Global Marine Technology Trends 2030

Autonomous Systems

Lloyd's Register

QINETIQ

University of Southampton

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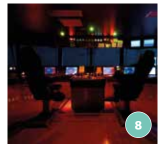
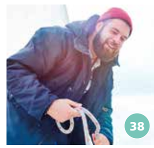
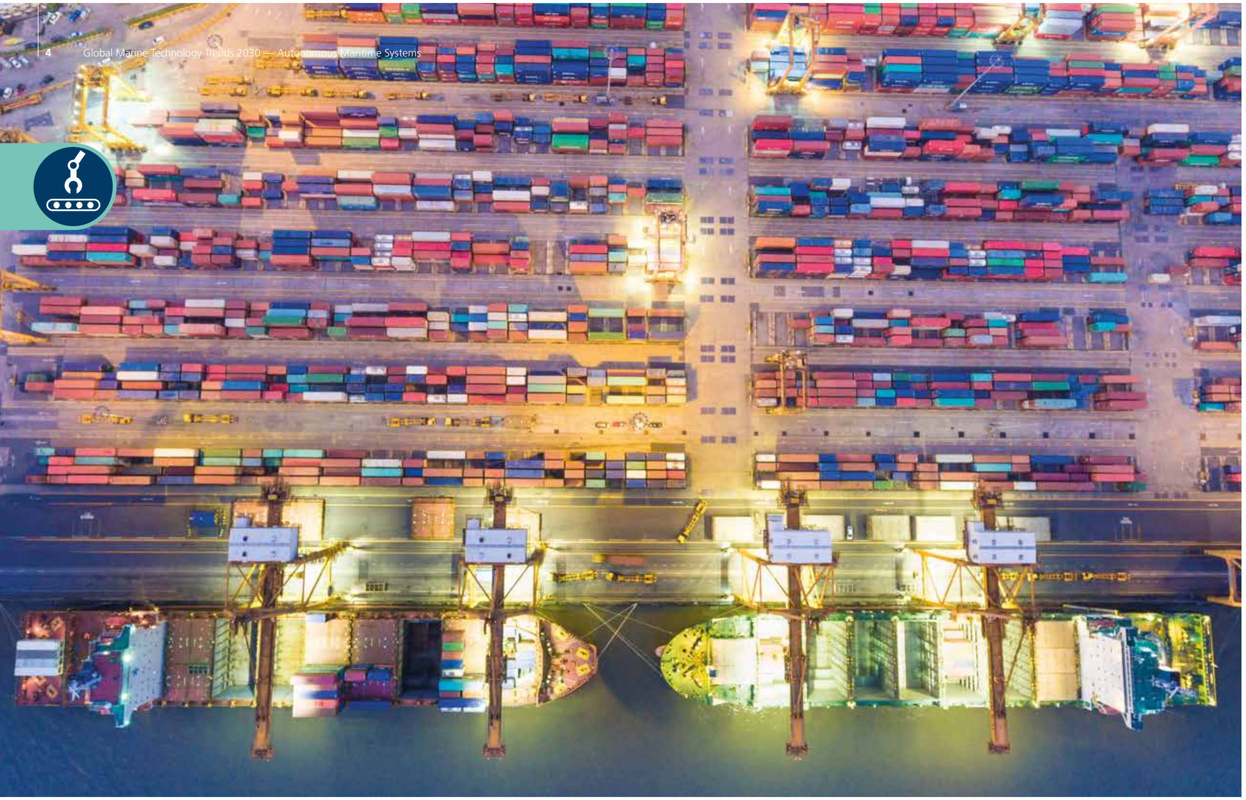






Foreword

In 2013 Lloyds Register, QinetiQ and Strathclyde University published the ‘Global Marine Trends 2030’ (GMT2030) report addressing the future of the marine and maritime sector. Using a scenario-based approach it presented three scenarios that offered differing perspectives on potential futures:

- Status Quo
- Global Commons
- Competing Nations

The publication highlighted the potential impact of technology on the future, a theme taken up in greater detail in the Global Marine Technology Trends 2030 (GMTT2030) Report produced by Lloyds Register, QinetiQ and University of Southampton in 2015. GMTT2030 used Horizon Scanning techniques to look at 18 technologies which could influence the future of the Marine and Maritime Sector in three areas:

- Commercial shipping
- Naval
- Ocean space sectors

In the relatively short period since we published GMTT2030 a number of developments have brought some of the issues raised in our previous publications to the fore:

- The apparent slowing down of globalisation caused in part by BREXIT and the new US Administration’s agenda.
- Rapid developments in consumer technologies, such as Artificial Intelligence (AI), personal and multimedia solutions, along with widespread digitalisation of businesses and economies.
- The start of a new industrial revolution (Industry 4.0) that has the potential to disrupt traditional businesses, markets and economies.

As a result of these global changes we believe that the Competing Nations scenario, described in Global Marine Trends 2030, is more likely. Given a Competing Nations context, what will the fourth shipping revolution look like? We will explore this over the following pages.

With the benefit of hindsight, we now see that in some areas our perspectives on emergent technologies were somewhat conservative. In this publication we are focussing on one such area of technology. Autonomy and autonomous systems – these have accelerated to an extent where it may be possible to deliver credible solutions within the next couple of years, enabled by the breadth of capabilities and adjacent technologies emerging from commercial and consumer worlds.

We offer our perspectives on the future of autonomy, its impact and the timescales.

1st

- Mechanization
- Steam power
- Water power

2nd

- Mass production
- Assembly line
- Electricity

3rd

- Computer
- Automation

4th

- Cyber physical systems

“We stand on the brink of a technological revolution that will funadamentally alter the way we live, work and relate to one another.”

Klaus Schwab
Founder and
Executive Chairman
World Economic Forum

Photo: Drop of Light / Shutterstock.com

Part 1: Maritime Autonomy

Where are we now?

Levels of Autonomy
It is worth noting that many definitions of Autonomous Systems exist. LR has set out the 'how' of marine autonomous operations in a new ShipRight procedure guidance[2].The guidance describes autonomy levels (AL) ranging from 'AL 1' through to 'AL 5' denoting a fully autonomous system with no access required during a mission and no on-board override possible.

Given the media focus on autonomous cars you would be forgiven for thinking that we are more likely to see self-driving vehicles on our roads before they reach the high seas. The reality is quite the reverse. Automation, robotics and artificial intelligence are already transforming most sectors. Technical feasibility combined with compelling economic advantages, such as improved efficiency, reduced operating and labour costs, is driving adoption especially in aviation, engineering and construction companies, manufacturers and healthcare providers who are all investing heavily.[1]

Autonomous technology is poised to reshape the maritime sector with crewless vessels; small craft are already developed and in service with larger vessels under development. It is time for the maritime industry to accept autonomy is coming, and to understand how autonomy will shape future industry and how best to exploit it.

The growth in Maritime Autonomous Systems over the period since the publication of GMTT2030 has exceeded our expectations. Major initiatives by organisations, such as Rolls Royce, Japanese shipbuilders, and Norway-based Kongsberg (in partnership with Yara, a Norwegian chemical company) have all revealed plans to develop all-electric and autonomous container ships by 2020. There is a fierce race to be first across the finish line. Other organisations throughout the world are developing complementary, even competing concepts and systems to support unmanned operations, coupled with infrastructure initiatives, including autonomous ports and high bandwidth communications.

Labour and costs are key factors driving this pace of change in maritime. A shortage of skilled people is accelerating the move to unmanned and autonomous ships. Navies world-wide are investigating how to substitute labour with autonomous technology in the face of significant budget cuts. Where labour costs are low, for example shipping containers, technology that requires substantial upfront investment will be less attractive. Each sector will need to review whether autonomous systems will prove to be an economical choice, though the cost-benefit ratio will shift as technology becomes cheaper and more widely used.

There are growing numbers of small-scale autonomous vessels being operated across a wide range of applications, such as:

- Ocean science
- Naval operations
- Surveying and exploration

Such vessels, operated in small fleets (swarms, although there is an argument that suggest they should be called pods), are now routinely employed by the National Oceanography Centre (Southampton, UK). Their MASSMO (Marine Autonomous Systems in Support of Marine Observations) events bring together the largest fleet of marine robotic vehicles simultaneously deployed in UK waters, operating together to collect a range of environmental data.

The Royal Navy conducted Unmanned Warrior 16. This event successfully demonstrated the latest unmanned system technologies, including air, surface and sub-surface vehicles and sensors, from a wide range of nations and technology providers. Key applications included Mine Countermeasures and GEOINT (Geospatial Intelligence).

On the regulatory front, the UK Maritime Autonomous Systems Regulatory Working Group (MASRWG) is attracting international interest. They have developed a Code of Conduct for Maritime Autonomous Surface Ships (MASS) and are following this up with a more detailed Code of Practice for MASS. On the international front they provided the draft of the request for a scoping exercise which was submitted by the Maritime & Coastguard Agency to the Maritime Safety Committee (MSC) of the International Maritime Organisation. The scoping exercise was accepted into the MSC work programme at MSC 98 in June 2017.

We see 2017 & 2018 as the turning point in the maturity of maritime autonomy and unmanned vessels.

Within this insights report we seek to provide a more in depth view of the developments and challenges in Marine Autonomy and stimulate debate about wider employment, skills and socio-economic aspects of their application.

[1] http://usblogs.pwc.com/emerging-technology/robotics/
[2] http://www.lr.org/en/news-and-insight/news/LR-defines-autonomy-levels-for-ship-design-and-operation.aspx

Part 2: Key Challenges

Technology is advancing rapidly and many are eager to embrace the benefits promised by new developments in Information and Communications Technologies (ICT). Whilst these changes enable alternative operational paradigms, such as the autonomous operation of systems and assets, it is important to understand the broader implications and challenges associated with such apparent opportunities.

Sometimes, in the enthusiasm to adopt 'domestic' or 'pocket' technologies it is easy to overlook such considerations in a business environment, even in the generally conservative maritime industry. However, in progressing towards autonomous operation, stakeholders become more dependent on 'the system' for safety- and business-critical functions. It is therefore, increasingly important to consider the system-related challenges in the broadest and holistic terms.

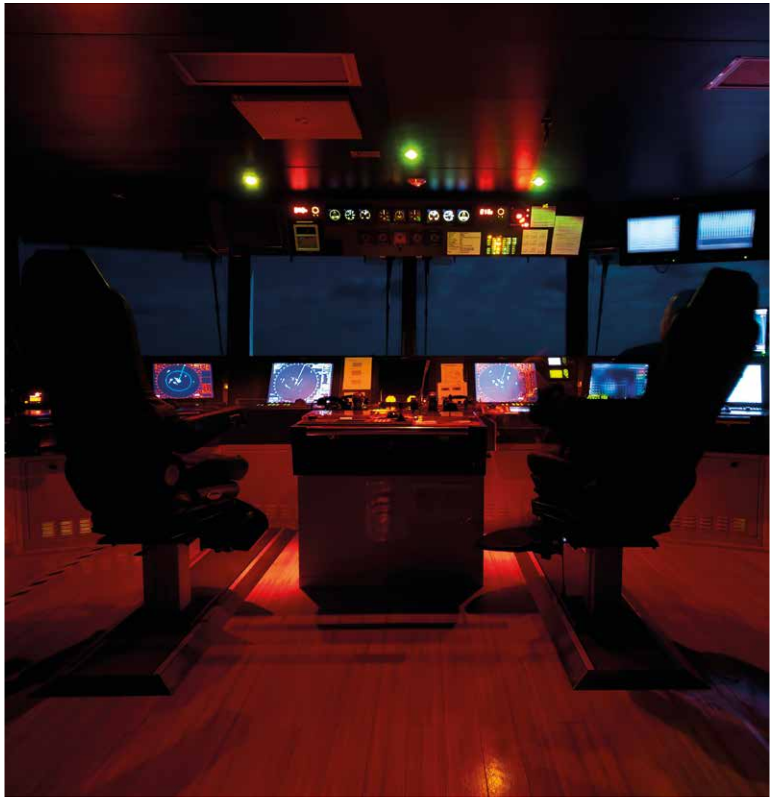
Central to the autonomous system is the technology and the functionality that it offers, but alongside that there needs to be consideration of:

- How the technology is developed, validated and applied in an autonomous system.
- Challenges associated with technology insertion and integration with existing assets.
- Associated risks, dependability/reliability in operation and overall system safety justification.
- Affordability and whether the technology represents a compelling infrastructure investment case.

As if these issues were not challenging enough, they need to be addressed alongside the prescriptive rules and standards to which the maritime industry is accustomed, without delaying innovation unnecessarily.

Beyond the engineering challenge, the effective application of autonomous technology will depend upon the environment in which it is deployed. It is not just the physical maritime environment that needs to be considered. The business, regulatory and legal environments all present challenges perhaps as great as the development and application of the technology itself.

For example, the regulatory environment has evolved over time, underpinned by the underlying assumption that manned operations are the norm and with the role of on-board crews explicitly specified in globally applicable



statutory conventions. As a result, the legal liabilities around the operation of manned vessels are well established. This is not so for unmanned or autonomous operation. This will throw up challenging issues, such as defining who the 'operator' of a fully autonomous vessel is. Is it the asset owner or the manufacturer who created the autonomous system that displaced the traditional crew?

There are then the socio-technical challenges of autonomous systems. The developers of autonomous systems often view people as fallible and seek to design them out of the system; replacing human weaknesses with automation strengths. This approach often fails to consider the limitations of autonomous systems and indeed the fact that designers themselves are fallible.

More broadly, even if an asset operates autonomously itself, what are the requirements for people throughout the asset lifecycle? And what are the implications for the associated industries' workforce and skills base? It is one of the ironies of automation that when advanced automated systems start doing the work of people, then the need for people often increases along with the requirement for them to be more highly skilled.

Societal acceptance and consent is also a consideration, particularly during the early phases of design and development whilst the technology is still 'novel'. The concept of autonomously-acting, crewless vessels may be one of the greatest challenges of all, especially in a 'mixed environment' where some vessels operate under manual control (e.g. pleasure craft) and others operate autonomously (e.g. shipping). Ideally the goal would be to design the seamless integration of human and technological capabilities, manned and unmanned, into a well-functioning, effective and efficient maritime ecosystem.

