The Route to Autonomous Control – Retaining the Crew-in-the-Loop

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Synopsis

The delivery of maritime capability through autonomous solutions is undergoing exponential development, and increasingly through the deployment of autonomous vehicles. Whilst there is already a range of capabilities with regards to UxV size, range and endurance, the push to develop larger examples is evident. The focus of development has been on mission planning, launch, recovery and execution of tightly bounded missions, typically within line of sight. As the evolution in autonomous vehicles gathers pace, autonomous vehicles will likely increase in size and complexity in order to carry greater payloads, enhance capabilities and enable greater range and operational endurance. This will necessitate a greater focus on platform engineering aspects including monitoring, control, availability management and battle damage assessment such that UxVs can be reliably deployed at range in operational environments. Without a crew on board, the ability to accurately assess platform system health of UxVs, at range, will become more critical to mission success. PMS development into intelligent diagnosis and potentially repair of degrading equipment and systems may be necessary.

Historically, crewed vessels have been operated with a clear command hierarchy which defines roles and responsibilities to ensure the success of a mission. Within this hierarchy there is a clear distinction between Combat System and Platform Engineering. Combat Systems' primary focus is on sensors and effectors, which are inherently dependent on the Platform Systems that deliver power generation, propulsion, and ancillary services such as heat management. As autonomous vehicles develop, demand on these systems will increase still further. Furthermore, with the deployment of increasingly valuable (financial and militarily) vehicles at extended range and durations, the ability to manage platform systems in harmony with sensors and effectors will become increasingly relevant. When operating UxVs, the distinction between platform and combat systems will become fluid, and PMS will need to develop to ensure platform systems can be operated, monitored, diagnosed and supported throughout the mission, at extended range.

This paper will consider how PMS must develop to meet the significant challenge of operating platform systems at range, some of the certification and classification challenges, diagnosing and repairing to ensure maximum availability, and a potential operating model where platform services are managed from the operating centre and some scenarios which highlight the value of having such an operating model to ensure the success of the mission.

Keywords: Autonomous solutions, autonomous vehicles, PMS development, maritime capability

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Author's Biography

Danielle Berenbaum is a System Design Engineer with experience in writing Technical Proposals, defining technical solutions and drawing up system architectures. Danielle's work has recently expanded to Project work, developing Platform Systems from a software perspective. She has an Aerospace Engineering BEng and is currently studying for her Marine Engineering MSc.

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1. Introduction

UxVs, or Unmanned Vehicles, are steadily increasing in size, complexity and cost. In addition, the range at which they are desired to operate is expanding. This means special attention has to be paid to the systems on board which will enable them to fulfil their missions whilst maintaining system functionality.

The imbalance between combat systems and platform systems has to change if operators wish to deploy the UxVs for longer periods of time, completing higher risk operations at greater distances. Combat systems, such as Radars, and Platform systems are inherently dependent on each other and it is becoming more apparent that one cannot be advanced without the other. This means for larger, and potentially more expensive, UxV designs to ensure all the required systems can be housed on board.

Platform systems, or hotel services, are not present in as many UxVs designs as the counterpart Combat Systems as they are not as vital for the success of shorter and simpler missions. However it has always been known that these systems are essential for the maintenance and management of on-board combat systems. This includes the Electrical Distribution and Chilled Water System which ensure a constant supply of chilled water is passed around heat generating systems, safeguarding them from exceeding their acceptable operating temperatures.

Much of the focus on Platform Management System (PMS) for UxV has been on the navigation systems, allowing for these vehicles to be manually or autonomously controlled from a remote location. As the operational potential and inherently the financial investment in these UxVs is increasing exponentially, the importance of fault detection and ultimately repair at ever extending ranges is becoming more apparent.

UxVs have historically not required a PMS on board due to the small size and simplicity of their systems. This will need to change, in addition to significant development, if UxVs are to perform longer, more complex and higher risk missions successfully as the number of systems on board and therefore the number of Input/Output (IO) increases significantly. The intention is to develop the PMS solution to enable more resilient and self-reliant UxVs.

Predictive fault checking and Enhanced Health Monitoring (EHM) will undoubtedly prove to be important functions on-board, allowing UxVs to identify where systems, down to individual component levels, are not exhibiting normal behaviour and thus allow for autonomous corrective processes to begin or alert the crew-in-the-loop to allow planned maintenance activities and change of mission parameters to make use of available functionality.

