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Autonomous safety on vessels

an international overview and trends within the transport sector

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A feasibility study initiated and sponsored by Lighthouse 2016

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Summary

The trend is clear, higher level of automation is entering all sectors of transportation and it stretches from searching for natural resources and all the way in to our homes.

Shipping vessels and the shipping industry is changing rapidly. The world’s first smart ship with shore-based monitoring and controlling “I-Dolphin” will be keel laid September 2016 built in China[1] and delivered 2017. US DARPA[2] is about to launch a 130-foot long remote controlled surface vessel with high level autonomous features and Boeing[3] a 51-foot unmanned undersea vehicle (UUV); both are designed for months of service in combination of remote controlled and autonomous modes.

There are several different ways forward and they may all be as valid as the other (not restricted to these scenarios):

- Smart vessels – manned vessels with higher level of automation giving the officers Sense and Decision making assistance.
- Hybrid solutions with remote operated vessels, vessels in convoy, what the automotive industry calls “Platooning” the first lorry in a convoy of lorries send its acceleration/retardation data to the following lorries, enabling them to slip stream and thereby save fuel and exhaust emissions to the air. In a nautical setting there is a manned “Shepard”-vessel guiding several unmanned vessels in a convoy, using Vessel 2 Vessel communication.
- Short manned vessels with 12hrs of manned watch and 12hrs with supervision/control delegated to a Shore Control Centre (SCC), and under certain conditions have some delegated responsibilities/possibilities to take specific actions.
- Vessels that are manned out to a point and then they are remote operated until they reach a point close to the arriving port and again they are manned the final part of the voyage.
- Unmanned Remote operated vessel from a Shore Control Centre 24x7 from port to port.
- Fully Autonomous Vessels that handles the planning and execution of the complete voyage from port to port. Only monitored from a SCC with the ability to invoke only if deemed necessary. A “Google”-approach would be to go for this, the unmanned goal, directly.

This study identifies the following primary objects to address:

- Improved sensor system, test current technologies and software and identify capability gaps (today not as good as an officer on watch)
- Development of sensors, integration technology and software for recognising and categorising different types of obstacles.

Sammanfattning

Trenden är tydlig, en högre grad av automation återfinns i alla transportslag och sträcker sig från kartläggning av naturresurser och hela vägen in i våra hem.

Världens första smarta fartyg med landbaserad övervakning och styrning ” I-Dolphin ” kommer att kölsträckas september 2016 byggs i Kina och levereras 2017. US DARPA är på väg att lansera ett 130-fots fjärrstyrd ytfartyg med hög nivå av autonoma funktioner och Boeing ett 51-fots obemannat undervattensfordon (UUV), båda är utformade för månaders tjänstgöring i en kombination av fjärrstyrd och autonom drift. Det finns flera olika vägar framåt och alla kan vara lika tänkbara (möjliga alternativ behöver dock inte vara begränsade till dessa scenarier) :

- Smarta fartyg - bemannade fartyg med högre grad av automatisering som ger styrmannen på bryggan assistans i att upptäcka mål och ett automatiskt beslutstöd system.
- Hybridlösningar med fjärrstyrda fartyg , fartyg i konvoj – dvs vad bilindustrin kallar "platooning " där den första lastbilen i en konvoj av lastbilar skickar sina gaspådrag/aktivering av bromssystem till efterföljande lastbilar, så att de kan åka med kort inbördes avstånd och därmed spara bränsle och minska sina utsläpp. I en maritim miljö finns ett bemannat "vakt"-fartyg som vägleder flera obemannade fartyg i en konvoj med hjälp av fartyg-till- fartygs-kommunikation
- Fartyg med lägre bemanning där man har 12 timmar bemannad vakt och 12 timmar med övervakning/kontroll delegerad till ett landbaserat kontrollrum (Shore Control Center = SCC) och under särskilda omständigheter har delegerade befogenheter/möjligheter att vidta specifika åtgärder.
- Fartyg som är bemannade ut till en punkt och sedan är fjärrstyrda tills de når en punkt nära ankomsthamnen för att åter igen bemannas den sista delen av resan .
- Obemannade fartyg som fjärrstyrs från ett landbaserat kontrollrum (SCC) dygnet runt hela resan från hamn till hamn.
- Helt autonoma fartyg som hanterar planering och genomförande av hela resan från hamn till hamn. Endast övervakning från ett landbaserat kontrollrum (SCC) med möjlighet att ingripa endast om det anses nödvändigt. En " Google "-approach skulle vara att gå direkt på detta obemannade upplägg.

Denna studie identifierar följande primära frågor att adressera:

- Förbättrade sensorsystem, testa dagens teknik och programvara och identifiera kapacitetsbrister (idag inte lika bra som en vakthavande befäl)
- Utveckling av sensorer, teknik för att integrera och kategorisera programvara för att förbättra deras kapacitet .

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Abbreviations

A	
AAWA	Advanced Autonomous Waterborne Applications Initiative
AI	Artificial Intelligence
AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
AUV	Autonomous Underwater Vehicle
AUT-UMS	Class notation for Unattended Machinery Spaces
B	
BNWAS	Bridge Navigational Watch Alarm System
C	
COLREGS	International Regulations for Preventing Collisions at Sea
D	
DARPA	Defence Advanced Research Projects Agency
DP	Dynamic Positioning
DWT	Deadweight Tonnage
E	
ECDIS	Electronic Chart Display Information System
ECR	Engine Control Room
EDA	European Defence Agency
eNP	Electronic Nautical Publications
H	
HW	Hard Ware
I	
IBS	Integrated Bridge System
ICT	Information Communications Technology
IMO	International Maritime Organisation
ISM	International Standard for the Safe Management
L	
LLMC	Convention on Limitation of Liability for Maritime Claims
M	
MARPOL	International Convention for the Prevention of Pollution from Ships
MASRWG	Maritime Autonomous Systems Regulatory Working Group
MCA	Maritime Coastguard Agency in UK
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
N	
NAVTEX	Navigational Text Messages
NAVDAT	Navigational Data
NM	Nautical Mile 1852 meters
O	
OOW	Officer On Watch
R	
ROV	Remote Operated Vehicle
S	
SAR	Search And Rescue
SARUMS	Safety and Regulations for European Unmanned Maritime Systems,

S-band	Frequency used for s-band radar system
SCC	Shore Control Centre
SMA	Swedish Maritime Administration
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watch keeping for Seafarers
SW	Soft Ware
T	
TKES	Finnish Funding Agency for Innovation
U	
UMS	Unmanned Maritime Systems
UNCLOS	United Nations Conference on the Law of the Sea
USV	Unmanned Surface Vessel
UUV	Unmanned Undersea Vehicle
V	
VDES	VHF Data Exchange System
VHF	Very High Frequency
VTS	Vessel Traffic Service
X	
X-band	Frequency used in x-band radar system

1. Introduction

In a go game (an ancient two-player board game originated from China) that attracts extensive attention worldwide on March 9th 2016, Google DeepMind's AlphaGo (AI-based computer) takes on a top class human player for the very first time. This has been widely considered as the biggest milestone in the AI-based computer history since 1997 when Deep Blue from IBM dominated chess playing. As AI-based computers and automation technologies are advancing at an incredible speed in the digital era, the traditional transportation section is facing unprecedented challenges and opportunities.

One of the prominent application fields is undoubtedly the expansion of fully or partly unmanned vehicles. Driverless metropolitan train systems in Copenhagen is already news of yesterday. Aerial drones were deployed to conduct certain tasks both in military and civilian fields. In the maritime domain, although the autonomous offshore applications and under water vehicles are not unusual any more in the industry and scientific community, the substantial research and development are still deeply rooted in the military domain.

Recent publicised work from European Defence Agency (EDA) SARUMS (Safety and Regulations for European Unmanned Maritime Systems), indicates the great potential of the automation development and application in future merchant shipping. The concept of full or partial unmanned shipping with enhanced automation technology has been received increasing attention from different classification societies, machinery manufacturers and shipping companies in recent years, as they have foreseen coming changes and opportunities that require early adaptation to meet the market's needs and demands.

An historic example is an early adaptation from single to double hull in the oil/product shipping industry which led the business blossom for a long time for those whom adopted early. Unmanned and autonomous systems are currently on the rise in various modes of transportation. How our Swedish industry plans to deal with the coming wave of automation and prepare ourselves with lasting "green" initiatives to stay competitive needs more open discussion.

This report is an overview of trends in the shipping industry and other transport/logistic domains that might be worth a closer scrutiny and reflection for inspiration and further development.

2. Overview of current development in the shipping industry

Based on the two major completed EU projects, MUNIN and SARUM, and ongoing projects around the world, this report focuses on projects that have either known governmental bodies or companies backing them up. There are probably thousands of smaller (or less known) projects that might also surface as game changer/enablers and some might be failures.

2.1 Legislation

Both the MUNIN and SARUMS projects dwelled on the absence of unmanned vehicle legislation, either it is a benefit, easier to move forward or it might hamper the development, since there are several contradicting nomenclatures in the current legislations.

Both projects conclude that on domestic waters, it is up to each state to set the rules. On international water it is more complicated but nothing that stops the development towards unmanned vessels.

Bases on the work done in SARUMS, the University of Southampton together with the UK Marine Industries Alliance have moved forward and are addressing IMO.
A paper for consideration will be presented to IMO in May 2016 by The Maritime Autonomous Systems Regulatory Working Group (MASRWG)[45] and will be supported by several governmental bodies such as MCA UK, SMA, since it is only a paper for consideration.

From the US the Department of Homeland Security and United States Coast Guard has mentioned the UMS development in a TDC[6] (Trends, Development and Challenges) to IMO.

But things will happen, an example of the current discussion in the US[7]: "There is no question that someone is going to die in this technology" and "The question is when and what can we do to minimise that." said Duke University Roboticist Missy Cummings in testimony before the US Senate committee on commerce, science and transportation.

In an article in Business Insurance[8] "Underwriters get ready for crewless ships. Five-year timeframe for unmanned vessels" by Donna Mahone has gathered some insights from different actors. In short, the underwriters are preparing for unmanned vessels and the time span is five years as the article states, but there are also questions raised about how to calculate the risks, who will look after the vast amount of money that a fully loaded vessels represent at sea – Who will look after the cargo, prevent fire etc. And there also seems to be a discussion on if an unmanned vessel is less of a target for piracy then a manned one.

2.2 World view on development

Inspired by the Figure 4 in chapter 3.1, the historical evolution of some of the on-board systems could be mapped as illustrated below;

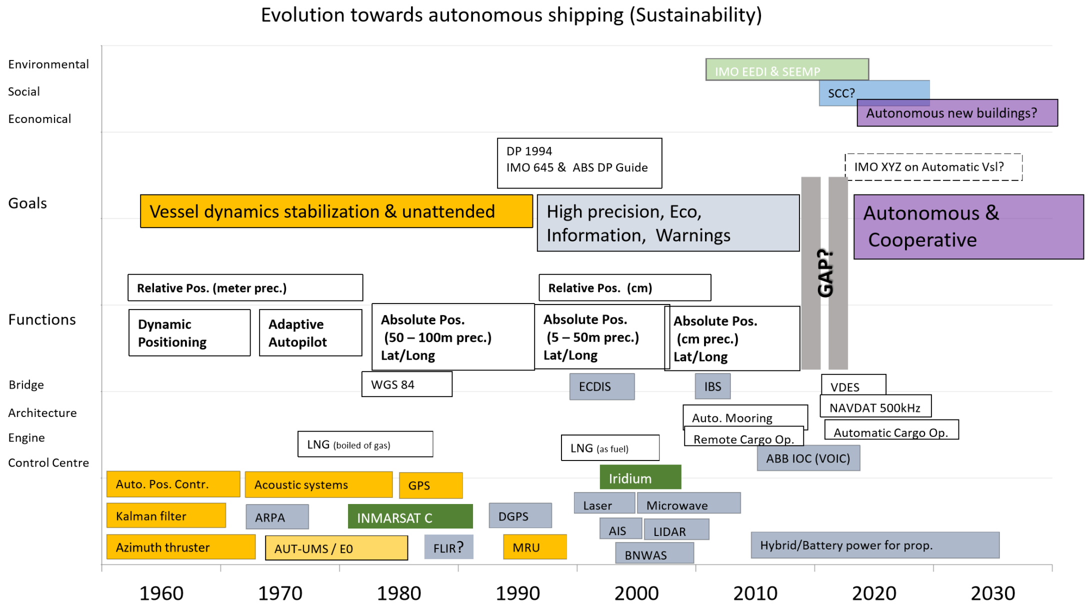


Figure 1 Evolution towards autonomous shipping

At the beginning, the goals were to have stable positioning of the vessel and reliving the engine room personnel from a 24x7 manned ECR. The development of vessels with dynamic positioning (DP) was driven by the Oil and Gas-sector. Unmanned ECR was developed so that the engineers could perform other maintenance tasks while the Officer On Watch (OOW) at the bridge which had to be manned 24x7 could monitor the ECR remotely and alarms were sent both to the bridge and an engineer on watch (in his cabin, personal pager etc.)