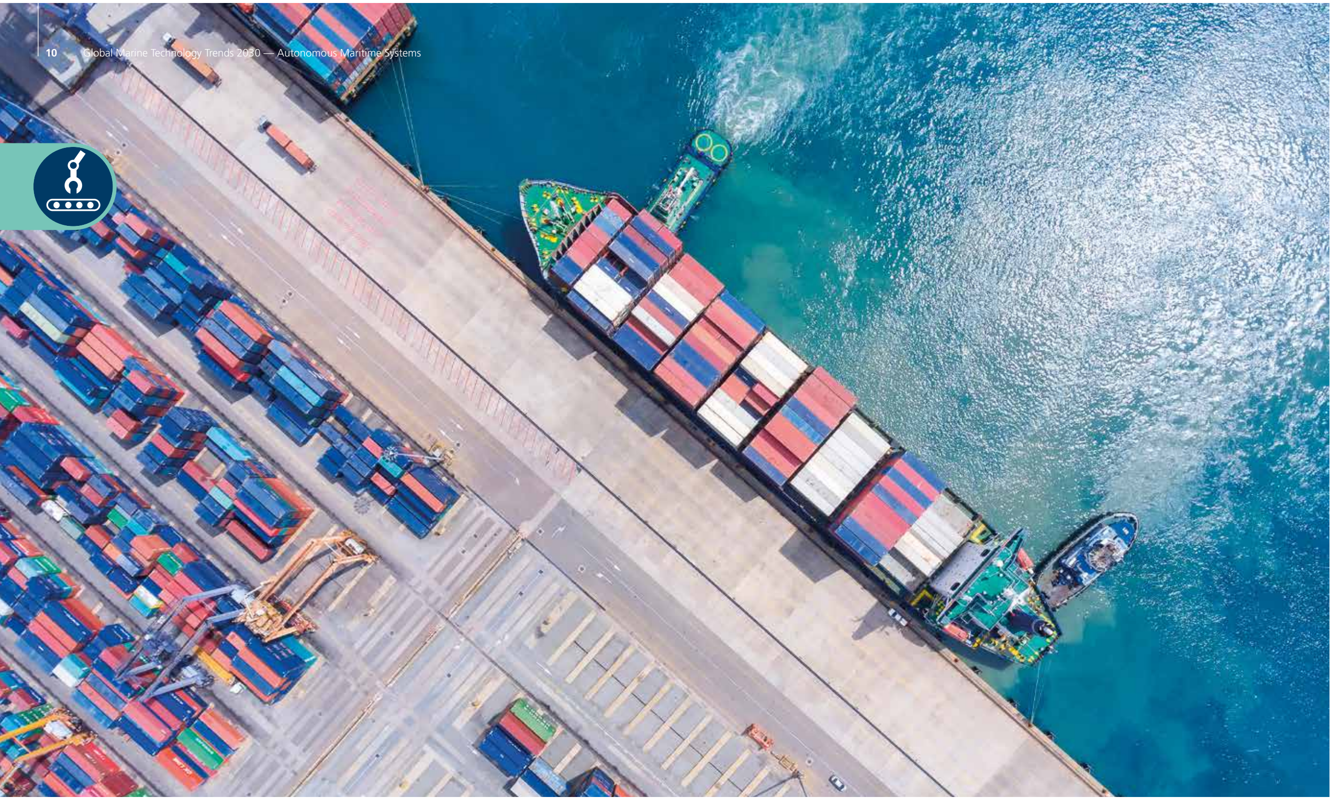
These challenges will undoubtedly mean that maritime autonomy will fundamentally disrupt existing operating paradigms, supply chains and overall business models related to maritime procurement and operation. It is important to recognise that we are not just talking about the application of commercial off-the-shelf ICT on-board existing vessels!

In the following sections, we provide a view on all of these challenges in greater detail, examining the underlying issues and suggesting how they may be overcome in time.

"The more we depend on technology and push it to its limits, the more we need highly-skilled, well trained, well-practised people to make systems resilient, acting as the last line of defence against the failures that will inevitably occur."[1]

Baxter et al., 2012

[1] Gordon Baxter, John Rooksby, Yuanzhi Wang, and Ali Khajeh-Hosseini. 2012. The ironies of automation: still going strong at 30? *In Proceedings of the 30th European Conference on Cognitive Ergonomics (ECCE '12)*, pp.65-71, ACM: New York, USA. DOI: https://doi.org/10.1145/2448136.2448149.



Part 3: Technology

Introduction

In this section of the report we take a more in depth look at what we see as the key emerging technologies driving the development of autonomous systems.

In GMTT2030 we identified autonomous systems as a rapidly expanding and diversifying area of growth driven by the consumer sector. They have widespread application across all aspects of our lives. Increasingly it is permeating areas such as automotive, home systems, the financial sectors and healthcare. In this section we specifically look at:

- **Artificial intelligence** – a series of closely entwined technologies which we believe will transform maritime operations and underpin autonomous systems.
- **Sensors and situational awareness** – technologies that are fundamental to the operation of autonomous systems, creating the required levels of situational awareness for their safe operation.
- **Connectivity** – developments in connectivity, communications and information exchange which will provide a catalyst for the future by enabling the digitisation of the marine environment.
- **Cyber security** – looking at the risks and mitigations for the protection of systems in ‘cyberspace’.
- **Energy management and sustainability** – seen as a limiting factor in the development and widespread deployment of autonomous systems.

We think that these are the key technology areas critical to the development of maritime autonomy. This is not a complete list. More important than the development of ‘individual’ technologies, will be our ability to:

- Integrate these technologies to create a maritime ‘Internet of Things’ (IoT).
- Exploit innovative combinations of technology to drive new business models and applications.
- Combine new technology with effective ways of working and personal lifestyle choices.

3.1 Artificial Intelligence

What is the technology?
There are many definitions offered for Artificial Intelligence (AI) although what generally is thought of as 'AI' appears to change as the field advances. The well-known technology analyst company Gartner has characterised AI as "a technology approach to enable machines to do what we formerly thought only humans could do".[1] However, for the purposes of this paper, we thought it apt to ask Microsoft's AI-enabled virtual assistant, Cortana,[2] for a definition. Cortana described AI as "the simulation of human intelligence processes by machines, especially computer systems."

AI is therefore, by necessity, a very broad field and includes much of machine learning, such as deep neural networks, also cognitive computing and many aspects of natural language processing. AI is a key enabler for so-called smart machines and intelligent systems, and its importance in the context of this paper is that it enables machines to exhibit autonomous behaviour, where little or no human intervention is required.

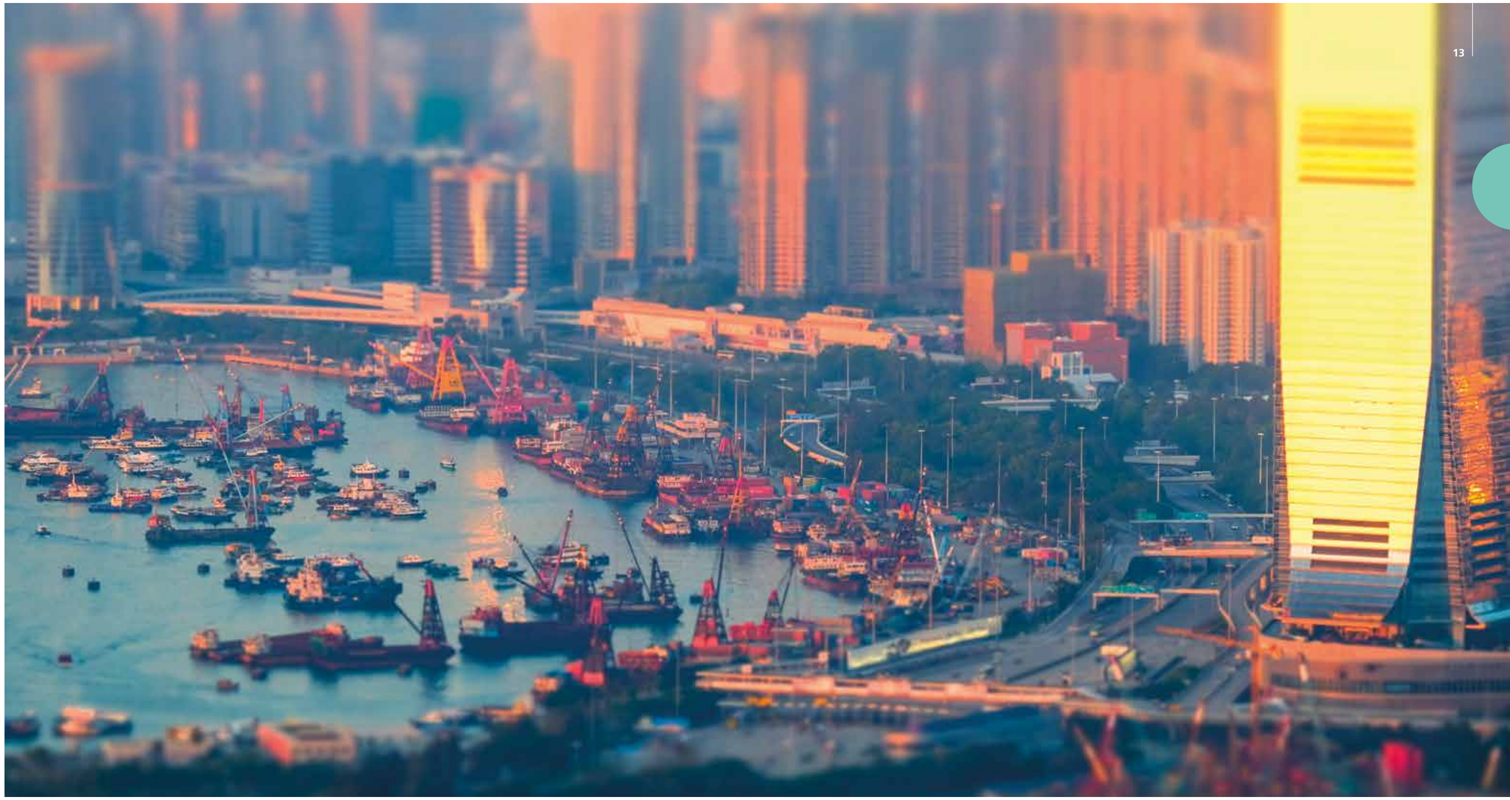
Why it is important
There is now little doubt that AI will eventually impact almost every facet of our everyday lives. AI has already become pervasive and is now used in many of our daily routines without us actually realising it. For example, you will find it in:

- Smartphones (as virtual assistants, e.g. Siri and Cortana)
- Purchase prediction (where retailers such as Amazon anticipate your next shopping need)
- Smart homes (where AI can learn your behaviour patterns and adjust lighting and heating accordingly)

AI is enabling machines to move into roles and conduct tasks that we only previously thought humans can do and in the course of doing so, is solving problems in novel ways.

In the commercial maritime sector AI is already enjoying considerable investment and interest. One of the key areas where it is receiving particular attention is automation. It

[1] A.W. Linden & T. Austin, Artificial Intelligence Primer for 2017, Gartner ID: G00318582, 3 Feb 2017, www.gartner.com/doc/3587258/artificial-intelligence-primer-.
[2] Microsoft Cortana, https://www.microsoft.com/en-gb/windows/cortana
[3] Bourbon joins Automated Ships Ltd and Konsgberg to deliver ground-breaking autonomous offshore support vessel prototype, www.bourbonoffshore.com/en/bourbon-joins-automated-ships-ltd-and-kongsberg-deliver-groundbreaking-autonomous-offshore-support, 11 Jul 2017.



is envisaged that the recent investment drive by companies, such as the Bourbon Offshore Consortium that includes Automated Ships Ltd and Kongsberg Maritime,[3] to develop unmanned shipping will be further enabled by placing AI applications on-board. Taking a ship, oil rig or any other ocean-going platform, AI has the potential to support both manned and unmanned options. If manned, conversational AI (through software entities such as virtual assistants) will be able to support command decisions by passing live, contextualised information to the crew on demand. If unmanned, an AI will have to use compiled information passed through machine learning algorithms in order to make a decision and then act upon it in a timely and correct manner, enabling autonomous operations. In fact, AI has already been used in some defence research work and proven to be an effective tool in recognising and categorising objects at sea to then allow for the correct application of the COLREGs and track planning.

Critical enablers for AI are the ever increasing computer processing power, connectivity and technologies such as voice and image recognition. It provides the ability for speed of analysis and decision making that far surpasses that of people. Natural language query and answer systems such as IBM's Watson continually improve and advance, challenging experts and attracting public interest. Major areas of application include share trading as part of the FinTech revolution.

Whilst AI plays a key role in enabling autonomous systems, it is important to note that these systems are highly dependent on a number of other technologies. Chief amongst these are:

- Networks and communications enabling connectivity
- Sensor technologies enabling situational awareness
- Security technologies enabling cyber security, and
- Energy management and sustainment

These areas are covered later in this paper.