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2. Autonomous Platforms Now

A number of autonomous platforms are currently on the worldwide market, having been developed, tested and demonstrated to Customers including the US and UK Royal Navy.

Each UxV requires evaluation from a number of perspectives. These include but are not limited to;

1. The potential for integration within Navies across the world
2. Capabilities and limitations for surveillance and force protection
3. Safety and regulatory compliance
4. Applications for missions, payloads and complex operations

Current UxV designs integrate mission equipment and systems which enable the autonomous control of the platform from a remote, land based location. This meant for an emphasis on combat systems, ensuring reliable and continuous communication between the control centre and the sensors and effectors. (Kumar, 2022)

3. Autonomous Platforms in the Future

As the desired complexity and length of autonomous platform missions increases, the systems on board need to adapt in parallel to facilitate.

Platform Systems, although previously a lower priority, are essential systems needed to maintain operational status. A PMS on board would facilitate the management of all these systems, enabling a holistic overview of all the data on board. The implementation of a Damage Surveillance and Control (DSAC) system would further enable the operator, even from a remote location, to effectively coordinate damage control actions in support of incident command and control.

Such a PMS has not yet been implemented on autonomous vehicles as their size and complexity has not dictated the necessity for one. However, as detailed previously, the market is changing and in order to facilitate the success of UxV development, considerable PMS development will also be required.

3.1. PMS Development

This section will look into a number of potential developments of existing PMS solutions which will increase capability with UxVs. In order to achieve a higher degree of automation for the UxVs, the PMS solution will need to adapt to provide more self-sufficient capability for the UxVs so that the remote operator interventions are minimised but still allow the operator to maintain situational awareness.

3.1.1. Crew-in-the-Loop

The UxVs currently on the market have been designed to automate as much of the operation as possible, with little crew interaction. They rely upon a remote operator located on board a control vessel or a shore based facility. This remote operator has the ability to monitor the status of each UxV and step in if required to inject control commands as a last resort mitigation.

The vessels work on automated sequences and algorithms which allow them to track, monitor, follow and avoid predetermined objects at sea.

As the mission objectives increase in complexity, more emphasis will be required to maintain the crew-in-the-loop so that integral platform systems such as the Chilled Water System and the Electrical Power Distribution System can be monitored and controlled.

3.1.2. Maintaining Situational Awareness

Situational awareness can be defined as the perception of elements in the environment, comprehension of what they mean and how they relate to one another, and projection of their future states. In the control of autonomous vehicles, it translates to the operator’s awareness of the current status and the anticipated future status of a system. (APA Dictionary of Psychology, 2022)

In order to sustain the required level of operator capability, each UxV will require a remote operator with access to the on board package of sensors. This level of situational awareness will allow the operator to assess the ever changing operational picture in real time and where necessary, override the autonomous control mode of the UxV and inject potentially vessel or mission saving control actions.

PMS solutions must ensure the data being relayed back to the remote operator is current, reliable and presented in a digestible manner. This is even more important if there are a number of UxVs operating on the same mission. The remote operator must be able to filter the information they are being presented with in order to create a tailored view specific to that situation in that moment. In parallel, the PMS must provide a

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comprehensive list of alarms and warnings, much like they do on board larger, crewed vessels, so the operator has all the necessary information to make informed decisions.

The operator must ultimately have confidence in the information they are receiving from each UxV. As the range at which these UxVs operates increases, it raises a number of questions, firstly on how this communication link between the vessel and the remote operator is preserved, and secondly, what is the UxV expected to do in the event the communication link is lost for whatever reason. This leads into important work required to classify and certify the UxVs.

3.2. Human Machine Interface

To facilitate situational awareness for the remote operators, PMS will have to include dedicated Human Machine Interface (HMI) pages to provide the operator with clear and concise information. These pages will present real-time updates from the suite of sensors associated with each of the systems on board. By developing the PMS to manage these signals and present them in a logical and comprehensive format to the operator, they are then given the tools they need to make the best decisions possible.