Then as technology developed and matured, increased precision, lower fuel consumptions, longer maintenance intervals and richer levels of data/information could be gathered and better situation awareness was achieved.

Now the shipping industry face a paradigm shift, the technology has matured to that extent that we can build in trust in to the systems. Commercial airliners take off and land fully automatically, so the shipping industry has to adapt to the new levels of safe automation that are mature and achievable.

Lessons learned in the defence and automotive industries should be engulfed so the “evolution gap” in the merchant fleet is bridged as fast as possible. As Figure 2 shows, the merchant fleet is way behind other sectors, where the defence industry has already proven that high level of automation in combination with remote control is “off the shelf solution” today.

Other civilian applications have high acceptance already, “self-driving” cars are on the streets, unmanned busses, trains and subways transport millions of people every day. So why not the merchant fleet?

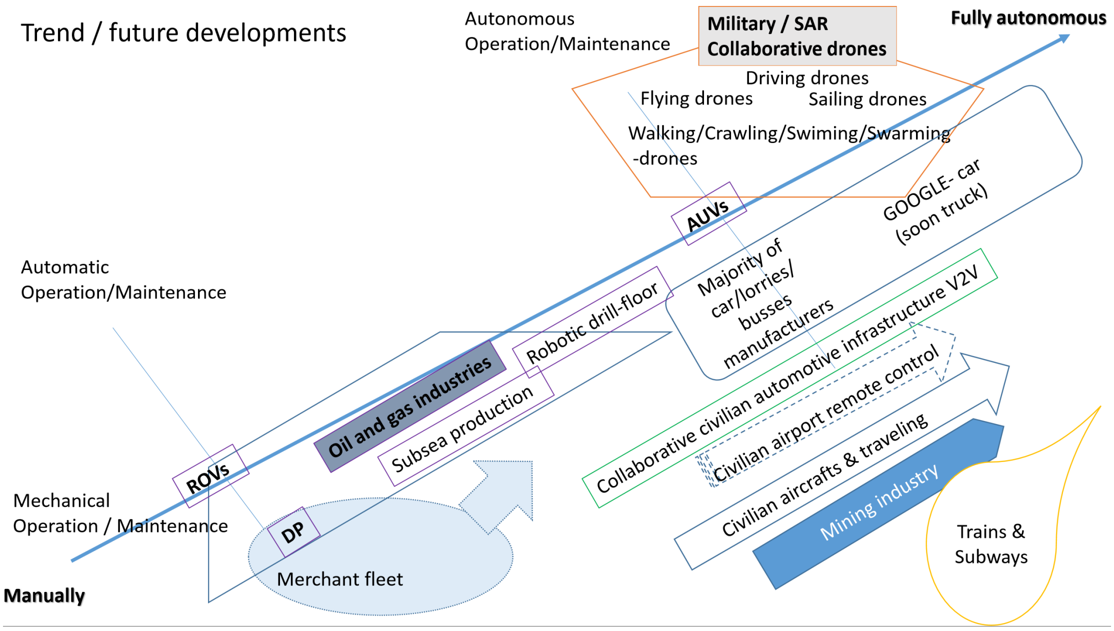


Figure 2 Parallels in other industries

Some of the on-board systems have started their evolution towards higher levels of automation. As Figure 3 below shows, the trend is clear, some systems have started their journey towards higher levels of automation and maybe full autonomy.

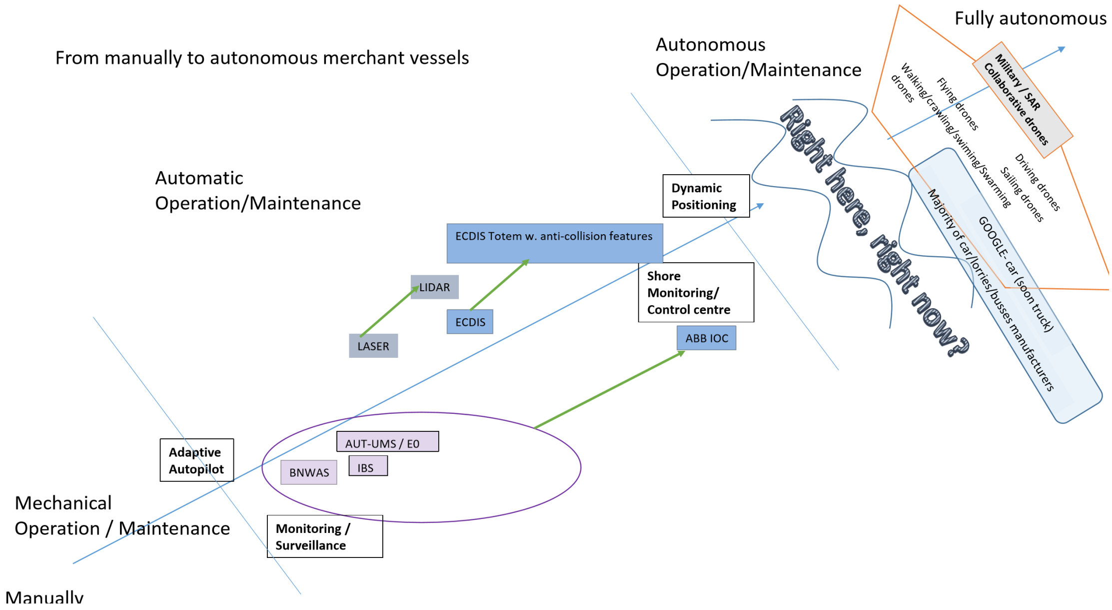


Figure 3 On-board technology moving towards higher levels of automation

Integration of alarm systems with monitoring system has progressed so far that manufactures are supporting the vessel crew by remotely receiving data and accessing the systems.

ECIDS manufacture TOTEM has add-on functionality where the OOW receives “Decision support” according to COLREGs based on ARPA and AIS data. The Dynamic Positioning systems of today has already the functionality to steer the vessel as a traditionally Autopilot, most of them also has the “Follow track” functionality, it is also configurable to run as part of redundant systems. So a remake of a DP Controller (DPC) with Sense and Avoidance software could be the way forward.

2.2.1 Outlook on projects relevant to Safe Autonomy

USA

In the US the driving force is the Department of Defence with its Defence Advanced Research Projects Agency (DARPA) and the defence industry/contractors, several types of automatic and robotic systems are currently being developed with the goal of having the "soldier" out of harm's way while still being able to be agile and equipped with the most powerful tools/weapons. As mentioned in the Summary above, both the US Airforce and US Navy are testing large unmanned vehicles that have the capability of high level of autonomy. The US Army is not far behind with autonomous vehicles[9] and humanoids such as ATLAS by Boston Dynamics mentioned in Section 3.4.
There is also an organisation "Association for Unmanned Vehicle Systems International AUVSI"[10] which has taken on the challenge to enlighten for example US Coast Guard on the UMS developments.

UK

As one of the larger actors on the international "diplomacy" arena, several defence projects with high level of automation emerges out of the UK. For example, the Royal Navy[11] has large projects. Also large defence contractor's/industry companies such as BEA and Rolls Royce (RR) have vehicles with high level of automation. Rolls Royce are also investing a lot in a project Advanced Autonomous Waterborne Applications Initiative (AAWA) with the Finnish governmental research institute TEKES[12]. Also the UK Marine Industry Alliance[13] is promoting research and development for future autonomous merchant vessels. *Also the* University of Southampton as mentioned earlier are pushing for an IMO awareness, partly based on the SARUMS work.

EU

The European Commission and Defence Agency has driven two large project, as mentioned earlier. One of them is the MUNIN project, which was a highly successful concept study, investigating the feasibility of unmanned merchant ships. The MUNIN-project now has a follow up project called Raven. The Raven project will use these results and outsights provided by MUNIN to make the short sea transportation systems in Europe. The objective of Raven is to develop an integrated transport system linking existing deep sea, feeder and rail services to a new and innovative waterborne national and inland system of autonomous short sea ships and shuttle barges. These vessels will be fully or partly electric to reduce costs and to provide a completely green transport service. Short distances and low capital costs makes electric propulsion feasible as one is able to provide sufficient port time for charging batteries. The focus in this project is on the "last mile" systems that today struggle with competition from truck transport, both because this will strengthen sea transport in this particular segment, but also because this will in general strengthen the existing hub and spikes structure in European maritime transport.

Norway
DNV-GL has launched the ReVolt-project[14]. Other big actors, such as Rolls Royce, have interest in Norway. ABB Marine has its centre in Norway and will reveal its autonomous project this summer. NTNU AMOS[15] (Centre for Autonomous Marine Operations and Systems) is involved or associated with many European projects.

Finland
As mentioned earlier, a joint project in AAWA, with big actors such as Rolls Royce, but also Inmarsat are partners.

South Korea
Several projects are emerging from South Korea. Korea Research Institute of Ships and Ocean Engineering (KRISO) and Korea Advanced Institute of Science and Technology (KAIST) are participating in several projects. KRISO in INTEROUS (SARUMS liaison) with KAIST[16]

China
2013 The "marine equipment information intelligent management and application technology innovation centre" was established in China. The centre focuses on the core technology development of smart ships.

2015.5 The national initiative "Made in China 2025" was issued by State Council to guide the next 10 years' industry development with the focus on intelligent manufacturing. Smart ships are highlighted in the strategy level as "shipping industry 4.0".

2015.8 State council published "Programs of action for promoting big data", which indicate the big data officially becomes the core national strategy and it would be extensively explored and utilised in the wave of smart ships.

2016.9 Start construction of the smart ship

2017 Delivery[17]

Key features of Chinese smart ship[18]:

1. Real time sensor data fusion.
2. Autonomous analysis, prediction and optimisation of decision based on the big data.
3. Ship shore communication, including shore-based monitoring, controlling and remote maintenance.
4. Underlying intelligent platform to provide value of the whole life cycle of vessels.

2.3 Typical Unmanned Vessels Projects in EU:

Two major EU founded works are based on the similar hypothesis that unmanned vessels can sail as safely as manned vessels. These are the MUNIN and European Defence Agency SARUMS[19] described in the next section below. Similarities can be found in their conclusion, along with other similar ongoing projects regarding autonomous vessels. The legislation will be solved, autonomous technology is maturing fast and the acceptance for autonomous systems to our society is paved by the automotive industries with Google leading the way.

2.3.1 Background of SARUMS and MUNIN

The EDA funded UMS-Unmanned Maritime Systems project has a military/SAR approach and focused on smaller vehicles; Unmanned Surface Vehicles (USV) and Unmanned Underwater Vehicles (UUV). But their findings are also direct applicable on merchant vessels.