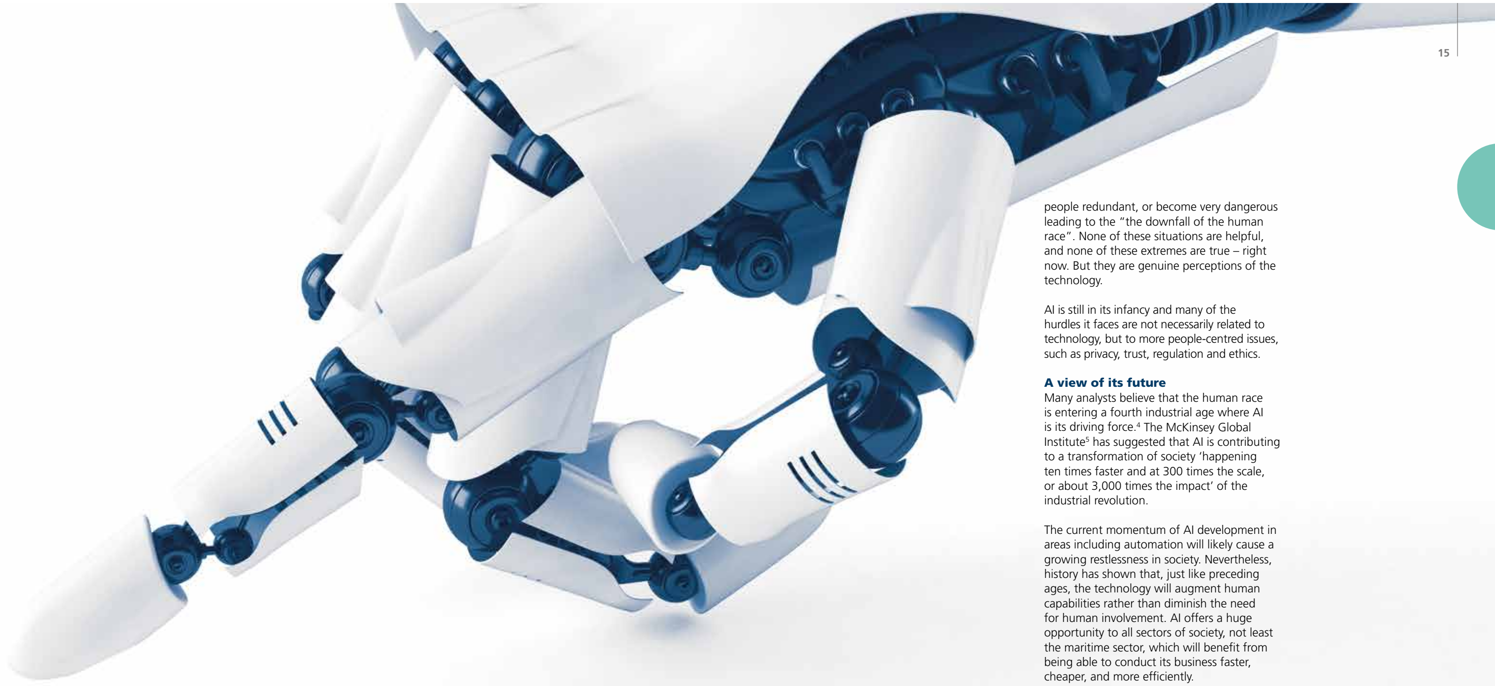
How it is changing and key challenges

AI is currently experiencing massive growth, fuelled by investment from nearly all the major industry vendors, including Google, Apple, Microsoft and Amazon. This trend will continue, but those seeking to adopt the technology and master its potential opportunities should be wary of its challenges.

People often regard AI as the 'silver bullet' that will solve all of their problems, make

[4] J. Aswani, The Fourth Industrial Age, Artificial Intelligence and Enterprise Class Drones, 3 May 2017, http://kespry.com/blog/the-fourth-industrial-age-artificial-intelligence-and-enterprise-class-drones.

[5] R. Dobbs et al., The four global forces breaking all the trends, McKinsey Global Institute, April 2015, www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-four-global-forces-breaking-all-the-trends.



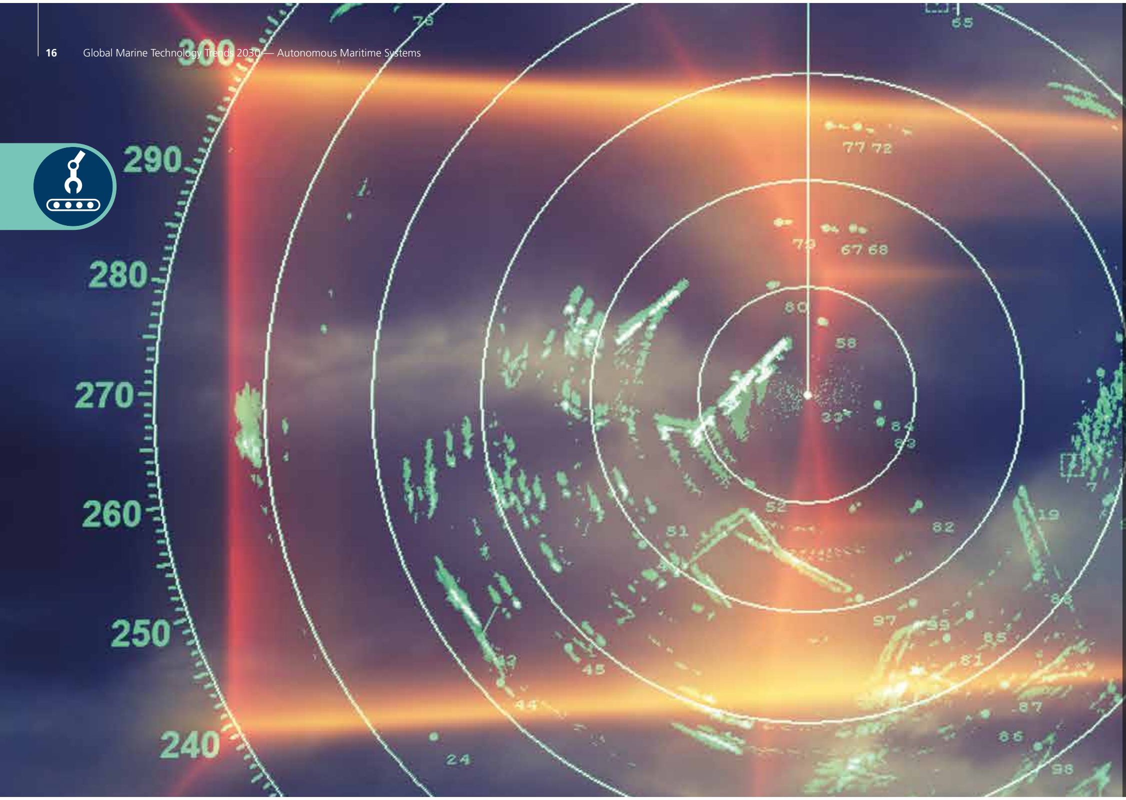
people redundant, or become very dangerous leading to the "the downfall of the human race". None of these situations are helpful, and none of these extremes are true – right now. But they are genuine perceptions of the technology.

AI is still in its infancy and many of the hurdles it faces are not necessarily related to technology, but to more people-centred issues, such as privacy, trust, regulation and ethics.

A view of its future

Many analysts believe that the human race is entering a fourth industrial age where AI is its driving force.[4] The McKinsey Global Institute[5] has suggested that AI is contributing to a transformation of society 'happening ten times faster and at 300 times the scale, or about 3,000 times the impact' of the industrial revolution.

The current momentum of AI development in areas including automation will likely cause a growing restlessness in society. Nevertheless, history has shown that, just like preceding ages, the technology will augment human capabilities rather than diminish the need for human involvement. AI offers a huge opportunity to all sectors of society, not least the maritime sector, which will benefit from being able to conduct its business faster, cheaper, and more efficiently.



3.2 Sensors and Situational Awareness

What is the technology?
Autonomous systems tailor behaviour and operations to context. To do this the system needs to 'sense' what is going on in its sphere of operation and adapt its course of action in accordance with what it 'discovers'.[1] Sensors are therefore fundamental to autonomous systems, combined with the ability to:

- Select sensors to gather data about on-board systems and the external environment
- Process the data (e.g. remove noise)
- Fuse the data with other data inputs
- Create a digital 'picture' of the world

The data collected enables the system to 'sense' the external environment, 'understand' the context of operations, develop situational awareness, then based on this information make decisions and adapt.

Autonomous vessels feature similar technology to self-driving cars and use a range of physical sensors to power autonomous functions, including: Global Positioning System (GPS), Inertial Navigation System (INS), optical and infra-red cameras, radar, lidar (light detection and ranging), high-resolution sonar, microphones, and wind and pressure sensors.

Why it is important
On-board sensors are primarily there for navigation and collision avoidance. The autonomous system needs to monitor location and heading, along with enough information about the world around it, so that it can manoeuvre to its intended position without collision or inflicting damage to itself or others. On a sea glider underwater vehicle this can be achieved with sensor technology as simple as a GPS, depth sensor and compass (possibly with a depth sounder). Unmanned ships require a sophisticated suite of highly advanced sensors to operate safely in a busy shipping lane.

In addition to navigation, sensors are also used for various ancillary operations, such as:

- **Oceanographic data gathering** – sea gliders and unmanned surface vehicles, equipped with a range of sensors, provide persistent measurement of oceanographic data (e.g. temperature, salinity, density and chemical concentrations) with mission durations of up to six months.
- **Hydrographic ocean floor mapping** – unmanned surface and underwater vessels with multi-beam and side-scan sonars technology produce cost-effective maps of the seabed.
- **Mine countermeasures** – sensors on-board naval unmanned systems accurately and safely detect mines without putting the crews of mine countermeasure vessels at risk.

How it is changing and key challenges
Unmanned ships will be more efficient, reduce emissions and operate at lower cost, but this will require effective integration of sensors with improved decision-making algorithms. Modern sensing techniques and sensor technology are developing at pace, predominantly in the consumer tech market. Miniaturisation of electronic components is being driven by everything from wearable technology and handhelds to the Internet of Things (IoT). Micro and Nano Electromechanical Systems (MEMS/NEMS) in mobile phones are also being exploited. MEMS accelerometers and gyroscopes are a 'must have' feature that has now found its way into the navigation systems of small unmanned underwater vehicles. Adjacent to this is that smaller components are more energy-efficient than larger ones, and the development of wireless sensors and ubiquitous connectivity enables a continuous flow of data[1].

[1] http://www.raeng.org.uk/publications/reports/innovation-in-autonomous-systems

Investment in non-consumer maritime sensors, such as radars and dynamic positioning systems (computer-controlled systems that automatically maintain a vessel's position and heading), has been significant and supports the rapid development of maritime autonomous systems. Wide uptake and use, means that these navigation technologies are relatively mature, but exploitation of consumer tech is driving further development. Maritime is also benefiting from the development of design of low-power sensor equipment introduced from consumer portable electronics markets.

Autonomous systems can now position sensors in almost any environment safely and cheaply. A wide range of weather, bathymetric sensors and miniaturised sonar equipment, mounted on unmanned systems, are used for hydrographic survey and object detection. Over time, the way in which these sensors are used will continue to progress, for example Simultaneous Localisation and Mapping (SLAM) will provide underwater autonomous systems with real-time navigation and mapping capability in an environment where GPS is unavailable.

Key challenges associated with sensor technology and situational awareness includes:

- **Data quality and accuracy** – incorrectly generated, processed or fused data will lead to inaccurate or low fidelity situational awareness, compromising the decisions and actions taken by an autonomous system.
- **Connectivity** – unmanned systems, particularly those collecting scientific data, collect an immense amount of data. High connectivity costs and poor bandwidth makes it difficult to remotely confirm that sensor data is of the quality required for safe/effective operations.
- **Processing** – most navigational sensor systems are designed for use by people, who manually process and fuse data (e.g. radar operators know to ignore clutter and manually look along the bearing to visually confirm the track). The programming required to 'train' AI systems is sophisticated and complex.
- **Resilience** – trained crew configure equipment for the prevailing conditions and assess relevant information, taking into account how the conditions have affected sensor range and sensitivity, to gain situational awareness of the vessel and surrounding environment. When sensors fail, the crew can detect the failure and, if needed, revert to traditional techniques. Fully autonomous vessels will need to overcome system failure without manual intervention.

Challenges of Watchkeeping

There is a considerable challenge in creating an equivalent 'electronic watch'. Recent research (MUNIN project[2]) indicates that current sensors may not have the have the range and resolution required to meet the requirements for watchkeeping as defined by Collision Regulations (COLREGs) and the Standards for Training and Certification of Watchkeepers (STCW). Currently a watchkeeper with binoculars effectively makes up the shortfall in the sensors.

Existing regulations assume that certain roles and activities are performed by crew on-board the vessel, for example performing the watch, and do not allow for equivalent autonomous approaches. Autonomous vessels are therefore constrained to the current method of watchkeeping rather than performing the task differently to achieve the same effect, i.e. monitoring the ship and surroundings to ensure the safe and smooth navigation of the ship. Creating regulations that allow equivalence will unlock more capabilities of autonomous sensing.

[2] http://www.unmanned-ship.org/munin/wp-content/uploads/2015/09/MUNIN-D8-6-Final-Report-Autonomous-Bridge-CML-final.pdf – MUNIN D8.6: Final Report: autonomous Bridge
[3] http://www.oceans17mtsieeeaberdeen.org/index.php/programme/workshops/sensor-and-system-innovations-for-the-oceans-of-tomorrow – BRAAVOO: Biosensors for Near Real-Time Marine Toxicant Monitoring
[4] https://www.newscientist.com/article/mg22229694-000-quantum-positioning-system-steps-in-when-gps-fails/ – Quantum positioning system steps in when GPS fails

A view of the future

Sensors will continue to develop. In the near future, they will have the range and resolution required to automate key roles and tasks on-board vessels, e.g. watchkeeping. The market for small sensors to fit on small vessels is growing rapidly. This will continue the drive to improve cost effective monitoring and the variety of sensors will increase. The use of unmanned systems will expand, enabling us to gather more data about our marine environment than ever before.

There are interesting developments that are transforming sensor technology. An emerging area is 'biosensing', where the sensor system incorporates a biological component, and has the potential to create highly sensitive sensors that are quick and easy to use. This technology is already finding uses in healthcare, agriculture and food production, environmental and security applications. In the maritime sector, biosensors mounted on an unmanned vessel are integral to the cost effective, near real-time in-situ monitoring of high impact, difficult to measure marine pollutants.[3]

Novel navigation sensors, predominantly based on quantum technologies are dramatically improving accuracy. The 'quantum compass' exploits the 1997 Nobel-winning discovery that lasers can be used to cool atoms to within fractions of a degree of absolute zero. In this frozen state atoms are extremely sensitive to the Earth's magnetic and gravitational field, and provide a type of inertial 'dead reckoning' navigation 1000 times more accurate that anything before. This is being trialled by the Royal Navy.[4]

Moore's Law, the continual cramming of more transistors onto silicon chips, is still a reality though near its physical limits with computing performance increases slowing.[5] However, emerging graphical processing units offer increasing computing power when matrixed together as an alternative to conventional computer chips that may not be up to the challenges posed by next-generation autonomous systems,[6] prompting a transition to alternative solutions, such as neuromorphic computing (a novel computer design inspired by the structure of the brain) and sensor technology. A pioneering vision sensor, inspired by the human visual system, is being developed to provide artificial vision for autonomous systems at a fraction of the current energy costs of existing technology.[7]

In summary, there are exciting advances being made in sensing technology that will better enable autonomous systems to gather exponentially more, and a greater variety of, data. We however foresee that the challenge will be making sense of this vast quantity of data and processing it with appropriate levels of fidelity to generate the levels of situational awareness that future autonomous systems will need to successfully operate in complex maritime environments. We believe that the main challenges will not be associated with the hardware, but with the software and processing elements. This will require smart uses of sensor fusion techniques, big data processing, and intelligent systems to condense vast quantities of raw sensory data into actionable information.