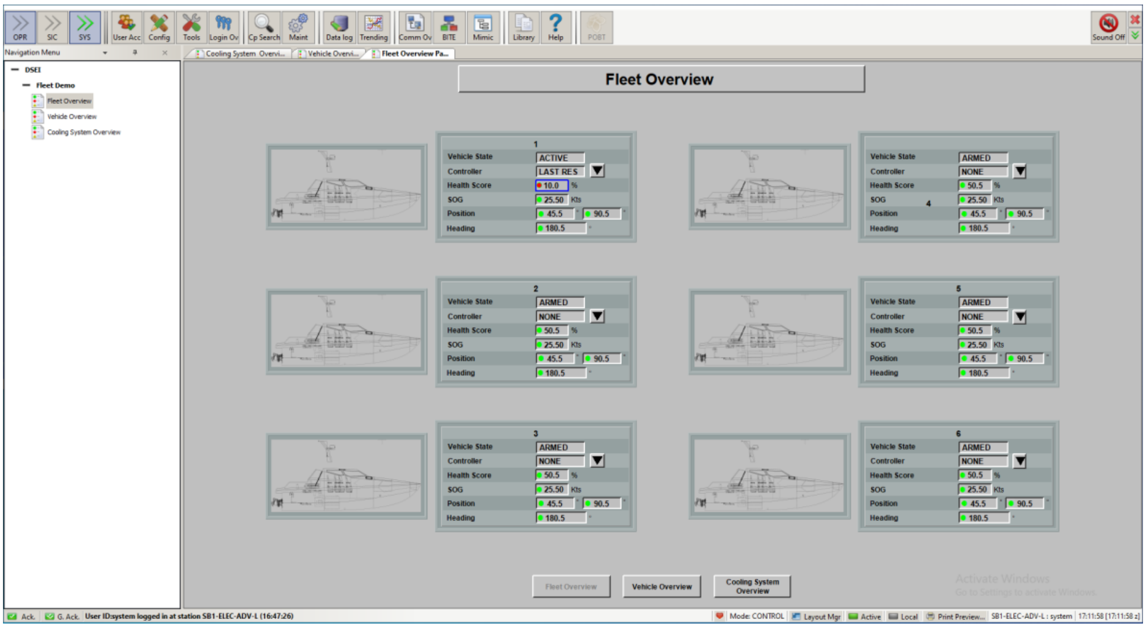

Figure 1: Indicative Fleet Overview Page

Figure 1 shows an indicative PMS HCI Page where a number of UxVs can be monitored from a single page, with high level information such as a health score, heading and mode of operation can be accessed at a glance. Providing an overview page for the UxVs will allow the remote operator to assess the fleet of vessels as a whole and may lead to better decision making. The information displayed will inform the operator of which vessels may be performing better than others and thus make them a better selection to carry out further missions, contributing to higher chance of mission success.

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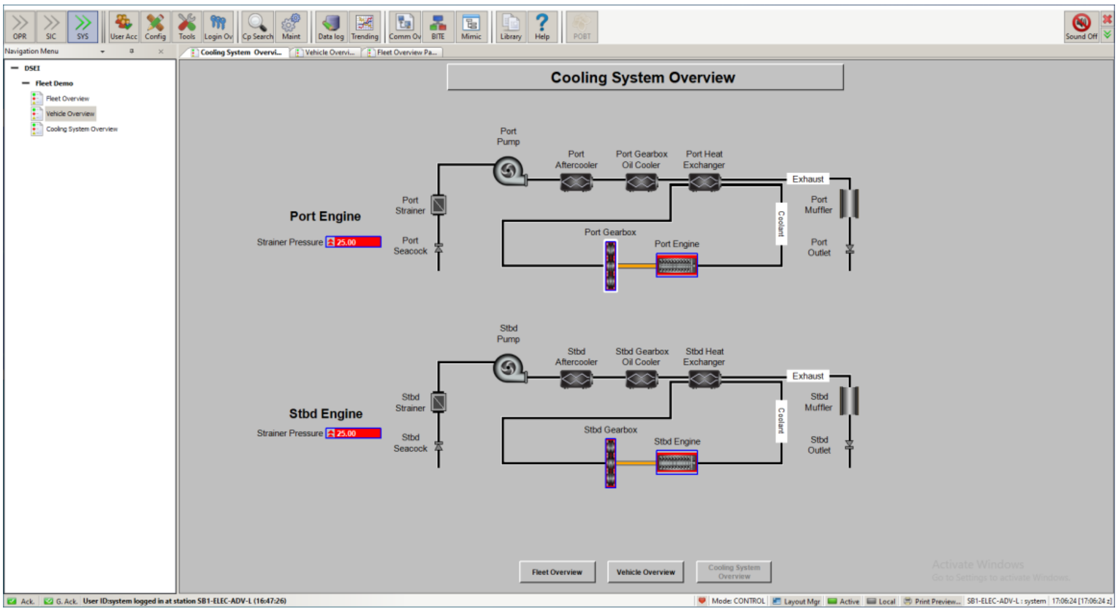