The other work is the MUNIN[20] funded by the EU Commissions. It had a more practical approach by designing and developing a virtual 200m dry bulk vessel and a supervisory shore control centre (SSC). This served as a test-bed to show proof of concept for feasibility of the autonomous vessel and supporting infrastructure.

There are many similarities between the outcome of MUNIN and UMS – SARUMS projects, and other similar projects that are ongoing around the world, to mention some: ReVolt (N, DNV GL), KRISO (S. Korea), AVUSI (USA), UK MI (UK), MASRWG (UK), Smart Ship (China), AAWA (FI &RR).

2.3.2 Concurrence of the two projects

Both projects came to the same conclusions regarding that autonomous vehicles/vessels are not mentioned in International codes and conventions such as: SOLAS, UNCLOS, COLREGS, LLMC, MARPOL, STCW, ISM etc. And therefore the topic is being subject to interpretations and uncertainties, for example UNCLOS use both the term ship and vessel and neither is defined.

There are movements[21] that strive to present the concept and way forward for legislation/liability concerning autonomous vessels at the IMO meeting in May 2016.

Both projects concur with that we can’t wait for IMO for a world ratification, since national initiatives allow autonomous vessels on their domestic waters. We will have parallel development of autonomous systems and the technology will mature faster than the legislation/liability will be finalised within IMO.

In short the SARUMS UMS findings:

- UMS needs regulatory framework in which their design and operation can be assessed.
- Owners needs to understand how to define requirements
- Industry needs to be able to demonstrate compliance
- Operator training needs guidelines of what would qualify as properly trained and suitably qualified personnel
- Improved communications may be achieved between organisations, regulators, industry and the wider maritime community
- International approach would enhance acceptance and interoperability

The MUNIN project concluded *“However, overall it can be concluded that the unmanned ship does not pose an unsurmountable substantial obstacle in legal terms. In* *terms of liability, the biggest issue will concern the attribution of the existing ship master duties to the relevant and adequate persons involved in the operation of an unmanned ship.[22]"*

2.3.3 More similarities of the projects

They overlap and also complement each other and their similar (maybe even same) conclusions on system overview, the demands on technology, addressing risk, design and functionality.

The work from SARUMS work group have been extensively focused on legal and liability aspects. Final Draft of "*Best practice guide for UMS handling, operations, design and regulations*" is produced in 2015. It was built around three levels of safety precepts:

- Programmatic: ensure that safety is adequately addressed throughout the lifecycle process.
- Operational: Safety precept directed specifically at system operation.
- Design: General design guidance intended to facilitate safety of the system and minimise hazards

MUNIN propose a slightly different concept, where the ship is autonomously operated by new systems on board for intercontinental voyages, but the monitoring and controlling functionalities are executed by an operator ashore in the Shore Control Centre (SCC). Based on this concept, MUNIN has designed and developed the following systems and entities as a proof of concept and established the corresponding hypothesis:

- An ICT architecture to support ship-shore communication
- An Advanced Sensor Module and an Autonomous Navigation System
    - The autonomous sensor module can sense sufficient weather and traffic data to ensure navigation and planning function on autonomous ships and enable situation awareness in an operation room
    - The deep see navigation system can autonomously navigate a ship safely and efficiently along a predefined voyage plan with respect to weather and traffic conditions.
- An Autonomous Engine and Monitoring Control system
    - The ship engine can reliably operate for 500 hrs without physical interference from a human in the ship's engine room.
- A Shore Control Centre, which continuously monitors and controls the autonomously operated vessel after its being released from its crew by its skilled nautical officers and engineers

2.3.4 Outlook

The similarities of the two projects are larger than the differences. MUNIN is very practical in terms of prototype design and test-bed development while SARUMS has more substantial work in guidelines making and recommendations. It is not just listing the comparison and trying to provide a conclusion of the two. One important question to pose is how we can absorb experience from the research and development from such practical projects and make use of them to build our own fast track towards the test-bed, which is assumed to be the milestone of the development in stage one.

3. Overview of current development in other domains

In general, we have two domains, the defence/military and the civilian, but these crossbreed on several levels. Technology that is mature in the defence sector might still not be accepted in the civilian domain. And civilian development and appliances are monitored by the defence industry.

Remote controlled systems have been used by Search and Rescue (SAR)/Police/Armed forces for a long time and the development towards autonomous technology is breath-taking.

With the two examples mentioned from USA defence industry that deploys a 51-foot UUV, a 130-foot USV and the 38800 dwt I-Dolphin dry-bulk vessel that will be keel laid 2016, it is shown that it is not just small research projects anymore.

Unmanned Maritime Systems (UMS), civilian or military, face and share the same environments, and have to cope with them in similar ways.

In this report we have focused on what we can learn from the automotive industry on their road to safe autonomy and also showing other domains close to shipping and logistic systems.

3.1 Automobile industry (Major):

The road to Advanced Driver Assistance Systems (ADAS)[23]

The incremental development of automation in road vehicles could be described in the following sections where three broad generations are distinguished: a) vehicle dynamics stabilisation systems, b) driver support, and c) partial or full manoeuvring control, see Figure 4.

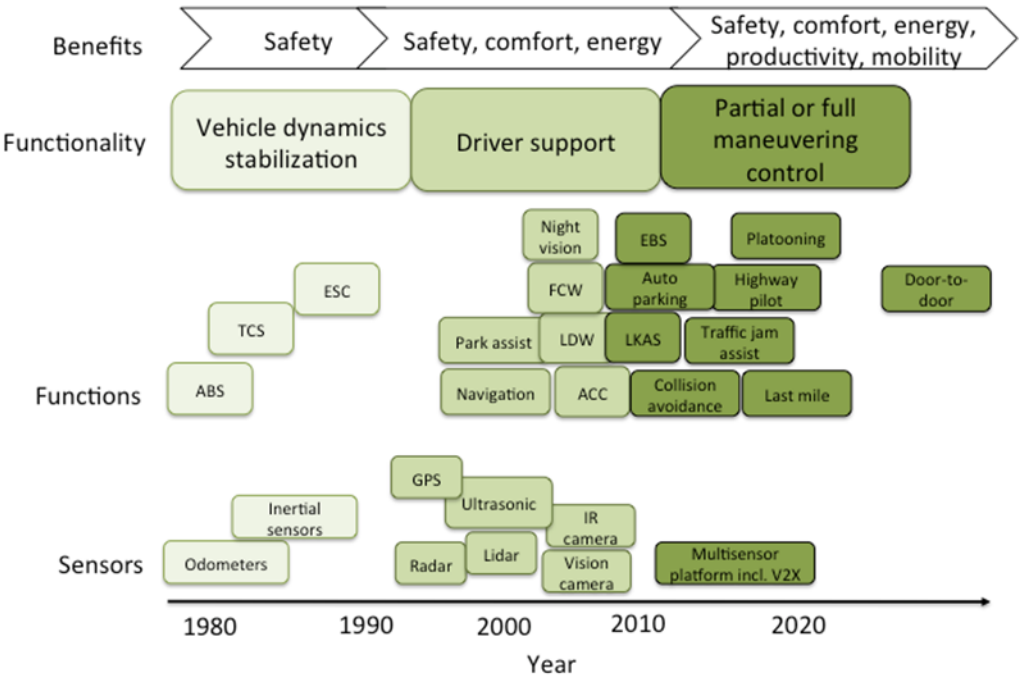


Figure 4 Incremental development of vehicle automation.

3.1.1 First generation: Vehicle dynamics stabilisation systems

One of the first, and probably the most widely used today, active safety system is the anti-lock braking system (ABS), which has been on the market since the 1980s.

3.1.2 Second generation: Advanced driver support systems

The second generation of ADAS was first introduced around 1990 and is mainly focusing on providing information and warnings to the driver, enhancing driving comfort, as well as improving energy efficiency.

The *information providing* active safety systems, also known as in-vehicle information systems, typically help drivers to navigate and inform them about road conditions, traffic environment, and vehicle status.

Substantially driven by the cost reduction of mobile devices, navigation systems using GNSS have become prevalent in today's vehicles. Due to the phenomenon of the "non-local risk", constituting that non-locals are involved in accidents more frequently than locals, navigation systems have safety implications. By aiding a driver in orientation, navigation systems hold the potential to reduce the driver's workload, allowing a greater amount of mental resources to be dedicated to the primary driving task, thereby reducing the risk of accidents due to inattention.

For warning providing systems, two types can be distinguished: imminent crash warning (ICW) and cautionary crash warning (CCW) systems. The ICWs are generally used in situations where immediate corrective action by the driver (such as braking or steering) is required. The CCW systems are viewed as useful in situations where immediate attention and possible corrective action by the driver is required. Systems providing functions such as forward collision warning, lane departure warning, drowsiness warning, parking assistance, belong to this category.

3.1.3 Third generation: Partial or full manoeuvring control systems

The latest generation of ADAS selects and controls trajectories beyond the current request of the driver.

The high certainty level required for such decisions can only be achieved with an interconnected set of sensors. Radar and camera technologies currently dominate the ADAS sector. Having complementary capabilities, an omission of one technology in favour of the other is not to be expected. Rather, data fusion strategies and joint sensor self-calibration will combine the strengths of both technologies. The short-term goal is to automate driving in selected situations. As an example, traffic jam assistance systems have recently been introduced based on radar and stereo cameras. Merging longitudinal and lateral control, these systems are designed for Automated Low Speed Driving on congested highways assuming full lateral and longitudinal vehicle control at low speeds. Maximum hands-off speed is still low (30 km/h), restricted to stop-and-go situations, but this function may eventually emerge towards automated highway driving.

Other extensions of current ADAS are soon to come. Examples include an assistant for collision avoidance by evasive steering assistants for the detection of oncoming traffic and pedestrians under adverse vision (weather) conditions, or assistants for improved intersection safety. Some of these systems require data exchange between traffic participants or with the road infrastructure, which is currently being investigated and demonstrated in field tests. This approach promises an extension of a system's boundaries with respect to the availability of information and the expansion of its function to an entire collective of road users allowing for assisted or automated cooperative manoeuvring.