[5] http://www.telegraph.co.uk/technology/2017/01/05/ces-2017-moores-law-not-dead-says-intel-boss/
[6] http://news.stanford.edu/press-releases/2017/03/13/moores-law-ends-computers-begin/
[7] http://optics.org/news/8/5/9 – Sensors that mimic the human retina promise improved machine vision

3.3 Connectivity

What is the technology?

Contemporary maritime surface communications technology is typified by:

- Ship to near ship / shore using VHF/MF (Very High Frequency / Medium Frequency) communications
- Ship to far ship / shore using satellite communications (SATCOM) and HF (High Frequency)

There are several important communications use cases for this technology, based around maritime standards and these include:

- Distress and safety systems
- Identification systems
- Electronic navigation
- Security alerting
- Voice communications

Each of these systems are narrowband in nature. This suits the communications technology with VHF/MF/HF being inherently limited by frequency of operation to a maximum of a few kbps (HF), tens of kbps (MF/VHF) and potentially hundreds of kbps (for emerging VHF) of data. SATCOM, which is capable of much higher data rates, is regarded as inherently expensive to use but will reduce in cost.

More recently, maritime has begun to make use of other technologies for general communications. Commercial cellular 3G / 4G networks can provide ship-to-shore coverage out to 30 km from the coast.[1] In addition, companies, such as Tampnet are providing offshore 4G to customers in strategic areas of interest such as the North Sea and Gulf of Mexico oil fields, where drilling platforms, Floating Production Storage and Offloading (FPSO) units and support vessels can make use of low latency (compared to SATCOM) and very high bandwidth communications. In addition, advances in SATCOM technology and lower operating costs have made it feasible for high value platforms, such as cruise ships, to be followed by individual satellite spot beams, delivering very high data rates for passenger convenience (voice calls and Internet access) over WiFi and cellular access.[2,3]

In contrast, underwater communications rely on Very Low Frequency (VLF) to a depth of 40m and acoustic waves below that depth. Both are extremely low data rate technologies, e.g. providing 300 bps.

Why it is important

Critical ship systems depend on off-ship connectivity to provide services ranging from electronic navigation (including weather reporting) to automated identification and distress and safety notifications. Included in this definition is access to Global Navigation Satellite Systems (GNSS) such as Global Positioning System (GPS). Without this connectivity, safety of life, cargo and the ships themselves are placed at severe risk and operations would be far less efficient.

Internet access is becoming a mandatory way of life to all generations of people. In the past, the challenges of delivering the Internet to crew and passengers were regarded as being too difficult (or expensive) due to the nature of the environment. However, it is now recognised that Internet access is a key differentiator for passengers (e.g. on cruise liners) and also for crew retention on non-passenger shipping (e.g. cargo transportation, fishing etc.) where young people are otherwise deterred from entering the industry due to the isolated lifestyle.

How it is changing and key challenges

Maritime communications is undergoing a step change in technological capability. The VHF Data Exchange System (VDES) will increase the throughput and reliability of data services for critical ships systems across all modes of off-ship communications.

In the future, autonomous ships will rely on a number of different layers of networks and connectivity: Beginning with the on-board network of sensors and actuators required to monitor and control the ships, these will form an extension of the Internet of Things (IoT, a collection of physical objects connected to the Internet or other networks allowing them to communicate with people or machines to monitor or improve automation) where reports are fed to cloud-based computing centres (which could be on or off-ship) that respond accordingly to control all aspects of the ship's physical and electronic systems. Next, the crew and passenger networks will provide a range of operational and convenience services across the ship and link up with the off-ship connectivity.

IoT technology on ships will rely on large amounts of electronic devices being connected through a ship's superstructure. This is notoriously difficult given the number and thickness of metal bulkheads and difficult to access areas. It will not be possible to rely wholly on wired communications, in particular when integrating with legacy shipping.

Autonomous shipping will be critically dependent on Position, Navigation and Timing (PNT) systems to geo-locate themselves. Currently, there is a high reliance on GNSS systems, which have an inherently low amount of received power at the Earth's surface and are therefore prone to interference. GNSS can be made more robust through high quality Multi-Constellation, Multi-Frequency (MCMF) receivers that use multiple antennas to receive services across multiple constellations (e.g. GPS, GLONASS and Galileo and Beidou in the future). Spoofing of GNSS signals is an emerging threat, where fake GNSS signals slowly slew a receiver away from its actual location. While MCMF techniques can help, by spotting outliers in the received signals, the most robust defence would be to use encrypted GNSS services where applicable, such as the Galileo Public Regulated Service.

Fully autonomous shipping will require remote monitoring and this may require (multiple) high data rate services including high definition video and real time radar streams. These services can be expected to need multi-Mbps of data throughput, with high reliability.

Improvements in connectivity widen the possibility of cyber security incidents. While safety critical systems are currently stove-piped (due to the nature of their historical development), the efficiency benefits of using common communications and computing platforms may become compelling. In the automotive industry, a currently common method of cyber-attack is to target infotainment systems which then open up access to other critical systems. Autonomous maritime systems would do well to consider security from the outset and define solutions with a 'defence in depth' mindset.

[1] Jennings, A, "Modern Maritime Communications", World Radiocommunication Seminar 2016, https://www.itu.int/dms_pub/itu-r/md/15/wrs16/sp/R15-WRS16-SP-0026!!PDF-E.pdf, accessed on 28th July 2017.
[2] Harris CapRock, "Cruising into the Future: The New Maritime Communications Standard", 14 Apr 2015, www.harriscaprock.com/blog/cruising-into-the-future-the-new-maritime-communications-standard/, accessed on 28th July 2017.
[3] Nautilus International, "Mobile technology could shape future of maritime communications", 3 Jul 2017, https://nautilusint.org/en/what-we-say/nautilus-news/mobile-technology-could-shape-future-of-maritime-communications/, accessed on 28th July 2017.

A view of its future

New communications technology will present itself as an opportunity for maritime systems. To support autonomous ships through on-board IoT, it may be necessary to embrace wireless connectivity within the ship. Different commodity technologies exist including: 60 GHz and WiFi that would need supplementing with 'relay' technology throughout the ship. This could include sections of wired connectivity spanning some sections. A key technology will be Wireless Mesh Networking (WMN), which is a general means for automatically establishing multiple paths through a network based on the available connectivity. WMN also has a part to play with ship-to-ship communications. Here, ships on busy shipping lanes could relay communications for one another, including beyond line of sight, as a cheap alternative to SATCOM.

Fifth Generation (5G) is the next generation of mobile, cellular communications, following on from Long Term Evolution (LTE) and 4G. 5G has a role to play in supplementing ship-to-shore communications, where studies with 4G have shown that with appropriate antenna and power configurations optimised for this environment, then ranges of 100 km could be achieved. There is also a possibility of extending 5G networks further out to sea, particularly in busy shipping areas.[4] In addition, 5G includes modes to specifically support IoT connectivity, which could be of value to autonomous ship IoT architectures.

There are many developments in SATCOM that could revolutionise off-ship communications. In particular:

- High bandwidth, low cost services derived from advances in technology in the Ku and Ka bands. Higher power satellites will change the antenna profiles required and open up the technology to more types of ships.
- Multiband access will also allow ships to switch between high throughput and low cost services as required.[5]
- Inter-satellite communications links are already in service, but will continue to evolve as they promise lower latency communications than using ground station relay over very long ranges.

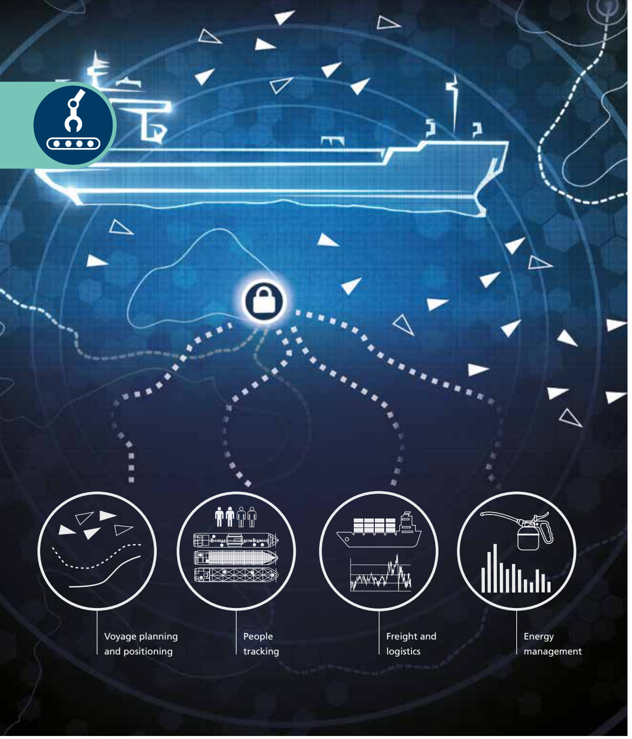
With a variety of methods for connecting and data rates that accompany them, maritime applications utilising the IoT concept will in time allow for live tracking and status updates being sent to ground control sites and other vessels in the local area. The outcome of such a network could make Automatic Identification Systems (AIS) obsolete, given the global reach of the connectivity options available.

Transferring data using visible light or Li-Fi is a promising development for underwater maritime communications. Although 'Optical Communications' are still considered experimental they present viable alternatives for underwater communications as the data rates, compared with traditional acoustic methods, are much higher. Such systems could offer two-way connectivity to unmanned underwater vehicles performing numerous tasks from mine hunting to biological surveys of the seabed.

Some ships already have PNT backup systems, potentially including marine grade Inertial Navigation Systems (INS). However, these rapidly become inaccurate and cannot be relied upon over extended periods. For instance, an inaccuracy of one nautical mile per hour is typical. Future PNT backup systems include:

- Automated Celestial Navigation (through star tracking, though limited in some operating conditions, such as heavy cloud-cover).
- Signals of Opportunity (using signals that are transmitted for non-navigation purposes, but may be exploited for navigation purposes).
- Quantum grade INS (using cold atom interferometry), which has an inaccuracy of 1m per day but is still in an early stage of development and potentially ten years away from practical utility.

[4] Marine Electronics and Communications, "A future for maritime communications without satellites", 3 May 2017, www.marinemec.com/news/view,a-future-for-maritime-communications-without-satellites_47532.htm, accessed on 28th July 2017.
[5] Marine Electronics and Communications, "Innovations will enhance maritime satellite communications", 25 Jan 2016, www.marinemec.com/news/view,innovations-will-enhance-maritime-satellite-communications_41537.htm, accessed on 28th July 2017.



3.4 Cyber Security

What is the technology?
Cyber security encompasses a raft of technologies, processes and practices that are designed to protect networks, computers, programs and data from attack, damage or unauthorized access.[1] It is more concerned with the protection of data and information than with physical security. However, as malicious activity grows and new technologies emerge, such as the Internet of Things (IoT), new security challenges will materialise and the need for the suitable protection of systems, networks and data in cyberspace will become more critical than ever.

The maritime sector is not exempt from cyber threats as they can affect any computer system and these do not necessarily have to be connected to a network. During the last decade there has been a rise in cyber-related incidents. Attacks have varied in their application and complexity, but there is little doubt of their current and potential impact.

A particular concern is internal threats, which could be anything from ignorant or accidental intervention to malicious activities by a disgruntled employee. Recent events have clearly demonstrated that attacks can be entirely indiscriminate. May 2017 saw the single biggest cyber-attack ever, with more than 200,000 organisations in 150 countries being infected with the 'WannaCry' ransomware. This attack demonstrated the importance of keeping software up-to-date and patching operating systems, as older systems or unpatched systems are more vulnerable to hacking attempts.

A major difference with maritime cyber security against other sectors is the impact of location. Currently vessels at sea rely heavily on satellite communications and available bandwidth is significantly reduced compared with that which is available when the vessel is dockside or in the littoral space. However, as ships become increasingly digitised and connected this limitation (or cyber protection, depending on your view) will diminish and location will eventually become irrelevant.

In 2016 the International Maritime Organisation (IMO) identified a number of key areas of cyber-related risk in the maritime sector. These include, but are not limited to[2]:

- Bridge systems
- Cargo handling and management systems
- Propulsion and machinery management and power control systems
- Access control systems
- Communications systems
- Personnel

While these have been identified as the key areas of risk, there still is no unified response on how to deal with this potential threat in the maritime sector.

[1] Definition: What is cybersecurity? TechTarget WhatIs.com, http://whatis.techtarget.com/definition/cybersecurity, accessed 28 July 2017.
[2] Interim Guidelines on Maritime Cyber Risk Management, International Maritime Organisation, MSC.1/Circ.1526, 1 June 2016, www.imo.org/en/MediaCentre/HotTopics/piracy/Documents/MSC1Circ1526%20%20Interim%20Guidelines%20On%20Maritime%20Cyber%20Risk%20Management.pdf.

Why it is important

Cyber security is becoming an increasingly important topic as current threat blocking and prevention mechanisms are becoming less effective against advanced attacks. The challenge for cyber security is to provide an adaptive protection process, integrating predictive, preventive, detective and response capabilities.[3] As part of the cyber security arsenal, advanced threat protection technologies are becoming an increasingly important in countering sophisticated attacks and are becoming a key part of a wider cyber defence strategy. These technologies focus on detecting attacks in the delivery, exploitation, installation and command and control stage of a cyber-attack.

Autonomous systems will represent a new challenge to cyber defence strategies. Whilst AI will be a key enabler for autonomous operations and will also take centre-stage in the mitigation of cyber threats, it will also potentially be a devastating tool for future hackers.

How it is changing and key challenges

With the increase in connectivity, data sharing and autonomous systems, there seems little doubt that the cyber threat will continue to increase in severity. The need to enable remote access to infrastructure and vessels might increase the risk of severe disruption to international shipping and maritime operations due to political, criminal or terrorist activities.

Technology and software developments have ushered in new ways of managing platforms. Currently, there exist platforms capable of being controlled anywhere in the world through the use of web-based piloting tools. Whilst this greatly increases the ease with which these systems can be managed, it also makes the dependence on cyber information a critical factor for successful operations. This internet connection provides a window for hackers to attempt to gain information, or even the control of platforms.