Figure 2: Indicative Cooling System Page

Figure 2 gives an illustration of what a UxV platform system page may look like, in this instance, the Chilled Water System. Having access to this information will allow the operator to monitor each system on board and give them access to control functions if necessary in emergency situations, which ultimately, may lead to the successful identification of a fault whilst it is still possible to recover and repair, all without deviating the control vessel from its original course and mission.

3.2.1. Health Monitoring

As UxVs, it is important to keep as much of the decision making autonomous, so as to not rely on the remote operator more than strictly necessary. To achieve this, the PMS should integrate a form of Enhanced Health Monitoring capability or ultimately a predictive maintenance tool. These would allow for control vessel/control base activities to be planned on priority, in advance.

These tools, alongside the appropriate algorithms, will allow the UxV to trend any combination of variables for real time analysis. The result of this analysis should then be able to indicate whether any equipment on board, from small sensors to entire systems, are not performing to the expected level and therefore trigger a response to investigate further or flag that a repair or replacement is required.

Taking this further, into predictive maintenance, would mean the UxV has the capability to identify a very gradual decrease in tank level for one of the cooling water tanks or in one section of the pipework for example. With development, a PMS based algorithm could then isolate the tank in question in the first example, under the assumption that there is a leak, and utilise the reversionary tank whilst the UxV is in operation. The UxV would then report this status back to the remote operator to allow following success or modification of the mission, the operator can schedule maintenance to identify and rectify the fault.

Developing these functionalities greatly increases the chance of mission success as it grants the UxV more resilience to maintain its own capability during operation without resorting to remote operator interaction or returning to the control ship as soon as a fault is identified.

4. Challenges

4.1. Fault Repair

Another way that the PMS solution on board can be developed to vastly increase the UxV capability is by introducing some form of fault repair whenever an issue is detected.

As it is the intention to continue to increase the duration in which each UxV can be deployed for, it would be highly useful if the UxV had the capability to autonomously make system changes on board in order to partially repair, or at least isolate the fault.

The presence of reversionary systems on board, something which is possible as the size and complexity of UxV designs increases, means that in the event of a failure, equipment can be isolated and functionality maintained.

The PMS solution requires development to include appropriate algorithms where the remote operator does not have to intervene at any point when a failure is detected. The automation sequences should identify where the fault has occurred and analyse the situation to see whether it is possible to manage the fault without returning to the control vessel. In this instance, PMS should assess whether there are reversionary systems on board thus allowing the PMS to isolate the section in which the fault has been detected, and redirect functionality to the back-up system.

A report should then be generated and communicated to the remote operator at the earliest opportunity so that they can produce a repair plan and this can be initiated once the vessel returns to the control ship.

4.2. Extended Mission Duration

Extended mission duration brings with it a number of challenges which must be faced to achieve longer deployments.

Each UxV must have sufficient fuel stores on board to maintain the vessel for the entire duration, with enough spare for lower efficiency manoeuvres if they are required. This means the UxV will be able to complete each mission without requiring assistance from the control ship.

Extended mission duration often goes hand in hand with greater distances between the UxV and the control centre. As a result, the operators must have confidence in maintaining the satellite connection between the two so that the remote operators can monitor the real time status of the vessels and maintain the ability to interject if required. Ensuring this connection remains stables also means that recovery of the UxV is still possible.

Maintaining a constant connection, instead of a UxV that moves in and out of range and status checks are carried out during predetermined check in slots, means there are fewer instances where the UxV could be lost. With each period of time where the UxV is not in communication, the potential delta between the predicted status and location of the UxV and the actual can worsen, a non-optimal solution.