3.2 Classifying road vehicle automation

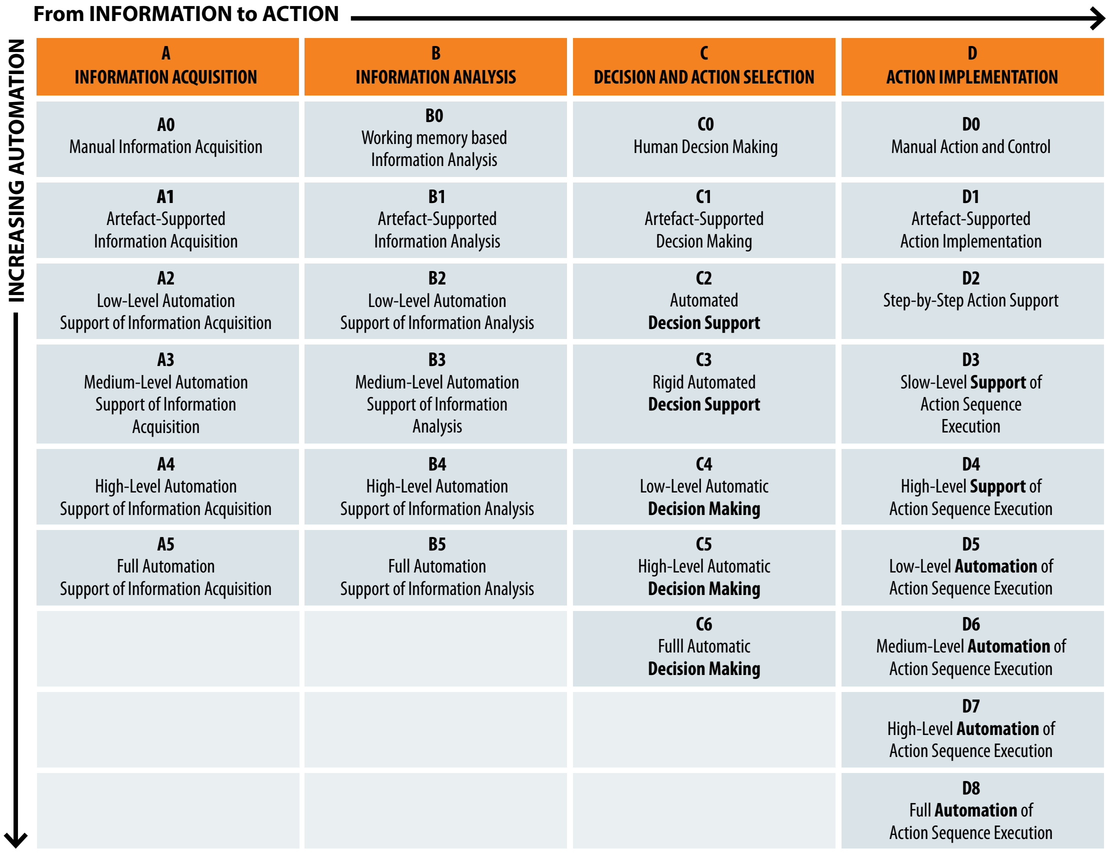
Currently, there is no globally accepted taxonomy for automation in road vehicles. There are many terms used such as self-driving, driverless, intelligent and robotic vehicles to denote different types of operation and control carried out by a technical system. Even a classification where control is divided into three degrees of automation (non-automated, semi-automated, and fully automated) is often used. However, the meaning of these terms and degrees is often unclear and varies depending on who is using them. Consequently, several attempts to establish a more generic classification have been made.

3.2.1 Issues regarding the classification

Classification of automated systems only with the respect to the degree of automation can be difficult and misleading. For example, such a classification does not show in which speeds a given system operates; a system can be of a certain automation level in one speed range, and of another level in another speed range. To capture the different characteristics of automated systems, a few different classification methods have been suggested.

In this report we focus on the ones used in LOAT, SARUMS, and MUNIN.

Level of Automation Taxonomy (LOAT) which shows the level to which each of the four basic cognitive functions (collect information, process information, make decisions and carry out the task) can automated. Automation scale information collection is for example from 0 to 5, while the corresponding scale for task execution goes from grade 0 to grade 8 (Figure 5). This classification is particularly suited for aerospace applications, but it is applicable in many other domains.



A INFORMATION ACQUISITION	B INFORMATION ANALYSIS	C DECISION AND ACTION SELECTION	D ACTION IMPLEMENTATION
A0 Manual Information Acquisition	**B0** Working memory based Information Analysis	**C0** Human Decsion Making	**D0** Manual Action and Control
A1 Artefact-Supported Information Acquisition	**B1** Artefact-Supported Information Analysis	**C1** Artefact-Supported Decsion Making	**D1** Artefact-Supported Action Implementation
A2 Low-Level Automation Support of Information Acquisition	**B2** Low-Level Automation Support of Information Analysis	**C2** Automated **Decsion Support**	**D2** Step-by-Step Action Support
A3 Medium-Level Automation Support of Information Acquisition	**B3** Medium-Level Automation Support of Information Analysis	**C3** Rigid Automated **Decsion Support**	**D3** Slow-Level **Support** of Action Sequence Execution
A4 High-Level Automation Support of Information Acquisition	**B4** High-Level Automation Support of Information Analysis	**C4** Low-Level Automatic **Decision Making**	**D4** High-Level **Support** of Action Sequence Execution
A5 Full Automation Support of Information Acquisition	**B5** Full Automation Support of Information Analysis	**C5** High-Level Automatic **Decision Making**	**D5** Low-Level **Automation** of Action Sequence Execution
		C6 Fulll Automatic **Decision Making**	**D6** Medium-Level **Automation** of Action Sequence Execution
			D7 High-Level **Automation** of Action Sequence Execution
			D8 Full **Automation** of Action Sequence Execution

Figure 5 A simplified version of the classification schema LOAT

The way LOAT is designed demonstrates the following principles:[24]

- An automated system cannot have one ‘overall’ level of automation as such. In other words, a statement about a level of automation for a system always refers to a specific function being supported;
- One automated system can support more than one function, each having a different level of automation;
- The description of each automation level follows the reasoning that automation is addressed in relation to human performance, i.e. the automation being analysed is not just a technical improvement but has an impact on how the human is supported in accomplishing his/her task.

It should be kept in mind that these generic functions are a simplification of the many components of human information processing. The functions are not meant to be understood as a strict sequence, but they may temporally overlap in their processing. From a practical point of view, the human may be performing a task that involves one or several functions. However, it is useful to differentiate the subtleties between the functions when one wants to identify how a specific automated system supports the human.3.2.2 Conclusion

In the absence of an international accepted standard, the LOAT-methodology seems to have an acceptance within the aviation industry and should therefor qualify for the maritime domain.

3.3 Trends in the automotive industry sector

- Google[25] has released its self-driving car into the wild and are soon bringing a self-driven truck on the streets. All other car/truck/buss/heavy tools manufacturers are moving into higher levels of automation and their goal is clear; autonomous vehicles that transport humans.
- Baidu has collaborated with BMW since 2014 on the development of driverless cars. In December of 2015, Baidu successfully tested its driverless car in dealing with complex road conditions on the 18.6 miles' route in Beijing, including U-turns, lane changes and merging into traffic from ramps[26]. Recently Baidu announced their plan to test driverless cars in the U.S. soon and introduce a commercially viable model by 2018[27].
- EU Truck Platooning Challenge[28] is a proof of concept where several lorries will use vehicle to vehicle communication to form a "train of lorries" with several independent trucks, using "slip stream" philosophy to reduce emissions by 20%.
- US Army[29] will try a similar set up as the EU Truck Platooning, but they will take it one step further by having autonomous trucks at the rear of the convoy.
- Scania[30] is launching remote/autonomous trucks for the Mining industry in a joint venture called iQMatic, with the Swedish Government and also involves researchers from KTH Royal Institute of Technology and Linköping University.
- Volvo Car Group[31] has after 9 years reached a point where they will release their autonomous IntelliSafe Autopilot equipped cars in metropolitan areas. The project is called Drive Me. Sets of 100 cars will run in Gothenburg, London and in China in the coming years.

3.4 Other industry (Minor): trains, drones.

Aviation drones
The U.S. Navy and contractor Northrop Grumman[32] are building an engineering development model of a sense-and-avoid (SAA) radar subsystem so that the drone can comply with International Civil Aviation Organisation (ICAO)[33] rules for international aerospace.

China's biggest internet retailer Alibaba Group Holding Ltd began actual deliveries-by-drone in February 2015 by delivering ginger tea packets to hundreds of customers. The trial lasted three days and was limited to areas within an one-hour flight of its distribution centres in Beijing, Shanghai and Guangzhou[34].

Helicopters
Sikorsky[35] retrofits old helicopters for remote operation and develops new systems.

Law enforcement
Swedish Police will use aerial drones from SAAB[36].

Firefighting
SAFFiR a humanoid fire-fighter for US Navy[37].

Port and Terminals
Automatic port terminals – DP World[38][39] container terminal 3 in Jebel Ali, Dubai. The big gantry cranes are remotely operated/supervised. And the container handling on shore is automatic like the ECT Delta[40] in the port of Rotterdam?

Remote operated air traffic control
SAABs[41] Remote air traffic control is based on several integrated and interacting subsystems. High-resolution images and other information are sent from a camera tower at the airport to a workstation in the remote control tower. This may contain several workstations where an air traffic controller can monitor two or three airports in parallel.

Search and Rescue and surveying ice situation.
Swedish Maritime Administration is participating in SAAB RPAS (Remote Piloted Aeroplane System) project that explores the new features that shipborne drones can deliver today.

Swarming robots are tested in domains such as SAR, mine sweeping[42] and so forth.

Railway and Metro systems
Automatic railways[43], already in 2002 Copenhagen has its unmanned metro system.

Humanoids
Atlas[44] created by Boston Dynamics started as a tethered robot but is now self-propelled and remote monitored with a high level of autonomy. It can move and interact freely in rural and suburban human environment.

4. Challenges in Autonomous Systems

Over the past 30 years, extensive work has been undertaken to create intelligent software using various forms of artificial intelligence, including agent-based reasoning, biologically-inspired reasoning, machine learning systems, etc. In addition, more automation software has been widely explored across industries in recent years, such as driverless vehicles. Under a foreseeable future, there will be vessels that are upgraded with new sensor technology and software to aid the OOW in the daily duties and enhance the watch keeping capabilities. Although it is likely that on-board monitoring and controlling will continue to be required but higher levels of automation and autonomy is on the horizon.

There are many challenges along the development of autonomous systems. Some of the fundamental challenges are, as for the automotive industry, what the different levels of automation stand for and how they will be compatible; what the systems would be capable of with higher level of autonomy and what will be the potential risks and hazards; how we are going to view so many concepts of automation and autonomous vessels around the world, etc. This chapter takes a foot hold in the SARUMS and MUNIN project and continues to explore the answers towards the challenges and risks from the existing studies.

4.1 Definitions of automation and autonomy

A number of related concepts and technologies may be drawn upon to deliver their conceptualisation and operationalisation in the case of MUNIN and SARUMS.

4.1.1 Automation

Automation has been applied in a wide variety of systems and generally includes the application of software to provide logical steps or operations to be performed. Traditional automation can be defined as that in which “a system functions with no/little human operator involvement: however, the system performance is limited to the specific actions it has been designed to do”[45]. Automation is applied to modern vessels for Dynamic Positioning, for guidance and navigating, the recent introduction of systems for energy efficiency in both bridge and ECR. These examples indicate that different levels of automation could be applied for the specific tasks under particular circumstances.

4.1.2 Autonomy

Recently, the term autonomy has gained favour in the computer science community. In general, it involves the use of additional sensors and more complex software to provide higher levels of automated behaviours over a broader range of operating conditions and environmental factors, and over a wider range of functions or activities. Autonomy is often characterised in terms of the degree to which the system has the capability to achieve mission goals independently, performing well under significant uncertainties, for extended periods of time, with limited or non-existent communication, and with the ability to compensate for system failures, all without external intervention. To achieve this goal, autonomy incorporates “systems which have a set of intelligence-based capabilities that allows it to respond to situations that were not programmed or anticipated in the design" (i.e., decision-based responses).

Autonomous systems have a degree of self-government and self-directed behaviour because the software approaches may extend beyond computational logic-based approaches to include computational intelligence (e.g., fuzzy logic, neural networks, Bayesian networks) in which intelligent agents "learns by doing" (i.e. machine learning). In conjunction with data mining process based on big data, high autonomy has the possibility to enable proactive actions under changing circumstances.

Autonomy can be thought of as a significant extension of automation in which very high-level mission-oriented commands will be successfully executed under a variety of possibly not fully anticipated circumstances, much as we currently expect intelligent humans to operate when given adequate independence and task execution authority. Autonomy can be considered as well designed and highly capable automation.

4.2 System capabilities and control philosophy

In terms of SARUMS[46] and MUNIN[47] project, despite the fact that one is for defence/military domain and the other is for pure civilian application, the control philosophy is rather similar. MUNIN lacks of what SARUSM defines as fully autonomous UMS. A vessel in the MUNIN project was designed to always be an autonomous unmanned vessel, which is primarily controlled by the autonomous ship controller on-board and monitored by the Shore Control Centre.