At present, the majority of marine insurance policies include a cyberattack exclusion clause (CL380 10/03). This places cyber-attacks outside the scope of most insurance policies, any company failing to develop the required levels of cyber security face severe financial and reputational risks.

As 90% of world trade is carried by international shipping, the potential costs of hostile acts could be crippling. If hostile acts begin impacting elements of critical national and international infrastructure, the result could be greater government involvement in the maritime industry. The recognition that cyber security has become an urgent issue for the maritime sector is evident by the release of the Interim Guidelines on Maritime Cyber Risk Management' by the IMO on the 1st June 2016.[2]

A view of its future

In the future cyber security solutions will require adaptive security architectures that focus on the security needed to support flexible digital ecosystems, the IoT and AI-based solutions. Security will by necessity, have to become fluid and adaptive. Security in the IoT and AI-related environments will be particularly challenging.[4]

As maritime vessels and infrastructure become more intelligent and independent of people, more tasks and processes will become exposed to the risks which to date, have mainly been experienced by other sectors. Given the highly connective nature of autonomous systems, it will be critical to ensure robust measures are put in place to ensure the cyber security aspect of maritime platforms and infrastructure.

[3] N. MacDonald & P. Firstbrook, Designing an Adaptive Security Architecture for Protection from Advanced Attacks, Gartner Research: G00259490 v2, 28 Jan 2016, www.gartner.com/doc/2665515/designing-adaptive-security-architecture-protection.

[4] D.W Cearley et al., Top 10 Strategic Technology Trends for 2017: a Gartner Trend Insight Report, Gartner Research: G00319572, 21 Mar 2017, www.gartner.com/doc/3645332/top--strategic-technology-trends.

Three areas to watch will be

Counter GNSS Spoofing

Military GNSS is encrypted which offers a level of protection, but civil GNSS systems are primarily unsecure and vulnerable. The lack of a human in the system means that if a cyber-attack is successful, there is no one on-board to visibly see or physically counter any such attack. It may be that civil GNSS on autonomous platforms will require encryption or additional independent navigational capabilities to warn of course deviations.

Communications

As platforms become increasingly controlled off-platform, communications will be the entryway for external cyberthreats. With the launch of the first ever quantum communications satellite by China, that is laying the foundation for a hack-proof global quantum network. This area of communications could have a new leader in the field.

Artificial Intelligence (AI)

The use of AI could have a profound impact on the management and exploitation of information in the maritime domain. AI also has the potential to revolutionise cyber security defensively and offensively, although it remains to be seen how this develops.

3.5 Energy Management and Sustainability

What is the technology?

Energy management encompasses the entire energy value chain, from exploiting energy sources, through to energy conversion, storage and delivery in a coherent and structured energy architecture and in management systems, maximising the efficient and flexible use of energy.[1]

Whilst non-renewable energy sources (e.g. fossil fuels) still provide the bulk of our energy needs, there is now a shift towards cleaner renewable sources of energy that are constantly being replenished, such as sunlight, wind, and water. At the same sustainability technologies are attracting more interest as they can improve the efficiency of energy management and enable businesses to be more environmentally friendly.[2]

In the maritime domain such trends are presenting huge challenges given the increasing nature of energy demand in modern ships. This has prompted interest in All-Electric Ships (AES) which are likely to create a paradigm shift in energy management whilst also reducing air pollution and creating lower CO_2 emissions to improve sustainability. As attention moves to autonomy and autonomous systems, which will be expected to operate with little or no human intervention, optimising energy management will become a critical concern. The remainder of this section looks at energy management and sustainability from the perspective of autonomous systems.

Why it is important

Energy management is a key area of consideration for autonomous platforms. One of the critical factors for selecting appropriate energy management for any platform is the intended application. For example, the energy management requirements of an Autonomous Underwater Vehicle (AUV) for oil pipeline inspection are vastly different to that of a Mine Countermeasure (MCM) vessel.

At the current time, many unmanned surface vessel designs use a blend of conventional (diesel generator and batteries) and harvested (wave, wind, etc.) energy sources. In contrast, underwater vessels are embracing a range of revolutionary technologies, with some vessels relying entirely on buoyancy engines or energy harvesting methods.

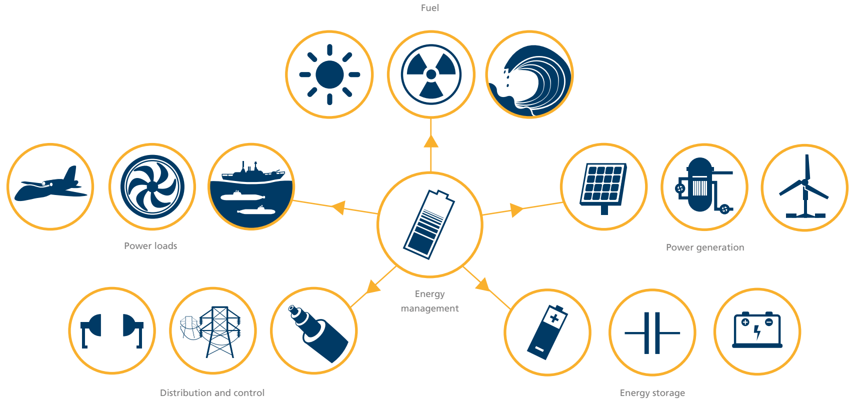
Emerging energy management and sustainability technologies are already demonstrating their ability to not only improve current tasking, but also allow for previously undoable jobs. This is due to an adoption of energy harvesting techniques that allow platforms to operate without the need to refuel.

How it is changing and key challenges

One of the key challenges facing the maritime domain is sustainability and related environmental issues. The current push for sustainable and greener energy sources is now a common theme across all sectors. The shipping industry alone is a significant contributor to global emissions (4% CO_2, 10-15% NOx and 5-9%SOx).[3] This makes energy management and sustainability technologies a key area of consideration for autonomous platforms. While smaller vehicles are already exploiting new and innovative energy management and sustainability solutions, it is more difficult determining how larger vessels will fare over the coming years, particularly as autonomous systems begin to allow greater design flexibility for vessels due to the reduction or removal of crew.

With the move towards all-electric platforms and AES in particular, a critical area is energy storage and therefore battery technologies.

[1] Global Marine Technology Trends 2030, Lloyd's Register, QinetiQ, Southampton University, Aug 2015.
[2] Gupta A., McIntyre A. 'Hype Cycle for Sustainability, 2017', Gartner Research ID: G00314631, 19 Jul 2017.
[3] Lane J., 'Sustainable Marine Fuel initiative consortium to launch 2-year testing, certification, scaling effort for drop-in marine biofuels', BiofuelsDigest, 27 Sep 2015, www.biofuelsdigest.com/bdigest/2015/09/27/sustainable-marine-fuel-initiative-consortium-to-launch-2-year-testing-certification-scaling-effort-for-drop-in-marine-biofuels/.



[1] Global Marine Technology Trends 2030, Lloyd's Register, QinetiQ, Southampton University, Aug 2015.
[2] Gupta A., McIntyre A. 'Hype Cycle for Sustainability, 2017', Gartner Research ID: G00314631, 19 Jul 2017.
[3] Lane J., 'Sustainable Marine Fuel initiative consortium to launch 2-year testing, certification, scaling effort for drop-in marine biofuels', BiofuelsDigest, 27 Sep 2015, www.biofuelsdigest.com/bdigest/2015/09/27/sustainable-marine-fuel-initiative-consortium-to-launch-2-year-testing-certification-scaling-effort-for-drop-in-marine-biofuels/.

Battery technology is developing rapidly, driven by demands across other sectors as electrical solutions come to the fore. Recent breakthroughs include lithium-sulphur, lithium-air and aluminium-ion. Whilst these are still in their early stages of development they are not yet commercially available. As the manufacturing processes, costs and associated safety issues are resolved; these types of batteries may prove to be revolutionary for the maritime sector. An emerging technology that may compete, or compliment, battery technology, is the supercapacitor (also known as the ultracapacitor).[4] A supercapacitor is like an ordinary capacitor, but it stores considerably more electrical charge. Unlike batteries they charge almost instantly, but do not store as much power. In the future it is likely that supercapacitors will be used more often, particularly when there is a need to store and release large amounts of electricity very quickly.

A view of its future

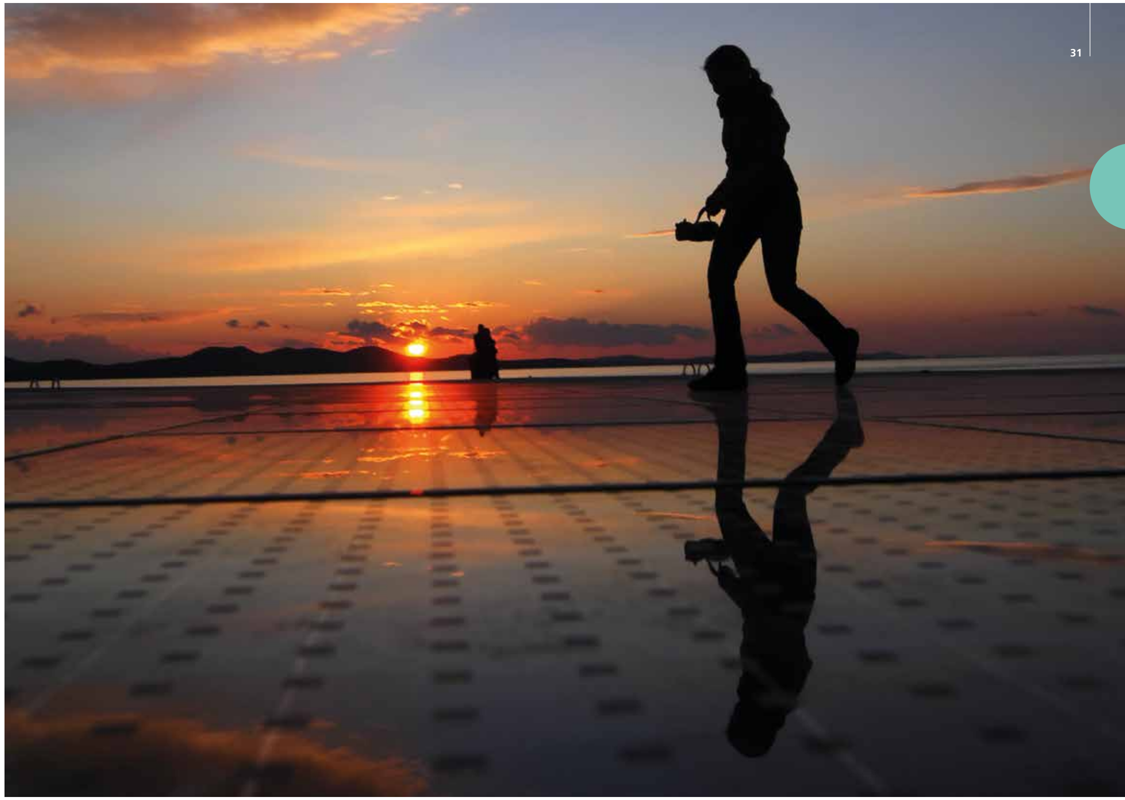
The possibilities created by improved energy management are extremely varied and are dependent on the area of the maritime sector concerned. It is possible for example, that autonomous cargo vessels could conduct entire journeys without needing to make port for refuel or resupply, reducing costs and cargo travel times. It is also possible to envisage smaller high endurance platforms that could conduct tasks, such as surveying, inspection and research, which are self-sustaining and rarely need to be manually serviced. Taking this latter example to the extreme, one can imagine swarms of autonomous platforms at sea, continuously monitoring environmental factors or assisting in search and rescue operations.

In the longer term autonomous vessels at sea may not even have to return to harbour to replenish their resources. If garaging systems are put into place, capable of replenishment, maintenance as well as recharge, it may be possible for such vessels to be left to freely operate; only requiring intervention for emergencies.

In the near future, mature technologies such as diesel generators will still see improvements, but these will only be in evolutionary increments. In contrast, there are technologies either in proof of concept or emerging, which could revolutionise energy management and sustainability in the maritime sector. In the case of shipping, there is already some movement towards energy source alternatives, such as biofuel, in an effort to tackle sustainability and environmental impact. Furthermore, some companies are exploiting innovative power solutions such as energy harvesting from wave motion,[5,6] and others that are working on biomimetic designs.[7]

Given the opportunities offered by autonomous, unmanned platforms, in terms of design and self-sustainment, it is difficult to predict what strange and revolutionary energy management ideas might appear in the future.

[4] C. Woodford, Supercapacitors, 22 Jul 2017, www.explainthatstuff.com/how-supercapacitors-work.html.
[5] 'Harvesting Motion into Energy', Witt Limited, www.witt-energy.com, accessed 27 July 2017.
[6] 'A Ship with Energy Harvesting System to Generate Power from Waves', MI New Network, 30 Jun 2017, www.marineinsight.com/future-shipping/a-ship-with-energy-harvesting-system-to-generate-power-from-waves/.
[7] Team Dédale, 'Air Ballast Biomimetic Cargo Ship', 26 Feby 2016, https://asknature.org/idea/air-ballast-cargo-ship/#.WXngi3KWwdU.



Part 4: Regulation and Legal Challenges

Regulation and legal aspects of autonomous maritime systems (AMS) will present significant challenges. Autonomous systems will expose the constraints of current instruments and highlight potential future areas where additional, proactive regulation and governance will be beneficial.

Regulation can take the form of legal provisions or it can be based on the industrial codes of practice and general principles of operation, in other words, self-regulation. Both are important for the development and the sustainability of new technology. The regulatory approach can be precautionary, aiming at the avoidance or risk, or it can be preventative, focusing on risk management. The timing and the type of regulatory intervention can accelerate, retard or prevent the adoption of new technology. We need to understand how technology and regulation can mutually influence each other.

Regulation of emergent technology
Emergent technology and its application provide significant challenges to current regulatory practice and the legal environment. These rapid developments are being driven outside of highly regulated sectors such as maritime and, as a consequence, technologies are being adopted without the in-depth understating of regulations and the legal aspects. The benefits, offered by the technologies are such that businesses are eager to exploit them with a view to increasing business performance, reducing costs and increasing safety. However, the mismatch between the time taken to develop and exploit technology and the ability of regulators to develop codes and practices gives rise to vulnerabilities. We need to readdress approaches to regulation in order to fully exploit the benefits of emergent technology whilst taking a considered approach.