4.3. Recovery Threshold

One of the benefits of maintaining crew-in-the-loop, even with UxVs, is the ability to make time sensitive decisions, based on a number of factors, which could not be done through algorithms.

In the event a UxV malfunctions or suffers damage, whether this be through warfare or not, it may fall to the remote operator to make a call on whether the vessel is recovered. In order to make this decision, a number of variables should be taken into the account to ascertain whether it is more beneficial to recover the UXV or abandon it.

To name a few of these variables; the financial value of the UxV, the distance between the UxV and the control ship the status of operation i.e. battle state.

The financial value and therefore exposure of the UxV can be expanded further by looking the value of the systems, equipment and data available on board. What if the UxV was captured by unfriendly forces? Can the link between the UxV and the controlling platform provide a weak point where it can be manipulated by someone else?

Data security is imperative for these UxVs. Take the scenario where the UxV has been captured by enemy forces and the control centre vessel is in the highest state of alert, carrying out battle operations. As no lives would be directly lost through the capture of the UxV, it is not unimaginable that it is not deemed a priority to attempt recovery. In this instance, the UxV should have a number of failsafe processes to ensure two main objectives; firstly that the line of communication cannot be manipulated to inject false information back to the control ship, and secondly, that the enemy cannot pull sensitive data from either the UxV or more seriously, the control ship.

In the event the UxV is captured, it would be pertinent to assume the UxV is no longer an asset, but instead a potential threat. This would mean a decision must be made by the remote operator as to whether a rescue attempt for the UxV should be made or whether it should be destroyed.

4.4. Responsibilities

Capabilities on board larger vessels such as Helicopters or F35s like those found on the Queen Elizabeth Class carriers, require dedicated teams on board whose sole job is to control and monitor these systems. These teams manage the capabilities whilst on and off board, ensuring there are no conflicts which would result in an unsuccessful mission.

When considering UxV capability, it is highly possible that the number of UxVs deployed to a single control vessel may not be limited to one. As a result, it would be pertinent that there be at least one crew member on board whose role it is to control and monitor their status.

This responsibility may fall to the Marine Engineers (MEs), who historically have taken similar roles on board, but consideration will be needed to ensure that there are enough MEs to carry out the roles and responsibilities required. Alternatively, a dedicated section may be required in order to fulfil the role.

4.5. Missions

With the discussed developments, UxVs have a much broader range of capabilities and can therefore be utilised for a greater variety of missions. By retaining crew in the loop, but having them remote operators, brings lifesaving opportunities and cost advantages for extended capability.

By replacing otherwise manned ships for high risk operations such as munitions delivery with UxVs means that crew are no longer exposed to the real threat of attack. The nature of these missions has previously meant that munitions ships are a high value target, with enemy forces wishing to cut of the supply of munitions to the larger vessels. Although this risk of attack is not necessarily mitigated, there would no longer be the risk to life.

Further to previous discussion, it is important to identify what impact the missions has, and consequently what cargo may be found on board the UxVs, on the recovery of the platform. Some missions may be categorised as high risk and therefore an automated recovery process should initiate as soon as any unfriendly objects are identified.

4.6. Acceptance

Navies across the world can be reluctant when it comes to accepting new and innovative technologies as it detours from what operators are comfortable with. As warfare changes and technology advances, the opportunity to remove bodies from life threatening situations as well as the cost saving opportunities cannot be ignored.

The Navy X group, a UK Navy initiative to develop autonomous capability within the Navy, aims to demonstrate the maturity and opportunity of unmanned autonomous systems. This includes dispelling negative connotations surrounding the use of UxVs and realising the benefits of taking human error out of many of the processes.

The goal is to communicate the benefits of using UxVs to remove human operators from monotonous or dangerous activities, thus saving lives and freeing up those same Navy operators to perform more suitable tasks.

Work already done to accept current Ship based PMS solutions will strengthen efforts to accept UxV based PMS solutions. Considering the UxV PMS solution as just an extension and a development of the capability already utilised on board means a lot of the acceptance work has already been done.