4.2.1 SARUMS

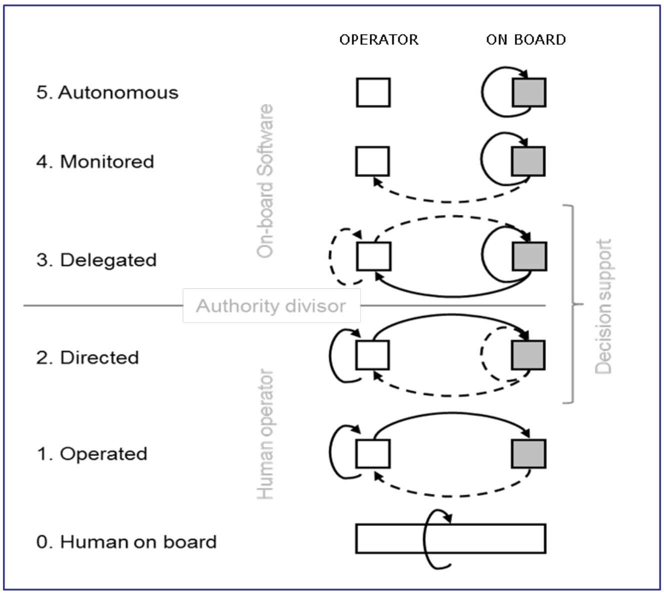


Figure 6 Five methods for controlling functions SARUMS

An illustration of the five methods for controlling functions is presented in Figure . These control methods range from traditional manned on-board control (method 0) to Autonomous control (method 5). White squares represent human operators. Grey squares represent on-board system/software. Arrows between squares represent data/information flowing between units. Filled arrows indicate data/information based on initiative and authorisation. Dotted arrows indicate data/information of less importance for the course of events. Arrows circling around a square represent reasoning and cognitive capability/function internal to the human operator or the on-board system. The majority of UMS are designed to combine several of these control methods and for different functions, subsystem or components. The method of control is also likely changing over time and with operational circumstances. Therefore, the choice of an appropriate control method should be based on understanding and definition of UMS functions, operational context and the consequences of changing conditions to the communication capacity. Manned on board operation is defined as method 0 (zero). The following sections will describe the five control methods to some detail.

4.2.2 MUNIN

An unmanned ship can be achieved by a combination of remote, automatic and autonomous control. Figure 6 illustrates the automatic and autonomous control possibilities for such a system, where the MUNIN focus is represented by the shaded area.

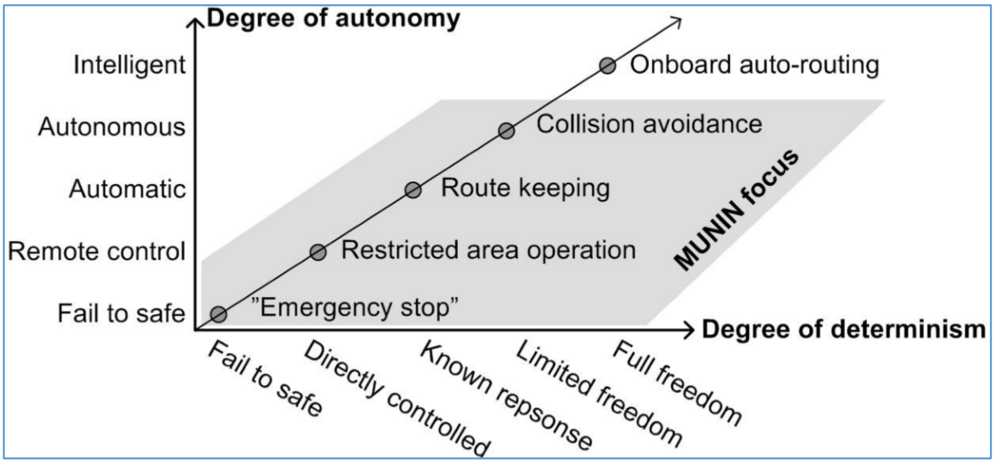


Figure 6 Degree of autonomy versus determinism - MUNIN

The figure also illustrates how the conceptual increase in autonomy from a simple and robust fail to safe mechanism via automatic, autonomous and up to "intelligent" control reduces the "determinism" of the control system. While fail to safe mechanisms typically will take the ship to one or a few possible "safe" states, e.g., dead in water, more complex control algorithms have an increasing wider range of outcomes. The text to the right of the plot points give examples of such functions or outcomes.

In the context of the MUNIN project, autonomous control is defined as the ability to make complex decisions that may not be easily described through mathematical or logic formulas, but which still are constrained within certain predefined limits. An example of this may be autonomous collision avoidance constrained by the limitations of international conventions such as International Regulations for Preventing Collisions at Sea COLREGS. This could be achieved through the use of automatic control routines supplemented by other technologies from the artificial intelligence domain.

If no constraints are defined, the system could be called "intelligent". This implies that the system has full freedom to take actions within its area of expertise and it cannot prior to the action fully know what the possible outcomes of the decision will be. However, when the system is encountering situations the original designers had never considered, the ship could send alarm to the Shore Control Centre to allow human operators to override the autonomous ship controller to conduct remote control through teleoperation. In such cases, the autonomous vessels would be in the semi-autonomous form (employing some automated functions such as follow certain waypoints) while the human operators serve as the final decision makers in the system.

When remote control is included, the MUNIN on-board decision system may be illustrated as in Figure 7.

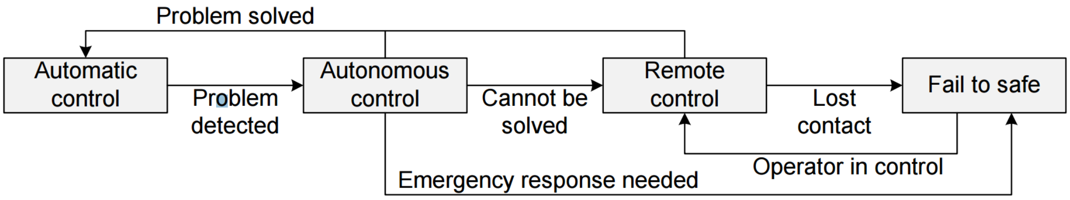


Figure 7 On-board decision flow in MUNIN

MUNIN would normally rely on automatic and fully deterministic control functions to run the ship. However, various sensor systems will be needed to detect problematic situations such as unexpected objects in the sea, dangerous weather conditions or danger of collision. If an unexpected situation occurs, an autonomous control module will be invoked trying to remedy the situation within its given constraints. If the system cannot achieve this, it will request support from a remote operator or start a fail-to-safe procedure if the operator is not available.

Referencing to Figure 8, it can be seen that MUNIN proposes to exchange intelligent control with human intervention and use fail to safe as a backup when timely operator response is impossible. Properly implemented, this type of autonomy will reduce the need for human supervision while maintaining a high and well defined level of safety. "Intelligent control" will normally be less desirable as operational limits by definition cannot be guaranteed. However, a major challenge lies in the reliability of device sensor systems and the stability of the data communication channel between ships and shore so that all relevant dangerous situations could be detected on-board and perceived remotely.

4.2.3 Automation taxonomy

As described earlier there are several different types of automation levels and the way forward is not clear. Most probably there will be different “classes” of automation that “allows” various levels of autonomy. From the Offshore segment parallels can be found when it comes to Dynamic Position of vessels. To put it simple:

Level 0 and Level 1
A single point of failure can lead to loss of the vessels capability to maintain its position.

Level 2
A single point of failure should not lead to loss of the vessels capability to maintain its position

Level 3
As with level 2 it should also withstand loss of one engine room, DP controller due to fire or flooding.

Depending on the type of operation, different levels of capabilities are demanded. Deliver a container to a platform could be level 0/1 at some regions of the world but diving with humans are normally considered to be a minimum class 2 or 3 operation.

Using this analogy, we foresee vessels with different levels of automations, capable of different types of operations. Not only the different types of control as mentioned in 4.2.1 and 4.2.2 but within these levels.

Using the Offshore and automotive analogy again:

Automatic level 1
The vessel is manned, having no redundancy and only integrations of sensors. S & A software might be present but only as advice to OOW in it decision making
- A single point of failure could set the vessel off course.
- The vessels bridge should be manned at all times

Automatic level 2
The vessel is manned, redundant systems, S & A software is integrated in the watch system.
- A single point of failure should not set the vessel of off course.
- The bridge could be left unattended for shorter times if these criteria's are fulfilled (for example)
" Hs below 2m, Current less then 1kts, Wind speed below 10m/s, Visibility over 2NM, and the SCC is manned"

Automatic level 3
The vessel is short manned, redundant systems of all components, S & A software is integrated in the watch system. The Avoidance system might alter the vessels course to take evasive actions.

- A single point of failure should not set the vessel of off course.
- The bridge could be left unattended for longer times if these criteria are fulfilled
" Hs below 2m, Current less then 1kts, Wind speed below 10m/s, Visibility over 2NM, and the SCC is manned"

As it is showed in this case, the automatic level could be leveraged depending on the dynamics of the environment. It further drives the system requirement analysis to explore the functional capabilities that an unmanned autonomous vessel should have in order to manage such complexity. A holistic approach is therefore required to address such issues.

4.2.3 S/T/O Approach

A systematic analysis approach using Strategic, Tactical & Operative is introduced for further functional analysis and modularisation analysis. There are different models of how to arrange the S/T/O, it appears that the most common are vertical hierarchal placing Strategic at the top, Tactical in the middle and Operational at the bottom. Executional is sometimes used as a synonym for Operational.

Strategic level
At the upper level, strategic decisions affect the general resource management for human operators and automated systems. It is particularly important in the planning stage. It includes the goals, control strategy, resource allocation, system configurations and threshold settings, and risks/cost management strategy. These can directly influence the choice of route and possibly transportation mode (fast/slow steaming). One of the major considerations in strategic level is about the integration of monitoring human operator and functioning complex automation and system optimisation, especially the management issue of the growing disparity between control and accountability. While autonomous systems can operate with reliable and consistent performance in certain constrained situations, humans are more capable of dealing with unanticipated situations. As the capabilities of autonomy increase, (including the ability to handle a broader range of situations and uncertainty) it is anticipated that the need for human intervention will decline, however, it is likely that some level of human-system interaction will continue to be required for the foreseeable future for the complex context that the vessel is situated in.

For example, depending on the situation around the vessel and the environment it is operating in, different levels of autonomy (higher or lower level) might be allowed. One could pose questions as follows under such dynamic circumstances: Is the vessel sailing on the high seas, in the middle of the Atlantic? Is it approaching the coastline? Is it on its approach to the harbour basin? Is the traffic situation relaxed, safe water for navigation and good weather conditions? Can we allow the bridge to be unmanned under these circumstances? Or does it have to be more specific conditions such as; "Hs below 2m, Current less then 1kts, Wind speed below 10m/s, Visibility over 2NM", can we then allow the bridge to be unmanned? There are many uncertainties that can influence the optimisation of the automated system and that need to be managed from the strategic level in a holistic manner. The strategic views can also enable different stakeholders to recognise the system's flexibility and vulnerabilities in order to optimise the management work in a distributed way.

Tactical level
Compared with Strategic level, tactical decision is done in shorter time frames,

minutes, depending on the vessels speed/traffic situation/safe navigational water. The tactical level is where the OOW and/or automated systems plan manoeuvres within traffic, decide to do the alteration of vessels course, reduce speed when approaching the coast, and prepare to cross a traffic separation.

Operational (execution) level
The operational is “spilt second” decision based on the decisions made at the tactical level. It responds to information coming from the tactical level, so rather than ‘seeing’ the surroundings, the layer executes the orders sent from the tactical level, which has the ‘full picture’, sends orders to the autopilot, engine conning and monitors the execution of these orders.

Corrections/Faults/Error handling
Fault handling is handled at both Strategic and Tactical level, if an issue is detected by the tactical layer, and the steering machine #1 is not responding. The tactical layer might start steering pump #2 on the steering machine and try again to alter course after ~10s. The strategic layer monitors the environment and looks for a “safe haven” such as anchorage areas and alerts the supervisor (Captain or Shore Control Centre) if the problem is not solved by the action that the Tactical layer took.