In addition to factual information and test results, public perception is an important parameter influencing the selected regulatory attitude. Public perception is influenced by several factors. It is more likely to be positive if the benefits are clearly demonstrable and the change is gradual and more likely to be negative when catastrophic regulatory failures happen or a perception is developed that the emerging technology is not compliant with existing regulations.

A future view of regulation
Marine autonomy disrupts the way existing vessels operate and will develop new vessels undertaking activities that have no equivalent in a 'non-autonomous' context. The potential impact that a malfunctioning autonomous system will have on people and the marine environment will vary for each system depending on its design, size, the density of sea traffic and whether it operates at the surface or underwater.

A supportive regulatory environment will need to reflect this diversity. In addition, the regulatory arrangements should be able to distinguish between the testing of new technology and its operational use. Thus the mixture of self-regulation and legal regulation, as well as its timing, needs to vary between systems and evolve with them as they mature.

International regulations are necessary for systems operating between states or operating in the sea bed areas beyond national jurisdiction. In addition, international design and production standards will be needed to facilitate the export of autonomous systems. International regulation develops and changes much slower than national regulation. However, it is important to understand that permitting national regulation to develop and then trying to unify these potentially diverse regimes probably has more risk than developing broad international standards based on those regulating non-autonomous systems.

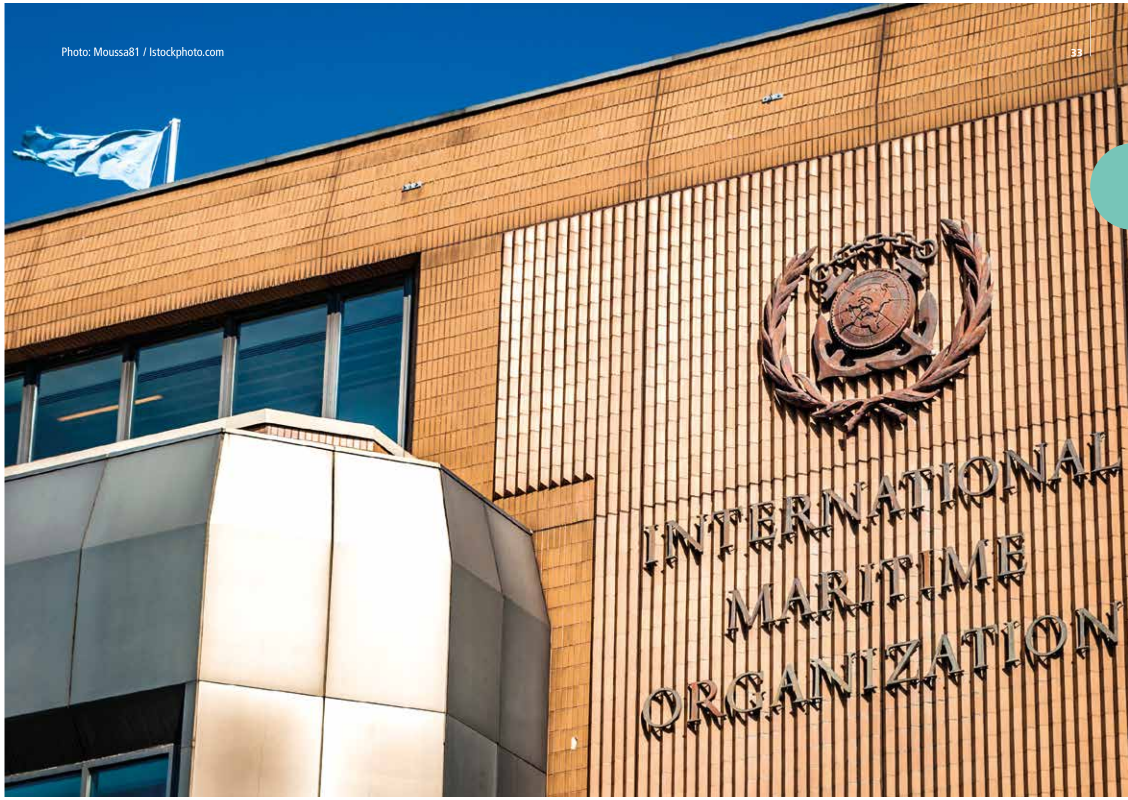
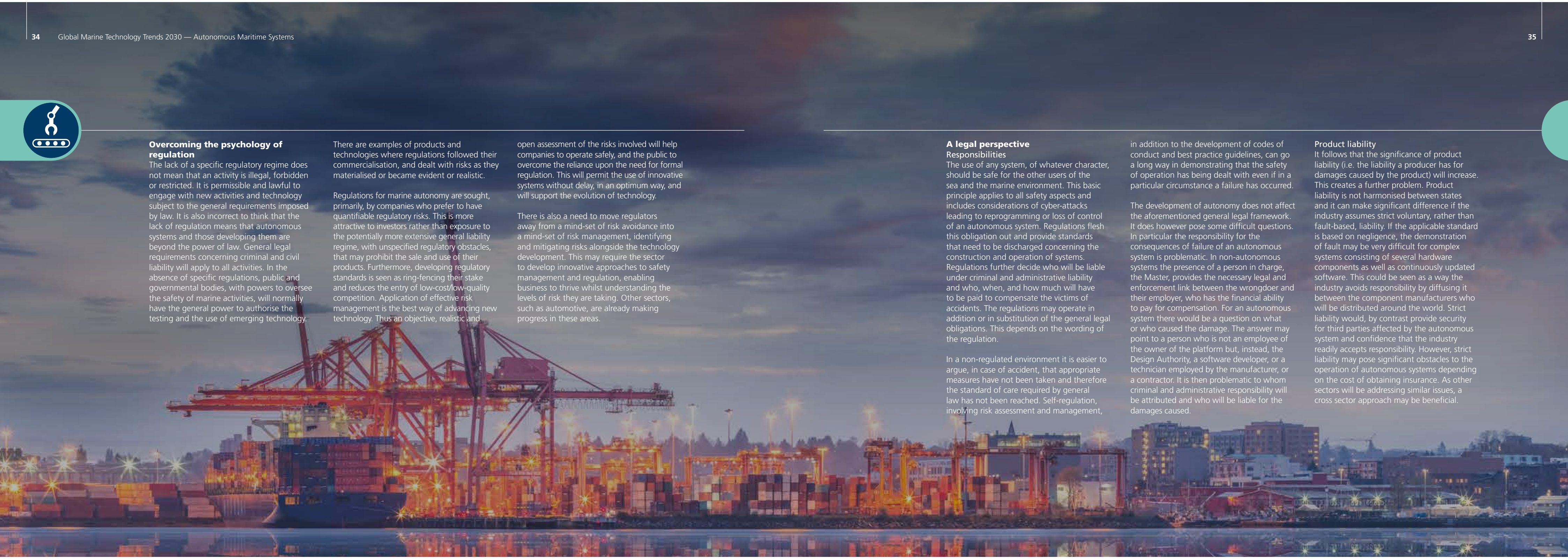


Photo: Moussa81 / Istockphoto.com



Overcoming the psychology of regulation

The lack of a specific regulatory regime does not mean that an activity is illegal, forbidden or restricted. It is permissible and lawful to engage with new activities and technology subject to the general requirements imposed by law. It is also incorrect to think that the lack of regulation means that autonomous systems and those developing them are beyond the power of law. General legal requirements concerning criminal and civil liability will apply to all activities. In the absence of specific regulations, public and governmental bodies, with powers to oversee the safety of marine activities, will normally have the general power to authorise the testing and the use of emerging technology.

There are examples of products and technologies where regulations followed their commercialisation, and dealt with risks as they materialised or became evident or realistic.

Regulations for marine autonomy are sought, primarily, by companies who prefer to have quantifiable regulatory risks. This is more attractive to investors rather than exposure to the potentially more extensive general liability regime, with unspecified regulatory obstacles, that may prohibit the sale and use of their products. Furthermore, developing regulatory standards is seen as ring-fencing their stake and reduces the entry of low-cost/low-quality competition. Application of effective risk management is the best way of advancing new technology. Thus an objective, realistic and open assessment of the risks involved will help companies to operate safely, and the public to overcome the reliance upon the need for formal regulation. This will permit the use of innovative systems without delay, in an optimum way, and will support the evolution of technology.

There is also a need to move regulators away from a mind-set of risk avoidance into a mind-set of risk management, identifying and mitigating risks alongside the technology development. This may require the sector to develop innovative approaches to safety management and regulation, enabling business to thrive whilst understanding the levels of risk they are taking. Other sectors, such as automotive, are already making progress in these areas.

A legal perspective

Responsibilities

The use of any system, of whatever character, should be safe for the other users of the sea and the marine environment. This basic principle applies to all safety aspects and includes considerations of cyber-attacks leading to reprogramming or loss of control of an autonomous system. Regulations flesh this obligation out and provide standards that need to be discharged concerning the construction and operation of systems. Regulations further decide who will be liable under criminal and administrative liability and who, when, and how much will have to be paid to compensate the victims of accidents. The regulations may operate in addition or in substitution of the general legal obligations. This depends on the wording of the regulation.

In a non-regulated environment it is easier to argue, in case of accident, that appropriate measures have not been taken and therefore the standard of care required by general law has not been reached. Self-regulation, involving risk assessment and management, in addition to the development of codes of conduct and best practice guidelines, can go a long way in demonstrating that the safety of operation has being dealt with even if in a particular circumstance a failure has occurred.

The development of autonomy does not affect the aforementioned general legal framework. It does however pose some difficult questions. In particular the responsibility for the consequences of failure of an autonomous system is problematic. In non-autonomous systems the presence of a person in charge, the Master, provides the necessary legal and enforcement link between the wrongdoer and their employer, who has the financial ability to pay for compensation. For an autonomous system there would be a question on what or who caused the damage. The answer may point to a person who is not an employee of the owner of the platform but, instead, the Design Authority, a software developer, or a technician employed by the manufacturer, or a contractor. It is then problematic to whom criminal and administrative responsibility will be attributed and who will be liable for the damages caused.

Product liability

It follows that the significance of product liability (i.e. the liability a producer has for damages caused by the product) will increase. This creates a further problem. Product liability is not harmonised between states and it can make significant difference if the industry assumes strict voluntary, rather than fault-based, liability. If the applicable standard is based on negligence, the demonstration of fault may be very difficult for complex systems consisting of several hardware components as well as continuously updated software. This could be seen as a way the industry avoids responsibility by diffusing it between the component manufacturers who will be distributed around the world. Strict liability would, by contrast provide security for third parties affected by the autonomous system and confidence that the industry readily accepts responsibility. However, strict liability may pose significant obstacles to the operation of autonomous systems depending on the cost of obtaining insurance. As other sectors will be addressing similar issues, a cross sector approach may be beneficial.

Insurance

Perhaps the best way, of supporting the development and use of new technology, is by ensuring that insurance cover is available so that recovery of damages will not depend on any company's financial situation. Coupled with strict liability, such an insurance arrangement provides the best arrangement for potential claimants, and the best defence for the autonomous industry, provided it is seen to have in place the required financial tools for its operation.

Insurance plays an additional role in enforcing the safety perspective. The premium paid will depend on both the behaviour of a specific system and the risks that may materialise with respect to each type of autonomous maritime system. Furthermore, it will also depend on the history of the company operating such systems. The financial incentive is crucial in encouraging a sector to become safer, through an understanding of the specific risks involved, at the point a new technology becomes operational – along with providing a level of insurance cover at an appropriate price. Shipping currently employs a system of strict, but limited liability with, compulsory insurance and direct action against the insurer in a very successful manner.

Ethical perspectives

Autonomy may facilitate or replace the involvement of seafarers in maritime operations. The acceptable safety standards need to be compared with the existing safety standards and/or by reference to equivalent human factors standards. How this equivalence is to be determined will need to be resolved. One problem is that not all people perform activities in the same way and, as a result, what is an equivalent for an autonomous system given there may be a range of acceptable solutions.

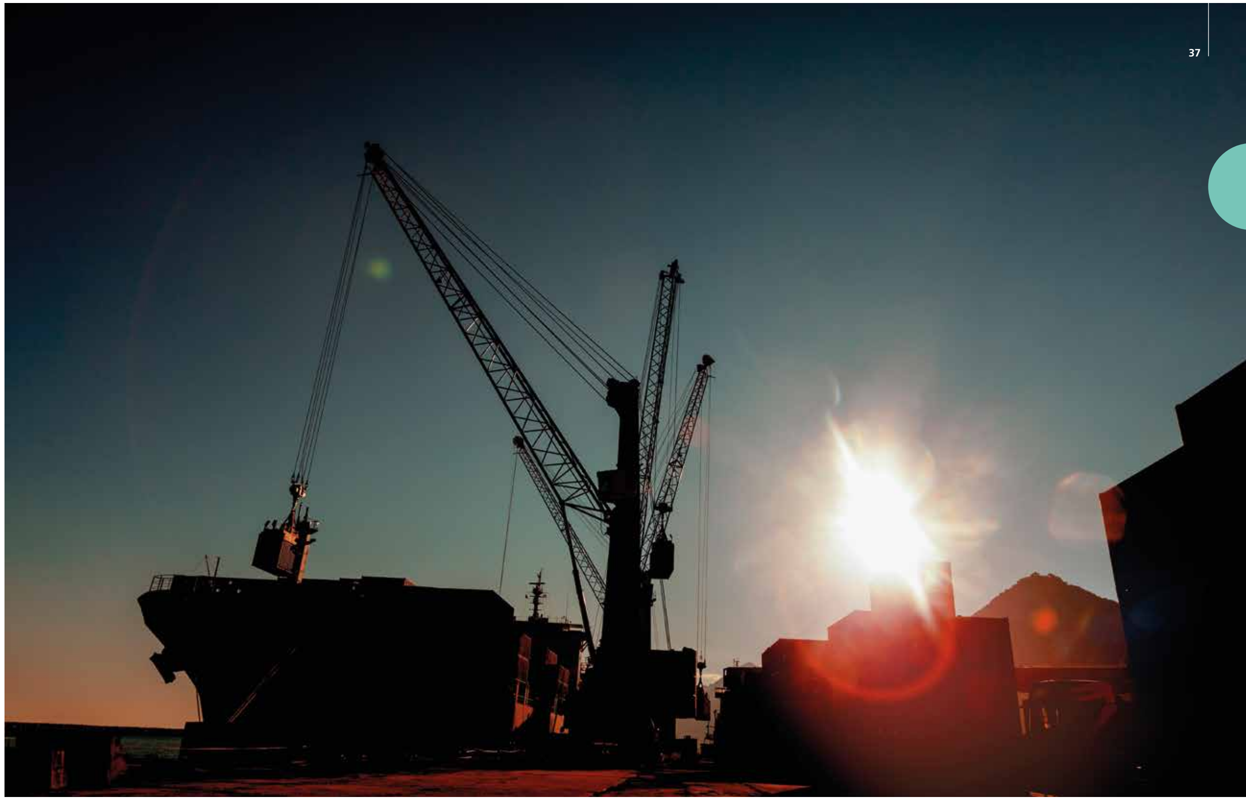
Assuming that overall, autonomous maritime systems are involved in fewer accidents than non-autonomous systems is also problematic. Key questions should include:

- How much safer should it be?
- Which type of accidents and criteria are included in such statistics?