These capabilities will be completely new to a lot of existing ship staff and therefore have the potential to hit resistance. This further strengthens the case for a dedicated team on board to manage the capability. Training and understanding for UxVs will be important tools to ensure consistency of approach and a smoother transition into operation. (UNMANNED WARRIOR, 2022)

Although this may take time, achieving agreement amongst the Navy personnel at all levels, is an essential stepping stone to facilitate further development of the vessels and their systems on board. Ultimately, this confidence should begin at industry level. Cooperation from industry partners in developing the PMS solution and enhancing UxV capability will help build the required confidence to achieve acceptance.

4.7. Certification and Classification

As defined by the International Maritime Organisation (IMO) for their Regulatory Scoping Exercise, there are four degrees of autonomy;

Degree One: a crewed ship with automated processes and decision support,
Degree Two: remotely controlled ship with seafarers on board,
Degree Three: remotely controlled ship without seafarers on board,
Degree Four: fully autonomous ship.

These autonomy classifications raise a number of questions which would dictate the degree assigned to the UxVs, which to require a PMS solution on board, this would be Level 2 and above. With each level of autonomy comes different levels of development required for PMS.

One of these is how to define seafarers. According to the 2021 IMO Regulatory Scoping Exercise, it could be argued that a remote controlled operator situated on the control vessel, but not on the UxV itself, can be classified as a seafarer. In this instance, it would drop the degree of automation from three to two. (Autonomous ships: regulatory scoping exercise completed, 2022)

This ambiguity should be cleared before full confidence can be reached on how to define degree two to four vessels and therefore be able to achieve classification from the relevant classification societies.

International standardisation has not yet been achieved for Assurance, Certification and Authorisation. Reaching this would mean a common agreement across the industry about terminology, the aforementioned degrees of automation and standards which all UxVs must comply with.

5. Conclusions

There a number of hurdles and obstacles that face UxVs before they are to be accepted industry wide but the benefits cannot be underestimated.

Achieving industry standard for the certification and classification of these autonomous platforms will enable confidence throughout the industry and help facilitate acceptance into Navies across the world. This cannot be achieved however until significant developments have been introduced to the platforms and their PMS. These advancements include updates to both the UxV itself, and the control vessel, to accommodate these further capabilities. This will enable a clearer understanding of the differences between degree three and degree four levels of autonomy.

In terms of the UxV, the vessel designs need to incorporate more platform systems alongside the combat systems and a clear appreciation of why these need to take a higher priority than previously must be understood. With longer durations and higher complexity of missions, the platforms must have the capability to be able to sustain themselves for longer. This includes delivering vital cooling water to systems like the propulsion system and the power generation systems, as without these, the combat systems cannot operate to their full operational potential.

Historically, UxVs have not warranted a PMS on board due to the relative simplicity of their systems and missions. This will need to change if UxVs are to perform longer, more complex and higher risk missions successfully as the number of systems on board and therefore the number of Input/Output (IO) increases significantly. This will facilitate more efficient monitoring and, where necessary, control from the remote operator by providing access to the big data picture on board, contributing to better decision making and ultimately leading to greater mission success.

In addition, the UxV will be capable of autonomously reacting to changes in the environment, as well as faults or damage. It will feed information back to the remote operator whilst maintaining capability to complete the mission without remote operator intervention.

The PMS solution on board may also need to deliver enhanced health monitoring, detection and therefore mitigation wherever possible. By enabling the UxV to perform potentially platform and mission saving measures autonomously, it will inherently increase the availability of these vessels and open up further opportunities for the type and duration of missions that they are suitable for.

There also needs to be a mind-set change within the industry, especially within Navies, to accept UxVs as a standard capabilities on board. Not only will there need to be a change in training, but also acceptance that the technology can be relied upon and can provide opportunity and help rather than be a hindrance. This lies parallel with achieving industry standard certification and classification, and communicating clear guidelines as to when the UxVs are worth saving and when they should be abandoned, so as to not negatively impact the control vessel.

Before UxVs can be fully integrated within military scenarios and fleets worldwide, the industry should address the factors described in this paper. As it stands, most UxVs are better suited to less onerous operations and so to be considered as standard deployment within a fleet, the UxVs require significant development of their design and platform management capabilities, and the industry needs to achieve a common understanding of their classification, operation and certification.

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Glossary

Acronym	Definition
PMS	Platform Management System
UxV	Unmanned Vehicle
EHM	Enhanced Health Monitoring
ME	Marine Engineer
HCI	Human Computer Interface
IMO	International Maritime Organisation
I/O	Input/Output

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