To exemplify what the different layers stand for in a maritime domain, some examples are:

Strategic indication
If the automatic system can choose from two alternative routes to get from A to B, say either use Kiel Canal or go around Skagen, that’s a Strategic decision the system has to handle.

Tactical indication
A vessel is approaching us on starboard side and it has a course and speed that results in a steady bearing, a close quarter situation is arising, even a collision is possible. We are the give way vessel, should we reduce speed or alter our course to starboard to give way?

Operational indication
The Tactical decision was to alter the course to starboard. An order of a 30dgr course change is sent to the auto pilot. The system is monitoring that the turn is initiated and completed as expected.

4.3 Risks/Hazards and Use Case Study

Fully autonomous system is not utopia, but still distant. Through this report a foreseeable scenario is several autonomous systems that will work synergistically with the crew as a part of an effective human-autonomy team where functions and situation awareness flow smoothly, simply, and seamlessly between them. Bearing this in mind, the Use cases indicate the challenges and the gaps that need to be filled with necessary functions and modules. In an effort to identify the functions/functionality needed to have safe automation of vessels, this report has chosen to analyse use cases that was raised during a workshop involving Stena, Wallenius, Swedish Maritime Administration, Chalmers, Lighthouse and Viktoria.

These use cases are shortly listed as:
- Collision avoidance
- Grounding
- Environment
- Piracy/unsafe waters for crew/personnel
- Detecting small object on the surface in harsh conditions

4.3.1 Collision avoidance

A general term for this function is “Sense and Avoidance”, the system has to sense (detect) the obstacle, crossing vessel etc. The detected “object” is processed in Sense-software and categorised, more sensors data can be over-laid/fusioned (Radar ARPA, AIS etc.) and a better situation awareness can be achieved. The “object” can then be matched towards strategic data such as– ECDIS sea charts to determine if it is a buoy, kayak, or just noise in a sensor.
There are lot of flaws in the current ECDIS system that needs to be addressed before it can be used as input for full autonomy, the quality of the majority of charts is way too low, zone of confidence e.g. “garbage in = garbage out” the quality of geospatial data is not detailed enough.

Then the Avoidance-software can do several things depending on the levels of autonomy:

Low
It can send a signal or indication to the OOW, or raise an alarm if is a critical situation or the OOW has not responded to the detected object in a certain time-span.

Medium
On top of the Low-level functionality, several scenarios are possible. The Avoidance-software can suggest counter actions to the OOW, if a Shore Control Centre is available, it can flag the situation to the operator at watch.

It could have the permission to sound the general alarm on the vessel and even to alter the vessels course if no action is taken from the OOW on the vessel.

High
At this level, the Avoidance-software informs the OOW and/or the SCC what it intends to do and if no one invokes, it performs the evasive manoeuvre. When the situation is clear, it returns the vessel to the original route.

Full autonomy
The SCC is informed about the situation and the counter action. No one is “supposed” to invoke, so the system does not wait for any replies. But a SCC still has the possibility to invoke if they find it necessary.

Support systems in Strategic Tactical Operational levels:

	Current	**Needed**
Strategic	ECDIS, Electronic Nautical Publications (eNP), VHF, AIS, Optical, Radars	- Integrated ECDIS to ensure safe waters for navigation - Integrated eNPs for updates - Automatic plotting systems based on several different types of position fixing methods - Voice recognition system - …
Tactical	X & S -band ARPA Radar, AIS	- Multiple layers of sensors, optical, microwave, audio, hydro-acoustic - SW with fusion, sense-categorise-avoidance capability. - Integration with ECDIS that ensures a "safety boundary" of the vessel, depending on current situation, such as navigational safe waters, speed, traffic situation
Operational	Auto Pilot with follow track functionality	- Redundancy of systems,

4.3.2 Grounding

The Use case of Grounding is similar to Collision Avoidance, off course groundings happens for different reasons, but often as a result that of lack of situation awareness. The vessel ends up on a course that will take it too close to shore, aiming straight for a submerged rock etc.

Loss of situational awareness can also be a result of many factors. But an automatic system that Sense that the vessel has a dangerous trajectory and the functionality to Avoid the grounding regardless of it is an operator error on the bridge or sub-system malfunction is the goal.

	Current	**Needed**
Strategic	ECDIS, eNPs	Integrated ECDIS with eNPs
Tactical	X & S -band ARPA Radar, AIS	- Multiple layers of sensors, optical, microwave, audio, hydro-acoustic - SW with fusion, sense-categorise-avoidance capability. - Full integration with ECDIS that ensures a “safety boundary” of the vessel, depending on current situation, such as navigational safe waters, speed, traffic situation
Operational	ECDIS with grounding detection. It raises alarm with both look ahead* function and when crossing the safety depth contour*.	Redundancy of system

* Both these are Operator settings in an ECDIS system, and recent incidents’ (Costa Concordia, Ovit...) show that they are not correctly configured and not correctly used for monitoring the planning and execution of the voyage. They should also (among other settings) be updated depending on the current position/environment that the vessel is facing.

4.3.3 Detecting small object on the surface in harsh conditions

New technologies, new SW for sensing small object (see through noise…)
New radars, new optics, fusion technology, categorising

	Current	**Needed**
Strategic	OOW, Binoculars, Radars, VHF, NAVTEX, GMDSS, ECDIS, eNPs	If the OOW is to be "obsolete" a system that can draw conclusions from a NAVTEX message "…partly sunk containers in the area of …" that extra attention or there is a higher likelihood that that "echo" or noise on a system could be a partly sunk container.
Tactical	OOW, Binoculars, VHF, X & S -band ARPA Radars, AIS	- Multiple layers of sensors, optical, microwave, audio, hydro-acoustic, - New types of microwave and optical sensors - SW with enhanced sense-categorise-avoidance capability. A SW that can adapt its search & categorising patterns based on information from the Strategic layer.
Operational	OOW, Binoculars, X & S band ARPA Radars	- Sensors that has the ability to track specific targets, not as the ARPA does today where a course alteration makes the ARPA data useless for several minutes.

4.3.4 Environment

The Higher level of safe automation will reduce the likelihood for the above mentioned use cases (Collision Avoidance and Grounding) These are rare occurrences within a well-managed shipping sector, but never the less WHEN they occur the consequences are large in terms of human/animal/environment perspective and costly.

Vessels with higher level of autonomy will reduce the likelihood of the occurrence by having systems constantly aiding the human operators to make proper decision making and keeping the whole system in safety.

4.3.5 Piracy and unsafe waters for crew

Piracy or "hacking" can both be a physical danger as well as a virtual attack that jeopardises the vessel and its cargo, possible leading to loss of lives, environmental impact and total loss of vessel and cargo.

New technology may enable vessels that are short manned and even unmanned while it is transiting unsafe waters for the crew. Or the crew can safely operate the vessel from a citadel with remote assistance from a SCC.

But a key factor is to have a *system with resilience and robustness,* this can be achieved in many ways but in general it is about distributed and isolated systems with redundancy. So if one system is under attack, there are barriers that prevent the attack from spreading to all systems before the attack is detected.

4.3.5.1 Piracy

As mentioned in the article from Business Insurance, will an unmanned vessel be less of interest to piracy then a manned vessel?

Some specific cargo might have a higher value than human lives to some people, but there seem to be few known cases of large ransoms paid out for the cargo.
For general cargo vessels, it seems to be the crew that the kidnappers are interested in. So a vessel with “normal” types of cargo without crew should be lesser of a target for piracy. But as fewer manned vessels pass the pirate infested waters, they might try to detain unmanned vessels for ransom.

4.3.5.2 Cyber Piracy

A vessel that has an uplink or is fitted with the possibility for remote operation, always has a possibility for a cyber-attack. But even a manned vessel is possible to attack from remote, or disable. MUNIN has mainly identified the critical parts of the infrastructure and indicated possible technical means to achieve a sufficiently high security and safety level. Cyber security is also a threat to conventional shipping so recent developments in IMO and international standards will also be of use to unmanned ships. This issue has been investigated and it is clear that while this is a challenging issue, it is not insurmountable.

This calls for different strategies and probably different types of redundancy within the systems. For example, if the S & A system detects an abnormality, say that the voyage suddenly changed from 7 days to go to all stop at a new waypoint 12 NM away, some logic in the system should detect this and raise alarms. If the SCC can’t be reached it should have “fall back instructions” to continue on its intended voyage in a safe way as it was planned before the sudden change of WP. The “faulty” system should be disregarded.

When designing the vessels redundancy, one way of reaching higher level of resilience is to use different vendors for the primary/secondary systems. If a bug is discovered in one vendors’ system, the other system should have the ability to detect anomaly and “call home” to SCC or take over.

There are so many scenarios that need to be addressed here but lessons learned from other mission critical systems should be investigated further.

4.3.6 Maintenance issue

Vessels will still need maintenance, even if they are modern, state of the art. This is not only an economical issue but also a technical issue and perhaps one of the most challenging issues of creating an unmanned ship for longer voyages. Solutions would be focusing on the methods to increase the reliance of the technical systems, such as the idea to have an extra vessel, so that one is “dock” for maintenance while the other keeps the business going, and then they rotate the vessels, or design of on board systems for easy maintenance and accurate monitoring of equipment status, as well as redundant power generation, distribution, propulsion and steering plus automated fire extinguishing systems in all relevant areas.

This is a question that needs more attention and of course it will vary depending on the type of vessel, type of cargo, type of route etc. MUNIN results are very encouraging, but inconclusive in its details. One will need a full design to do the necessary assessments of reliability and availability. However, it seems clear that good technical solutions are available. Controlling the cost of these solutions is the main challenge.

And so on, all depending on the type of environment the vessels are sailing in and the capability of the systems.

4.4 Identifying needs and priority areas

Based on the above Use cases, the need for further development on current technology or new hardware for sense/detection/tracking is needed.
From the automotive industry[48] we can see that the demand on the hardware that runs the Sense/Categorise/Avoidance software are high.
Sensor technology that will be installed on vessels has to withstand harsher environment and endure longer period's service before maintenance can be performed. An alternative is extra layers of redundant sensors.

There are main modules in the autonomous ship system in MUNIN: advanced sensor system, bridge automation system, engine automation system, autonomous ship controller (ASC) and shore control center (SCC). Their relations are embodied by the following structure.