These will need to be detailed as part of an overall safety perspective.

To pose the questions correctly it has to be determined whether the statistic is to be evaluated in the context of autonomous operations in an exclusively autonomous system environment or in a mixed environment involving autonomous and non-autonomous systems.

It could also be argued that autonomous systems may yet be riskier because they do not currently consider the difference in the seriousness of damages caused by following one or another way of reaction to a risk. This is an important design consideration; this will also need to address specific biases introduced by the designer(s). Developing decision making for autonomous systems (a kind of 'machine morality') or a way of referencing, or passing tasks to, human operators in difficult situations is a paradox to be discussed and developed if we are to avoid unintended consequences.



Part 5: Smart Ships

The end of the seafarer?

Current forecasts indicate remotely operated local vessels will be in operation in the next few years, closely followed by unmanned ocean-going vessels. This will have significant implications for the nature of work in the maritime sector and the people who will be doing the work in the future.

In this section we explore what is driving the shift to autonomous systems, how it is likely to transform the maritime workplace, the skills required therein and the future of maritime in an autonomous era.

The future is here

Industry 4.0 (Fourth Industrial Revolution) is the confluence of cyber-physical systems that are reshaping most sectors. Autonomous systems, including artificial intelligence, machine learning and robotics, are being rapidly introduced across airlines, engineering and construction companies, finance, manufacturing, agriculture and healthcare providers, driven by heavy investment.[1] Technical feasibility combined with compelling economic advantages, such as improved efficiency, reduced operating and labour costs, is accelerating adoption.

The maritime sector is not immune. Autonomous technology, along with greater digital connectivity, is poised to transform the sector. Crewless vessels are now under development. It is already possible to explore the most extreme oceanic environments using autonomous and robotic systems. These changes will have an impact across related sectors, for example environmental challenges are causing companies to explore alternative logistic models that reduce road haulage in favour of autonomous coastal shipping.

It is time for the maritime industry to understand how autonomous systems will shape the sector and how best to exploit them.

Change accelerators

From a people perspective, availability and cost of labour are driving the pace of change in maritime. A shortage of skilled people, particularly officers, is resulting in an accelerated move to unmanned and autonomous ships. In addition to reducing environmental impact, safety is another driving factor underpinned by a need to remove people from hazardous work environments, such as those associated with deep subsea operations in oil and gas and mine clearance operations.

Navies world-wide are investigating how to substitute labour with autonomous technology in the face of significant budget cuts and retention issues. In contrast, the container shipping industry, experiencing downward pressure on freight rates and over capacity,[2] will find substantial upfront technology investment to field autonomous ships less attractive compared to low labour costs that currently account for a small fraction of their total operating costs.

In industries such as this, algorithms that automatically optimise route designs, operating conditions and logistic chains present greater opportunities to reduce costs. In contrast where crew costs are a higher proportion of overall costs there is a greater case for autonomy. This means autonomous ships will first appear in coastal and littoral waters, characterised by smaller ships and shorter routes, than the open sea.

Ultimately, each subsector will need to review whether autonomous systems will prove to be an economical choice, though the cost-benefit ratio will shift as technology becomes cheaper and more widely used.

Technology is not destiny

The evolution of work facilitated by technology development is not new. We are moving from an industrial age, which at its inception led to massive social disruption, to an automation age which promises the same. There is a perception that technology is the answer to all your problems, largely driven by the 'tech is good' propaganda of the large consumer tech companies. However, there is an opportunity to consider some of what history has to teach us. While "technological advancement often seems to take on a mind of its own",[3] it is also empowering; giving people control of the political, social, and economic systems that can influence whether automation has a positive or negative impact. Active engagement from the maritime sector – the people who experience the current challenges, constraints and opportunities of this environment – will enable them to shape its destiny.[4]

[1] http://usblogs.pwc.com/emerging-technology/robotics/
[2] Container shipping faces critical moment after years of losses, https://www.ft.com/content/8b633cfa-e7f0-11e6-967b-c88452263daf?mhq5j=e1
[3] http://www.pewinternet.org/2014/08/06/future-of-jobs/
[4] Brynjolfsson, A. & McAfee, A. (2014). The second machine age: work, progress, and prosperity in a time of brilliant technologies. New York: W.W. Norton & Company, Inc.

Integrating tech with people (and augmenting people with tech)

GMTT2030[5] emphasised the crucial role of Human-Computer Interaction (HCI) has in ensuring that technical systems are effective and fit-for-purpose. A future where workforce autonomy and intelligent systems are common place means that the effective integration of people and technology should be a primary concern. Historically, technology investment has often neglected integration and usability, sometimes to the detriment of safety, but more commonly resulting in elevated levels of frustration and stress when people are required to interact with said systems.

Technological systems are integrated with one another (though not always effectively) but not with the way people work.[6] It is already recognised that maritime technological advances, typically designed by people shore-side with limited experience of life at sea, often increase role complexity and workload.[7] To maximise effectiveness, people-machine integration needs to be carefully considered from a user-centred design perspective. This is as important for the design of autonomous systems, as it is for new ways for people to interface and interact with new tech (e.g. haptic controls, augmented reality or affective computing). To achieve this there needs to be close collaboration between tech providers, seafarers and behavioural scientists.

Impact on the nature of work

Technology is changing the nature of work and the work place. Autonomous systems are primarily designed to enhance or substitute the maritime workforce. Roles, organisational constructs and responsibilities will shift from operating at sea platforms to on-shore management and supervision of these systems. This will require new concepts for traditional tasks, such as watch keeping, and fundamental changes to working patterns, for example traditional 'watches'. One radical change could be the rise of the maritime equivalent to Air Traffic Control, akin to existing managed waterspace like the English Channel.

Social, demographic and economic factors are also reshaping the way people live, work and, more importantly, who they work for. Workforces are becoming increasingly multi-generational, older and female. For the maritime sector this is compounded by long periods at sea or off-shore, hazardous often monotonous working conditions and disrupted home lives. This traditional requirement to be at sea for prolonged periods of time is, increasingly, unattractive to a Western workforce, especially younger generations. As navies are discovering, the ability to 'stay connected' is more attractive than a career at sea with poor connectivity.

The negative impact of autonomous systems is widely discussed. It is useful to also consider the positives. These technologies have immense potential to improve working conditions by reducing exposure to hazardous working environments, and for seafarers, particularly monotonous routines and extended periods away from home life. The introduction of autonomous systems could make the maritime sector a more attractive employment proposition by eliminating many of the more negative aspects of life at sea.

People and machine collaboration

The impact of autonomy on the maritime industry will not simply be technological. It will fundamentally change ways of working, the workplace and the workforce. Autonomous technologies designed to operate independently or with minimal intervention, will target specific tasks rather than jobs. The implication is that few occupations will be eliminated entirely,[8] but nearly half of the tasks people are currently paid to do could be automated by adapting existing technology[6]. This proportion will rise with technological advancement.

The nature of work will change and, in tandem, a new relationship between people and machines will emerge. Increasingly people will be working alongside automated systems. We believe three models will predominate:

- AI enhancing the work people do, such as systems designed to optimise voyage planning.
- A 'co-bot' where true collaboration between people and machines occurs, for example a human-robot team conducting routine maintenance on oil rigs.
- Having a machine manager – a partially manned fully autonomous ship would illustrate this scenario.

The changes will present new challenges to be overcome, not least the need for people to re-skill and up-skill to adapt to the changing nature of work, and autonomous systems will be the newest recruits to the maritime sector.

Will seafarers be able to trust an autonomous system?

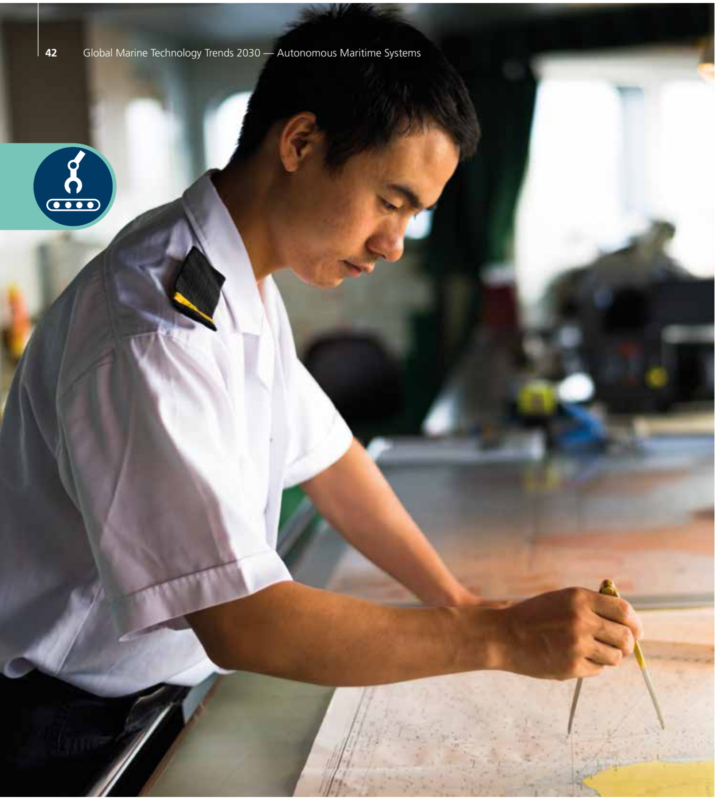
The dynamics of trust between people and autonomous systems are, as yet, poorly understood. We have an innate tendency to mistrust things we do not understand or cannot control. This response can markedly influence our willingness to adopt, trust and rely on automation.[9] Critically it is only through using autonomous technology that a user will develop confidence in its capabilities and begin to trust it. Key elements that facilitate this process include[10,11]:

- Perceived usefulness
- Ease of use
- Reliability
- Safe
- System performs as anticipated/expected

Given the move towards greater collaboration with technology these elements need to be considered during the early stages of autonomous systems development.

If people, who are tasked with working alongside or to use the outputs of an autonomous system, do not understand or trust the system they are unlikely to use it. Poor implementation and adoption of this emerging tech will ultimately mean that the desired economic or operational benefits are not achieved.

[5] Global Marine Technology Trends 2030 (GMTT2030)
[6] https://www.bcgperspectives.com/content/articles/technology-digital-people-organization-smart-solution-productivity-paradox/
[7] https://knect365.com/talentandtraining/article/842b789d-aa16-411f-95c9-6393715daf35/digital-transformation-how-will-it-change-the-seafarers-role
[8] http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/where-machines-could-replace-humans-and-where-they-cant-yet?
[9] J.D. Lee & K.A. See (2004). Trust in Automation: Designing for Appropriate Reliance. Human Factors, the Journal of the Human Factors and Ergonomics Society, 46 (1), 50-80, doi: 10.1518/hfes.46.1.50_30392.
[10] Davis, F.D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology, MIS Quarterly, 13 (3), 319–340, doi:10.2307/249008.
[11] Davis, F.D., Bagozzi, R.P. & Warshaw, P.R. (1989). User acceptance of computer technology: a comparison of two theoretical models, Management Science, 35, 982–1003, doi:10.1287/mnsc.35.8.982



Skilled seafarers of the future

The maritime industry is a growing sector that is struggling to find adequately skilled seafarers and predicting significant shortfalls out to 2025, particularly in the supply of qualified officers.[12]

Indications from a recent UK government report[13] echoes this, noting an overall increase in global demand for seafarers over the last 5 years. Importantly estimates highlight that global demand for officers is now greater than that for ratings – a continuation of a 25 year trend that looks set to persist explained, in part, by the higher skill levels required for vessels that are becoming ever more technically complex. In the short-term an additional challenge will be the need to define and train the workforce of the future.

Workforce planning needs to be informed by a detailed understanding of how emerging technology and trends in ship design will shape future operations. Already, there is a move towards larger, more technically advanced vessels, increasingly specialised towards particular tasks.[12] This is now changing the types of skills required towards an increased requirement for highly specialised crews and people with expertise in technology and IT systems (e.g. electro-technical officers).

The predicted deficit of labour could be offset by deploying automation. Remote and autonomous operations will transfer many seafaring jobs to land-based operations centres, opening up the industry to a new set of people who will find a maritime career, ashore, a more attractive proposition.

Maritime roles are going to look very different in 2030. Seafarers will be operating on vessels that are highly digitised and 'connected'. The integration between people and machine will be critical to effective maritime operations. This shift from manually crewing the ship to monitoring machines, often remotely, will require higher skill levels including:

- Greater levels of digital and technical competency
- Working across cyber-physical boundaries spanning the physical machine and computer networks
- Seamless collaboration with autonomous and robotic systems
- Virtual and remote working with land-based crew (including robots), experts and other colleagues
- Ability to manage cyber hygiene and respond to threats
- Managing fleets from remote control centres

Overall 'smarter ships' will require 'smarter people' as they adjust to new routines, lower manning levels, and technology that is not infallible.[14] Training needs to also adapt to equip seafarers with these skills.

Future of maritime in an autonomous era

Emerging autonomous technologies are primarily driven by business efficiency and cost-savings. Technological changes are now increasingly focused on substituting rather than enhancing people in the workplace to drive down labour costs. The economic and social implications of this, paint a picture of extreme change with a radical alteration of labour markets and new operating models. Future ship systems and equipment will be more dynamic, evolving and changing to meet emerging technologies. Interactions with intelligent systems will be commonplace. The nature of most roles will change and most will move ashore.

