and kept in the latter part of March. Of the original attendees from January, only two remained. However, one company sent other representatives and one completely new company participated. As is, this brought some new ideas, but also some disruption in the proceedings of the working group. Eventually, the meeting was carried out, with some new information being presented.
Working group 3 proved to be a difficult case. The list of possible attendees was short to begin with, and it proved to be very hard to find a suitable meeting date and, indeed, find suitable attendees.

The situation was worsened by the timetable of the Novia researcher, which called for other scheduled duties until mid-April. All this made the quest all the harder, and eventually an emergency plan had to be affected. A single meeting was, after a lot of work, convened in the beginning of May, only a week before the final report was to be submitted.

The tight timetable overall did restrict the outcome to at least some degree. Attendees from diverse companies and organizations clearly have difficulties integrating their daily jobs with R&D activities. It also seemed that the interest in the project was, over all, not very high.

The outcome of the study can only be described as passable, with a lot of potential but the restrictions implemented by the tight schedule did not allow a more satisfying result.

7 Continuing the study

Possibly, the study can be continued by Lloyd’s Register. Especially WG 3 did not yet achieve the results hoped for.

8 Conclusions

The main findings were clear. The classification procedures have to be developed extensively.

As basis for the development work the following can be used:

- Goal-based procedures are to be used, but with some basic rules of prescriptive type.
- All aspects addressed by ship owner have to be done using FSA – Formal Safety Assessment methods.
- Ship requirements are to be based on intended sea area, ship type and autonomy level.
- Ship requirements are to be based primarily on existing equipment, sensors etc. In some applications, new equipment/sensors have to be introduced.
- Simple redundancy is required, to be enhanced by using diverse systems.
- “Technical” redundancy of propulsion, steering etc. over and above existing levels is primarily not required, however some ambiguity on this item still exists between the working groups.
- Contingency (recovery, fallback) plans have to be made during the planning process and tested during building and outfitting.