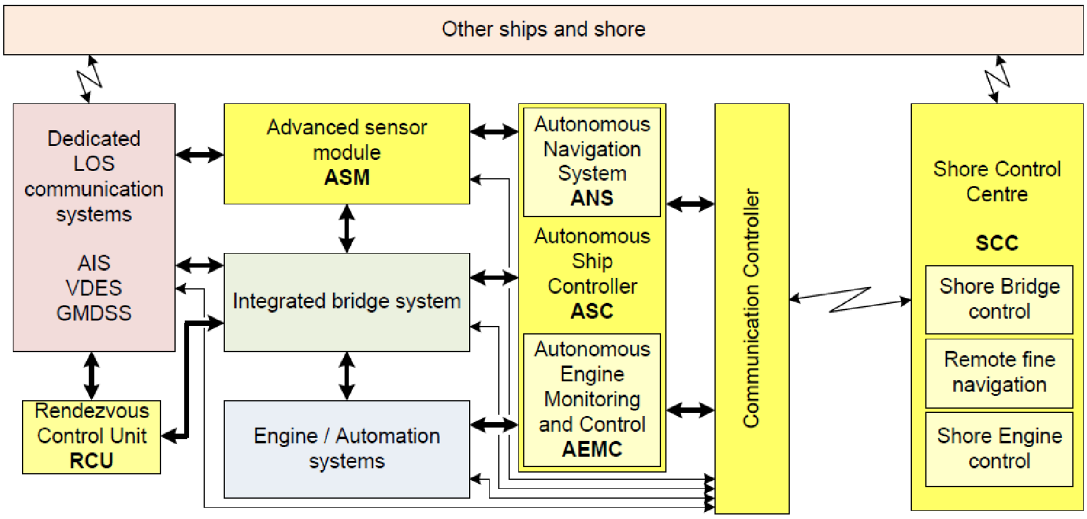


Figure 8 Overview of the high level modules from MUNIN Final Report[49]

These modules were tested in the MUNIN projects. However, the need for enriched situational awareness, either it is used for Decision support or Autonomous tasks, follows the golden rule: Garbage in – garbage out. If we can't "see" our surroundings, what good are all other systems? From another perspective, the sensing quality is directly influencing the performance of autonomous navigation module. Therefore, we focus primarily on sensor modules and automation navigation modules at the current stage as priority areas. The description of these modules and their major results in the project is listed below:

Advanced sensor module (ASM)

ASM is developed to maintain an automatic lookout for traffic and obstacles as well as lookout for environmental conditions surrounding the vessel, so that an unmanned vessel can comply with COLREG, minimise the risk of collision and ensure safe voyage. The ASM fuses all individual raw sensor data and then extracts the required information from that data base with the help of sensor and feature processors (so called Sensor Fusion Approach) to build a world model around the vessel. The prototype integrates marine radar, AIS receiver, and general nautical data via NMEA as well as electro-optical sensors. The module hypothesis is that "A Deep- Sea Navigation System can autonomously navigate a ship safely and efficiently along a predefined voyage plan with respect to weather and traffic conditions".

Results from MUNIN[50]: The TRL status of ASM is 4-5. It is important to note that the only reason for the negative results was insufficient range. The ASM <u>was able to detect</u> and <u>classify the different objects</u>, <u>but at a shorter range than specified in the sub hypothesis</u>. Hence, proving the hypothesis true should be possible, if solutions for the shorter range are identified. Such solutions could be higher accuracy on detection sensors or slower speed on the unmanned vessel. <u>Alternatively, better radar antennas than those used during the test can also further improve test results.</u>

This is **not as safe as a human**, and certainly not good enough for a 200m ~60 000DWT vessel. But this was conducted on "off the shelf" X-band radars and software from APTOMAR[51] and it highlights one of the gaps that needs to be filled, high performance sensors designed for this task, mature sense/categorising/avoidance technology and functionality need to be developed and thoroughly tested. Again, the defence industry has a solution, but it is not "SOLAS" approved for example the Kelvin Huges SharpEye[52] pulse Doppler radar seems to drastically improve the detection capability of ship mounted radar systems

Building vessels with these capabilities such as redundant power and propulsion, bridge-systems is already done in the Defence industry and Oil & Gas industry. Using for example LNG and hybrid power solutions should ensure safe long hauled operations.

Automation navigation system (ANS)

The Autonomous Navigation System (ANS) is basically only active in the autonomous operation mode. Its task is to navigate the UAS safely from boarding point to boarding point. Besides using existing functionalities of Integrated Bridge Systems, it comprises the tasks Conduct weather routing, Determine Ship dynamics, Control buoyancy and stability, Avoid collision and Manage alarm and emergencies. Most critical hazards for navigation in deep sea areas are collision and foundering. Thus, the ANS prototype mainly comprises those two functional areas. Safe weather routing is ensured by anticipatory route optimisation using the A*-algorithm and emergency handling procedures, while the collision avoidance algorithm works with a formalised description of COLREG. The module hypothesis is that "A Deep- Sea Navigation System can autonomously navigate a ship safely and efficiently along a predefined voyage plan with respect to weather and traffic conditions". It is an important module in the autonomous bridge above(Figure 8)

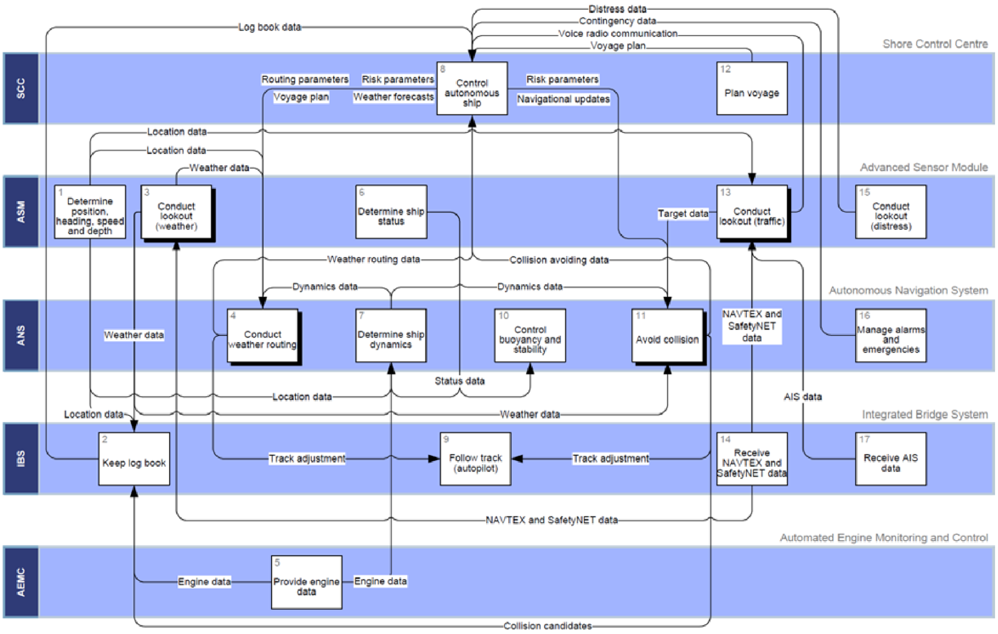


Figure 9 Process Map of the Autonomous Bridge from MUNIN Final Report

Results: The validation tests give it a TRL status of 3-4. It shows that navigation should be quite simple in normal cases when everything goes as planned. For more detailed validation of the Collision Avoidance module, large scale analyses are aspired. AIS recorded data might be a possible validation baseline, however certain missing information like the prevailing weather conditions in the specific area make a simple ex-post validation complicated. Furthermore, the decision criteria need to be further enhanced to make the concept applicable to other vessel types than the chosen bulk carrier in MUNIN and especially the assessment of COLREG-conform collision avoidance in restricted visibility is aspired. In the long run, general accepted operational criteria and/or performance standards for the use of such assistance systems should be developed by additional test campaigns. For further assessment of the WR-System, in-situ tests with sea state radar equipment is necessary, as the ship handling simulation test can't cover all relevant harsh weather effects sufficiently

4.5 Improvement needed to bridge the gap

To generalise a little, all this can be done today with small upgrades on hardware and software making them redundant and compatible (standards are under development).

But several obstacles remain, and by looking at the use cases in this report, target detection, categorising and decision support or avoidance need high performance sensors. Again, it reveals the gaps that we need to fill with priority in the development process of the test-bed.

1. Better HW in sensors OR high end HW made available for the civil market
2. Improvement of software but to validate the improvements,
3. Test-beds need to be available and put in to the “wild”

Autonomous vehicles of today, Google etc., run in “controlled” environments such as limited city areas, weather limitations, specifically test areas.

To rise above these limitations, the system must be put to test, and the Sense and Avoidance functions must prove to be reliable under all types of conditions.

5 Integration of human elements in system design

Research conducted on the integration of human elements and the technological system provides a firm foundation for understanding the challenges involved in creating a resilient human-technology system that must function in complex and unpredictable environment. As it has been mentioned earlier, automation has provided the capabilities to perform routine tasks in a consistent, efficient, and reliable manner. However, most automation today still can only operate well in the situations for which designers and programmers have designed and programmed. Automation today still needs human intervention to handle complex situations, particularly unexpected situations, as humans are not rule-based as software but depend on pattern cognition, mental model and sense-making, which enable human operators to react in a resilient manner to cope with unexpected situations. However, humans are not as good at monitoring automated process, processing large volumes of data, or sustaining attention for long periods of time. The system design shall fully consider the advantages and disadvantages of different operating agents in the system and incorporate human centred design to overcome some of the typical the human factors issues stated as below.

5.1 Situation Awareness and Out-of-loop Syndrome

Situation awareness (SA) is being aware of what is happening around the operator and understanding what that information means now and in the near future. SA is a goal-directed concept, meaning that the attentional resources are used to capture the elements that are relevant for the goals of tasks. It would be very critical for the operators to stay on the right track towards their goals when they are constantly monitoring automated process. A key challenge is the out-of- the-loop syndrome. While automation can reduce the cognitive workload in normal routine tasks, it can undermine SA by making the operators mistakenly believe the system in control is in one status/mode when it is actually not. This could be very dangerous if the operator needs to verify or diagnose the real problem when there are unanticipated incidents/signals coming from the system a.k.a. false positives.

The maintenance and development of SA is so important for the interaction of human agents and automation system that it has two very significant indications in the system design:

1) Information should be clearly provided to the operators as salient feedback via usable interfaces.

2) The system that require extensive human monitoring should counter the human “vigilance-decrementing” affect and involve operators in an active manner.

Future systems will need to pay significant attention to the development of autonomy approaches that emphasise maintaining required levels of situation awareness and truly support users for decision making. The system design is a critical factor to influence the operator’s understanding and dynamically constructing their mental model of the complex world.

5.2 User-Centred Design

Traditionally, systems have been designed and developed from a technology-centred perspective. It is common to see that the sensors and modules are developed to perform certain functions. In the face of changing tasks and situations, the operator is called upon to find, sort, integrate, and process loads of information that is needed from all that which is available, leading inevitably to a cognitive barrier for the human operators to make efficient and safe decisions considering the human has certain information processing bottlenecks. As the display of data or the modularisation in these systems is centred and organised around the technologies producing them, it is often scattered and not ideally suited to support human tasks. A considerable amount of additional work is required to find what is needed and extra mental processing is required to calculate the information the operator really wants to know.

As an alternative to the downward spiral of complexity and error induced by a technology-centred design philosophy, the philosophy of user-centred design is a way of achieving more effective systems. User-centred design challenges designers to build the interface around the capabilities and needs of the operators, rather than displaying information that is centred around the sensors and technologies that produce it.

A user-centred design approach is required in order to integrate the gigantic amount of ship information in ways that fit the goals, tasks, and needs of the users. This philosophy is not born primarily from a humanistic or altruistic desire, but rather from a desire to obtain optimal functioning of the overall human–machine system. With the introduction of user-centred design, errors can be reduced and productivity be improved without requiring significant new technological capabilities.

The key essentials of early involvement of users in user-centred design fashion would be:
i. Organise technology around the user’s goals, tasks, and abilities.
ii. Organise technology around the way users process information and make decisions.
iii. Technology keeps the user in control and aware of the state of the system instead of introducing automation-induced error or design-induced error and tag them as *Human Error*.

6. Socio-technical System View

6.1 New synergies needed for multiple stakeholders

In 2015, the MUNIN projects explored and analysed the implications of the use of unmanned autonomous ships and introduction of SCC on existing maritime stakeholders by interviewing total 22 people from 14 different related organisations[53] :

- Swedish Ship-owners' association
- Union of Marine Officers
- IMO representative
- Marine Engineers (Chalmers senior lecturer)
- Mona Lisa 2.0 vs. MUNIN
- Coast Guards
- Port Authority
- Insurance Company
- Ship Building (Chalmers senior lecturer)
- Fire Fighters
- VTS
- Pilots (Gothenburg)
- Maersk
- Navy

In general, the concept unmanned autonomous vessels means opportunities and uncertainties/risks to many of the participants. On the one hand, it received many positive replies concerning the problem of fatigue and fatigue-related accidents. On the other hand, the majority believed that this type of change needs the emergence of new synergy effects among different stakeholders, which are hard to predict in a clear form now when the development of autonomous unmanned ships is facing so many uncertainties at this stage.