This is against a backdrop of a global shift in both maritime trade and technological development from West to East. The indications are that we are "completely unprepared for the social, economic and political disruption about to take place".[17] Opportunities will favour those individuals, companies and countries who adapt quickly to skill and industry obsolescence. It will be necessary to fundamentally re-evaluate the role of the seafarer.

The ironies of autonomous systems

A common aim of automation is to replace people. However, **"the more we depend on technology and push it to its limits, the more we need highly-skilled, well trained, well-practised people to make systems resilient, acting as the last line of defence against the failures that will inevitably occur."**[15]

Manual control of maritime vessels is a highly skilled activity across a wide range of conditions (wind, sea state, tides, etc.) and skills need to be practiced continuously in order to maintain them. Yet highly reliable autonomous systems that fail only rarely deny operators the opportunity for practicing these basic control skills. This means that when manual takeover is necessary – usually because something has gone wrong or a situation unforeseen by designers – this means that operators need to be more, rather than less, skilled in order to successfully cope with these atypical conditions.[16]

This is the 'paradox of automation'. As autonomous systems become more advanced the contribution of people becomes more crucial not less. But the opportunity for the person to gain the required experience significantly decreases.

[12] https://www.bimco.org/news/press-releases/20160517_bimco_manpower_report
[13] DfT Seafarer Projections Review, November 2016, www.gov.uk/government/publications/maritime-growth-uk-seafarer-projections.
[14] http://www.globalnavigationsolutions.com/takes-two-smarter-ships-smarter-people/
[15] Baxter, G., Rooksby, J.R.N., Wang, D. & Khajeh-Hosseini, A. (2012). The ironies of automation… still going strong at 30? In Proceedings of the 30th European Conference on Cognitive Ergonomics (ECCE '12), pp. 65-71. ACM: New York, NY, USA. DOI: https://doi.org/10.1145/2448136.2448149.
[16] Harford, T. (2016). Crash: how computers are setting us up for disaster. The Guardian, Tuesday 11 October 2016, www.theguardian.com/technology/2016/oct/11/crash-how-computers-are-setting-us-up-disaster.
[17] https://www.theguardian.com/books/2015/oct/01/the-rise-of-robots-humans-need-not-apply-review

Part 6: A View of the Future

Having addressed the technical, legal and regulatory, and social aspects, we now look towards the future. The speed at which autonomous systems have been adopted by the Maritime industry has been beyond our original expectations in GMTT 2030. Looking forward, therefore, we now aim to be more ambitious. We now paint a picture of future scenarios in the:

- Commercial shipping
- Naval defence, and
- Ocean space domains

Commercial shipping and the advent of 'Smart Ships'

Commercial shipping will be a major adopter of autonomous and 'Smart Ship' technologies, as outlined in earlier sections. Initiatives are underway throughout the world driven by fuel costs, crew costs and environmental needs. These smart ships will emerge as sensor-rich, digital data dependent and software-driven vessels with minimal crews on-board. These smart ships could lead to:

- Enhanced safety, with removal of people from dangerous tasks, and minimising human error (MV Rena, MV Costa Concordia and MV Sewol are examples where operator error has contributed to a major incident and / or the loss of lives).
- Lower operating costs, owing to potential reductions in labour costs and improved operational efficiency.
- Optimised commercial flexibility as a result of real-time data mining and analytics across a combination of technical, logistical, financial and operational aspects.

New disruptive business ownership models for shipping are emerging, mimicking trends in shopping, hotel and taxi industries. The main driver is increased efficiency in an end-to-end logistics chain with shipping being one link in the chain, albeit a critically important one in a global trade context. The developments in the Fourth Industrial Revolution, the adoption of additive manufacturing and the ability to create 'bespoke' products at the point of use/consumption will have a direct impact upon the nature of trade along with the products that are carried. Increasingly, as the use of fossil fuels decline throughout the world, we will see major changes to the nature of the shipping fleets and their routes.

In such a world, unmanned autonomous ships will account for an increasing proportion share of this shipping trade. This will be predominantly in shipping segments, such as dry bulk transport, where the economic impact of unmanned operations will be demonstrably high, combined with relatively low safety risks associated with cargo transport (i.e. the value of the cargo is lower than the cost of the ship).

These autonomous ships will have an impact upon; ship design, shipbuilding, port infrastructure including services and interfaces. We will see changes such as:

- Pilotage for transit into the port and on to a berth being handled from shore.
- Active management of congested waterspace through the maritime equivalent of air traffic control.
- The development of international fleet control centres monitoring and managing these fleets of autonomous ships throughout the world.

Automation will transform on-shore elements of shipping, from port infrastructure and cargo handling through to the land-based logistics and transportation chain. Ultimately the goal will be a just-in-time service where shippers and customers are able to instantaneously tailor dispatches and receive deliveries from this autonomous logistics transport chain.

Naval defence
In naval defence, surface, aerial and sub-surface autonomous sensor and weapons platforms will be controlled by 'Smart Machine' technologies that exploit AI and machine learning techniques, albeit under the oversight of naval personnel. Workplace automation will replace traditional operators who now manage information rather than operating equipment (possibly located remotely from the vessel). The role of intelligent systems will increase and automated decision-making will become more commonplace where people's reaction times are to slow to react to high-speed high-volume threats.

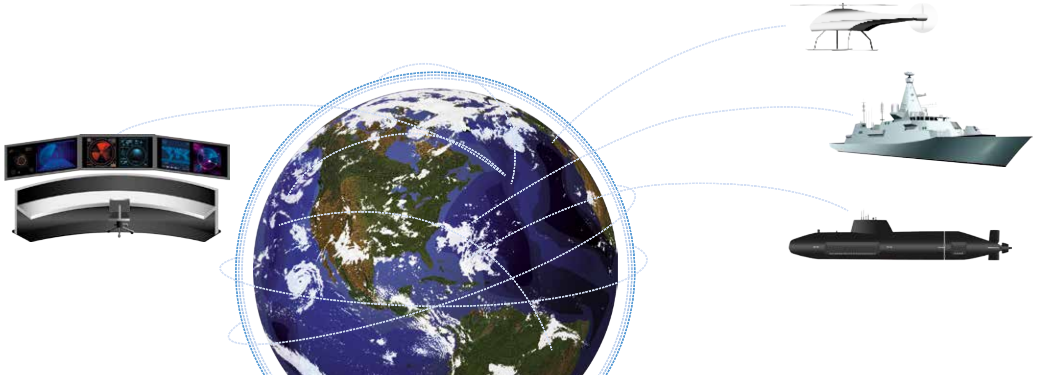
It is important to highlight that this will raise significant legal and ethical issues that will need to be thoughtfully resolved, especially where autonomous systems are making high-stake decisions that involves people's lives. However where the adversary is another intelligent system, does this reframe the debate?

These changes will have a profound effect on the type of activities that naval personnel will have trained for and the skills they will need to develop. As the technology progresses and as different forms of AI (from simple decision support to fully autonomous systems with machine learning) are implemented, new working practices will emerge. This will be accompanied by a shift in the balance between autonomy and human decision-making, with people increasingly leveraging the power of AI and machine-learning. The nature of existing trades, branch structures, command organisations and logistics support will be transformed.

Fully autonomous naval platforms – surface ships, submarines and airborne vehicles – are emerging in significant numbers for a variety of functions, such as, intelligence gathering, search and rescue, piracy, coastal protection, etc. These platforms will have the ability to:

- Work with one another in a 'team/swarm' towards a common goal.
- Intelligently adapt to novel situations, for example redistribute tasks in the event that one or more of the 'team' experiences degraded performance.
- Evolve mission plans based on information received during the conduct of an operation.

Such technologies will require new and different levels of support and oversight. These may include manned centres ashore, on-board systems (for example on a mother-ship which may be in the relative vicinity of the autonomous system) and the ability to 'transfer' control during missions between these local and remote operational centres.



Ocean space

The wider ocean space environment will see a host of autonomous unmanned underwater, surface and air vehicles (UUVs, USVs and UAVs) emerge that will be capable of completing joint autonomous operations and missions. They will be equipped with:

- Highly efficient propulsion systems
- Energy storage and marine renewable energy harvesting devices
- A diverse range of sensing hardware supported by localised data processing and decision-making software facilities
- Advanced navigation and communication technologies

Together, these will enable a novel framework for exploring, monitoring and safeguarding the ocean environmental space.

The marine science community will continue to exploit the ability of multiple aerial, surface and sub-surface vehicles to undertake combined oceanographic surveys. A current example is the recent (May-June 2017) MASSMO4 campaign[1] which involved 11 autonomous surface vessels and submarine gliders. These were deployed off the north of Scotland to collect a range of oceanographic measurements, seabed imaging, and passive acoustic monitoring of marine mammals.

Research that is underway today is developing sensors and vessels which will enable continuous, long-term monitoring of the oceans. This provides the ability to continuously monitor, at both micro and macro levels, the health and changing nature of the ocean environment. As an example, enhanced "Argo"-type floats,[2] such as JAMSTECs "Deep Ninja"[3] can now reach the deep ocean (~4000 m), and new sensors are being added to long endurance sub-surface vehicles (e.g. floats, gliders) to measure critical oceanographic parameters, such as the partial pressure of carbon dioxide (pCO_2) used to monitor ocean uptake of carbon dioxide.

It is noteworthy that recent incidents, such as the loss of Malaysian Airlines Flight MH370 and Air France AF447, demonstrate the inability of current technologies to rapidly locate a large object (i.e. modern wide-bodied long-range jetliners[4]) where its location is uncertain. Long endurance systems such as adapted Argo floats or gliders will provide wide-spread ocean monitoring and when coupled to intelligent acoustic sensors will provide essential emergency location information at a fraction of the cost of 'blind' ocean volume geophysical searches using ships.

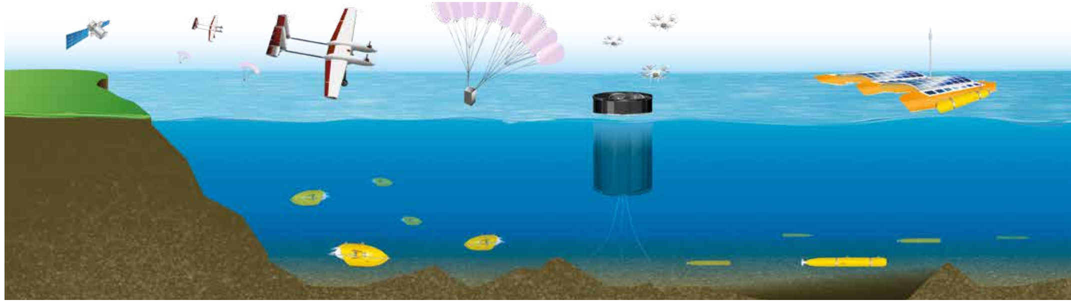
Previously inaccessible regions will be opened up through the use of autonomous systems. This will enable access to the wealth of resources within and under the ocean, and protect the marine environment through a greater ability to conduct high-precision, low impact mining and extraction activities. Such systems will also reduce the risk to people who currently work in hazardous environments. Combined aerial and sub-surface autonomous vehicles will be able to launch small sub-surface sensor platforms into remote or dangerous regions (e.g. calving ice shelves in the Antarctic). These will bring a number of advantages, including the rapid-deployment for emergency pollution monitoring or to tackle sub-surface oil pipeline and well leakages.

[1] https://mars.noc.ac.uk/missions/massmo-4 (14th June 2017)
[2] http://www.argo.ucsd.edu (14th June 2017)
[3] https://www.sea-technology.com/features/2013/0213/deep_ninja.php (14th June 2017)
[4] https://www.theguardian.com/world/2017/jan/17/malaysia-airlines-flight-mh370-search-called-off ; http://www.mirror.co.uk/news/pilot-doomed-air-franceplane-shouted-4429508 (14th June 2017)

Final thoughts

Maritime autonomous systems exploiting rapid and disruptive technologies will fundamentally change the nature of the way in which we interact and operate in the marine and maritime environment. We recognise that a number of significant challenges remain to be resolved, but the benefits to the environment, business and society will necessitate combined action to confront these issues. There is a need to develop a more consolidated approach to our activities in the maritime sector on an international basis.

The oceans provide a critical opportunity to support global prosperity and growth, overcoming a range of socio-economic and national issues arising from population growth, climate change and scarcity of resources, in tandem with a desire for greater parity in standards of living across the world. The adoption of maritime autonomous systems could be a powerful enabler to achieving this. We, therefore, need to proactively resolve the important issues around control, ethics, informed consent and market uptake as these systems are designed and implemented.



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Glossary

4G Fourth generation mobile communications standard intended to replace 3G, allowing wireless Internet access at a much higher speed

5G Fifth Generation mobile communications standard

AES All-Electric Ships

AI Artificial Intelligence

AIS Automatic Identification Systems

AL Autonomy Levels

AMS Autonomous Maritime Systems

AUV Autonomous Underwater Vehicle

FinTech Financial technology

FPSO Floating Production Storage & Offloading

GEOINT Geospatial Intelligence

GMT2030 Global Marine Trends 2030

GMTT2030 Global Marine Technology Trends 2030

GNSS Global Navigation Satellite Systems

COLREGs Collision Regulations

GPS Global Positioning System

HCI Human Computer Interface

HF High Frequency

ICT Information and Communications Technology

IMO International Maritime Organisation

INS Inertial Navigation System

IoT Internet of Things

LTE Long Term Evolution

LR Lloyd's Register

MASS Maritime Autonomous Surface Ships

MASSMO Marine Autonomous Systems in Support of Marine Observations

MASSMO4 The fourth MASSMO event that occurred May–June 2017 and demonstrated the use of marine autonomy in a scientific marine observations application

MASRWG Maritime Autonomous Systems Regulatory Working Group

MCA Maritime & Coastguard Agency

MCM Mine Countermeasure

MCMF Multi-Constellation, Multi-Frequency

MF Medium Frequency

MEMS Micro Electromechanical Systems

MSC Maritime Safety Committee

NEMS Nano Electromechanical Systems

pCO_2 Partial Pressure of Carbon Dioxide

PNT Position, Navigation and Timing

SATCOM Satellite communications

SLAM Simultaneous Localisation and Mapping

STCW Standards for Training and Certification of Watchkeepers

UAV Unmanned Aerial Vehicle

US United States

USV Unmanned Surface Vehicle

UUV Unmanned Underwater Vehicles

VDES VHF Data Exchange System

VHF Very High Frequency

VLF Very Low Frequency

WMN Wireless Mesh Networking

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