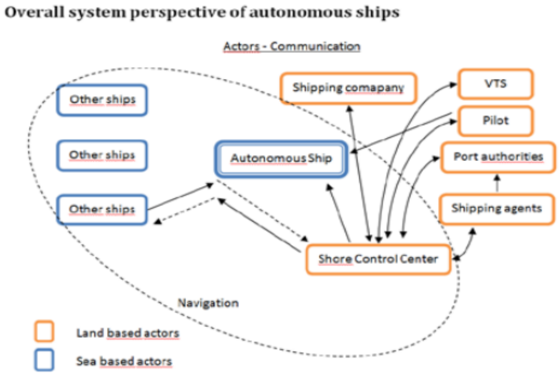


Figure 10. The Overview of the Shore Control Centre with a complex, socio-technical system in MUNIN

For example, it is unclear which geographical locations of ships the SCC will monitor, which makes it difficult to describe the future cooperation and integration of SCC and VTS. The communication between SCC, ships and various organisations is considered as the critical part to form the robust synergy for the goal of safety.

Gothenburg is mentioned as example because they have VTS, pilots and port control (facilitators) within the same premises, which brought great benefits even if they have different owners, both private and governmental. The development of SCC will contribute to a positive development for the traditional shipping industry but also to new business areas such as offshore and wind power industries, even though it remains unclear in this initial phase, according to respondents.

In terms of the legislation, which in many cases was outdated and impeding the development of shipping industry according to the respondents, IMO is often mentioned as the most significant player in the legislation on the international scene, along with the changes on the national level. All respondents agree on that there are many issues to be resolved through cooperation and that the authorities have a responsibility to begin changing the framework for shipping to allow a development to take place in a broader and faster manner. Some respondents, including Maersk, mention that one must first see the development turned into reality before any real answers can be delivered. The synergies and financial gains would be critical for the speed of the implementation.

To sum up, the regulatory authorities need to be better informed about the concept and the emerging technologies, while organisational synergies should not only further reduce implementing costs, but allow for more efficient and emerging e-navigation strategies. The interviews also revealed that technologies not yet developed remain both an opportunity and a barrier to acceptance of this concept. *These findings significantly indicate the need for a industry-driven national initiative and drives the innovation in a “out of the box” fashion to fill the gap.*

6.2 Emerging service and business

The available navigational assistance services and business opportunities have also been investigated in the MUNIN project (See Deliverable of MUNIN)[54]. There is a wide range of services that can be shaped and developed to accommodate the characteristics of the autonomous unmanned shipping in the future, such as Navigational Assistance Service, Traffic Organisation Service, Local Port Service, Service Pilotage, Tele-medical Advice Service, Ice Navigation Service, Real-Time Hydrographic and Environmental Information Services, Search and Rescue Service, Armed Security Service. Specifically, potential business opportunities in the segment of ocean and coastal shipping services, offshore supply services like windfarms or oil platforms, concerning condition-based maintenance and repair services, shore-based navigational services have been extensively discussed in the deliverable reports in the work package 10 of the MUNIN project. A SWOT analysis was conducted to describe the business opportunities in unmanned autonomous shipping in the report as well:

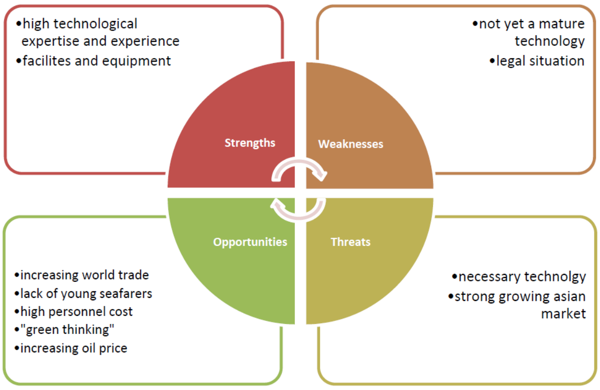


Figure 11. A SWOT analysis for European unmanned autonomous shipping in the MUNIN project

From these reports we can estimate that the crews may still remain on-board short term but the total number would gradually be reduced with the increasing level of automation introduced on-board to provide integrated navigational service and decision support. Long term, the operation costs can gradually be reduced with system efficiency being increased by migrating services to the shore side, which is assumed to have the most abundant resource. The cost-benefit assessment from the MUNIN project provides a reference model concerning the business opportunities and potentials in autonomous shipping.

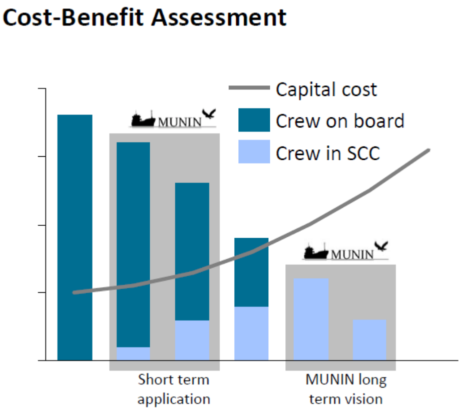


Figure 12. Cost-Benefit Assessment in the MUNIN project[55]

6.3 Manning, competence and training

This is a new era of shipping, but old traditions will last for while, vessels will still be manned for a longer period, but the trends within other transport sectors is a reduction of human labour. But the future training needs might not be the same as STCW Manila 2010 that we have today. There are important questions to answer, such as how to keep the skills of the operators at the highest level without having to send them to sea, or what types of operator we are going to need to accomplish the tasks with more automated technology.

6.3.1 Short term perspective

Small crew on-board (higher level of automation on the vessel) optimised maintenance crew with nautical competence (STCW Manila 2010) to take action if needed.

Besides, search and Rescue (SAR) operations at sea depend on the use of ships in the vicinity of an accident. Ships in the accident area are coordinated by the appointed SAR centre and an assigned On Scene Commander (OSC). The introduction of manned vessel with higher level of autonomy would be of great value to participate not only in search but also rescue of persons and vessels in need, considering the modern state-of-the-art sensor technology could help the vessel be more vigilant in a way that no current manned ship could be. This would require the reduced ship crew to be well-trained in SAR operations and using the system in active detection of abnormal situations.

6.3.2 Long term perspective

Similar to a VTS, for the SCC sufficient staff must be available and suitably qualified and trained for performing the required tasks, taking into consideration the type and level of services to be provided in conformity with the regulations on the subject.

Since we do not know the reliability of these vessels but we expect them to be even more reliable than manned vessels, it is reasonable to suggest one operator can monitor multiple vessels. For example, the self-driven metro line in Copenhagen has 4 operators in the control centre watching 34 trains.

If unexpectedly more than one vessel would need attention at once, then a back-up crew could be called in. The back-up crew is on stand-by in case their skills are required. In the foreseeable future, this crew is suggested to be comprised of at least one supervisor, one supervisor's assistant and one engineer. They are fully trained on the SCC activities they don't have to be mariners. Note that a capable master mariner does not necessarily mean he is capable of being a SCC operator, just as the case in the aviation industry – being a well-trained pilot does not make him or her a perfect air traffic controller because of the difference in the sets of skills that are needed.

The number of vessels one operator can handle depends on the position of the vessels (open sea in this case), weather conditions (night, day, storm) and status of the ship (autonomous operation, autonomous control, remote control and fail-to-safe).

6.3.3 Retraining

Higher use of simulator retraining would be required. Parallels to the aviation industry are clear, where it is compulsory to use simulators to retrain the pilots regularly.

The simulator set up could be both what is called a "full mission bridge" (that is used today for training nautical officers and engineers) and a full mission SCC so the actions in the SCC can be replayed in the full mission bridge, so that the OOW (SCC Operator) can see how its action will look in real life and vice versa.

7. Conclusion and Recommendations

To summarise a quotation from Mica R. Endsley, Chief Scientist United States Air Force[56], says a lot of the road ahead for automation and autonomy:

> *"In this first volume, a summary of the challenges of automation and autonomy for airman interaction are presented, based on some four decades of experience and research on this issue. These include (1) difficulties in creating autonomy software that is robust enough to function without human intervention and oversight, (2) the lowering of human situation awareness that occurs when using automation leading to out-of-the-loop performance decrements, (3) increases in cognitive workload required to interact with the greater complexity associated with automation, (4) increased time to make decisions when decision aids are provided, often without the desired increase in decision accuracy, and (5) challenges with developing a level of trust that is appropriately calibrated to the reliability and functionality of the system in various circumstances. Given that it is unlikely that autonomy in the foreseeable future will work perfectly for all functions and operations, and that airman interaction with autonomy will continue to be needed at some level, each of these factors works to create the need for a new approach to the design of autonomous systems that will allow them to serve as an effective teammate with the airmen who depend on them to do their jobs."*

Incremental approach
Both SARUMS and MUNIN show the way forward, if the Guidelines from SARUMS are re-worked with civilian shipping in mind, remove weapons and include passengers and crew as types of cargo, it appears to cover most aspects that is needed to be explored and documented. Merge this with the work done in MUNIN and its predecessor Raven, a complete (or as good as it gets to have in advance of a project) is achieved. And the work can begin as proposed in chapter 7, with an incremental approach, by "retrofitting" some suitable vessels with hardware and software, giving them "Decision support" features seems to be the first step.
As the functionality matures, and the OOW can trust the system to relieve him or her for shorter periods, and as "proof of concept" is established and legislations has caught up with technology, the bridge might be left to SCCs and automatic systems for longer periods.

Vessels solely designed for unmanned operations will emerge soon, at first they might be used in convoys, guided by a manned vessel. Then as this technology matures and can show fault free track record, new building of autonomous vessels will take off.

Annex 1

Relating projects around the world

A short list of some identified projects

Retrofit of vessels

BEA
http://www.baesystems.com/en/new-unmanned-boat-technology-set-to-enhance-naval-operations#

Decision support and autonomously systems

Buffalo Automation Group
http://www.buffautomation.com/

Automatic vessel concepts

ReVolt (N; DNV-GL, NTNU)

KRISO (S. Korea)

AVUSI (USA)

Smart Vessel (China; LR)

AAWA (FI; RR)

UK MI (UK)

Legislation, class societies, industrial cluster

UK Marine Alliance
http://www.ukmarinealliance.co.uk/MAS

MASRWG (UK)

SARUMS (EU) part of the EDA UMS project

Classification Societies

DNV – GL
https://www.dnvgl.com/technology-innovation/revolt/index.html

Lloyds Register
http://www.lr.org/en/marine/

Companies

BAE UK
http://www.baesystems.com/

Google and its car USA
https://static.googleusercontent.com/media/www.google.com/en//selfdrivingcar/

Kongsberg Group, Norway
http://www.vestviken24.no/vv24naringsliv/kongsberg-gruppen-vil-teste-forerlose-skip/s/5-83-31715

Rolls Royce, UK
http://www.rolls-royce.com/media/press-releases/yr-2015/pr-02-07-15-rolls-royce-to-lead-autonomous-ship-research-project.aspx

ABB Marine, CH
http://new.abb.com/marine-ports

CMG, S
http://www.cgm.se/

Equipment / Functionality

Microwave – Optics
Guidance
http://www.guidance.eu.com/rangeguard

ECDIS
TOTEM
http://www.totemplus.com

Academia & Research

Scandinavia
NTNU
https://www.ntnu.edu/amos/centre-for-autonomous-marine-operations-and-systems

KTH
https://www.kth.se/en/ees/forskning/strategiska-forskningsomraden/intelligenta-transportsystem/smart-mobility-lab

CTH
Maritime Human Factors and Navigation, including human factor research for autonomous systems design & development

https://www.chalmers.se/en/departments/smt/organisation/Maritime%20Human%20Factors%20and%20Navigation/Pages/default.aspx

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