Generational Shift: How technology is shaping a step change in the future of mine counter-measures

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Synopsis

Developments in the command and control of offboard maritime assets, and evolution of the design of the assets themselves, have opened up new avenues to navies, industry and research institutes to change the way in which they consider and conduct Mine Countermeasures (MCM) operations. However this shift, driven by the opportunity for risk reduction and a potential increase in operational tempo, requires a change in Concepts of Operations; this will affect the way both MCM vessels and the associated MCM equipment are designed and operated in the future.

This paper explores how BMT and QinetiQ have investigated the changes this new disruptive technology will have on MCM operations, and the concept of operations that can be adopted to maximise the use of this technology. Working with mine warfare and autonomous systems industry leaders, along with lessons from Unmanned Warrior 2016, and drawing on the experience of operators from several navies, the team established a range of operational concepts that can be employed to clear a minefield or hunt individual mines. Detailed Operational Analysis (OA) was carried out to validate these concepts and determine the required Unmanned Vehicle (UxV) numbers and capabilities. Aligned with this approach is the development of the QinetiQ Unmanned Autonomous Systems Architecture (QUASAR); a flexible system which maximises the use of UxV technology without adding to the operator burden. The outcome of this work is a new breed of MCM platform design which, thanks to the significant effort in developing the concepts of operation and the underlying OA over a number of years, is able to deliver mine warfare as technology transitions from the current capability to the future. This paper outlines the road taken to arrive at this design and the technology incorporated within, the lessons learnt along the way and what this means for the future of mine countermeasures operations.

Keywords: Mine Countermeasures, Autonomous Systems, Unmanned Autonomous Systems Architecture.

1. Introduction

In the upcoming decades, the settings and the tempo in which navies operate will be dramatically different to that encountered in the last 30 to 40 years (UK Ministry of Defence DCDC, 2015), due in part to the emerging advancements witnessed in technologies, complicated and driven by significant global changes such as population growth, climate and energy. With the rapid rate of change in the availability of materials, systems and technologies, there is a need to develop new operational concepts in order to keep pace.

Important and noteworthy developments in automation have been witnessed in recent years in many fields, from the development of unmanned cars to the intricate workings of traffic management systems. This symbiotic relationship of man and machine working collaboratively in an optimal relationship will be a driving factor in delivering optimum benefit in the battlespace. As the operational environment changes so should how navies think and conduct Mine Counter Measures (MCM).

Authors' Biographies

J C Rigby – A Naval Architect at BMT in Bath for over 4 years having previously trained at UCL. Specialising in the areas of Ship Signatures and Survivability, he also has experience of autonomous systems and their operability with ship designs. He is currently in the role of Research and Development lead.

J McWilliams – With 24 years' service in the Royal Navy, Jacqueline is a subject matter expert in Mine Warfare and was responsible for the delivery of trials of autonomous survey systems for the UK MCM and Hydrographic Capability project as the Officer in Command of the RN MASTT. She is now a member of QinetiQ's Maritime Autonomy Campaign operating between project SME advice and delivery of unmanned vehicle test and evaluation activities.

J Johnson – A Senior Naval Engineer at BMT, with experience in the design of the Tide Class Fleet Tankers, Norwegian Logistic Support Vessel and other naval platforms. Specialising in operability and operational analysis, he also has experience in government side support to programmes such as the Australian SEA1180. He was previously a Warfare Officer in the Royal Navy.

The first step is accepting that maritime autonomous technology can offer a credible capability and as such can reshape the maritime sector, and how MCM operations are undertaken. This will lead navies, industry and research institutes to change the way in which they consider and conduct Mine Warfare. This shift, driven by innovative and robust autonomous development, provides the opportunity for risk reduction and in doing so requires a change in the concepts of operations for both MCM vessels and associated MCM equipment.

Today, post-cold war, many maritime nations have sought new ways to tackle the growing security threats of the 21st century. One persistent and significant threat is the sea mine. Global proliferation of the sea mine, both existing (often antiquated) variants and modern technologically advanced models present unique challenges to maritime security.

The naval mine is relatively cheap, easy to employ and highly effective; the ultimate fire and forget weapon. Consequently Naval forces must be prepared and appropriately equipped to counter the threat that sea mines pose to shipping, including safeguarding key sea lines of communication (SLOCs), strategic straits, chokepoints, commercial harbours and naval ports. Figure 1 presents a map of global ocean trade routes, highlighting key chokepoints and strategic areas that could be vulnerable to mining operations. One key series of chokepoints includes the Mediterranean Sea, through the Suez Canal and the Bab el-Mandab Straits and up to the Arabian Gulf via the Straits of Hormuz; these areas have been the focus of significant enduring MCM effort over the last 30 years. The flow of trade and freedom of navigation in other areas, such as the South China Sea, are also particularly vulnerable to the mine threat.

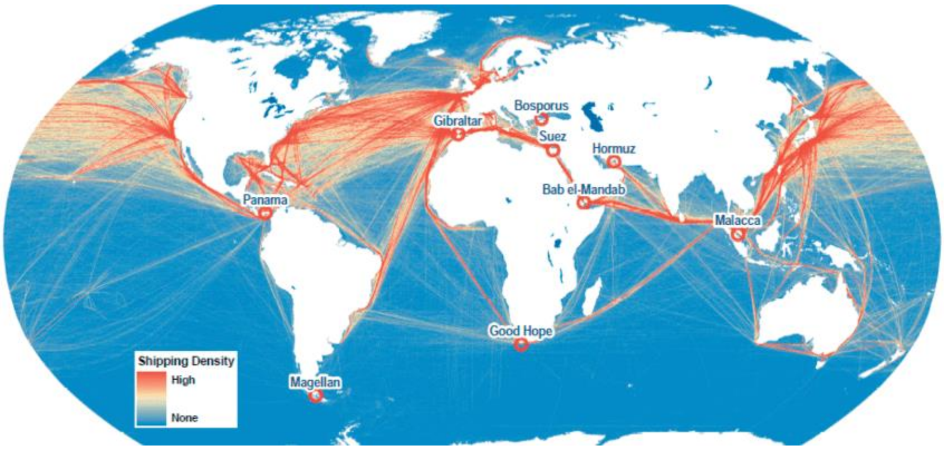

Figure 1 – Shipping density across global maritime trade routes over the last 30 years show areas vulnerable to naval mining operations. Image reproduced from (Asariotis et al., 2014).

Automation/Autonomy can play an important role in countering mines, but needs to be integrated appropriately in a stepped approach which assures the system as a whole. Autonomy offers the following to the clearance of these mines:

- Increased safety (direct intervention or avoidance);
- Improved efficiency;
- Reduction in Dull, Dirty, Dangerous tasks;
- Increased operational effectiveness (persistence);
- Reduced/hostile communications environment;
- Reduced cost.

It is important to emphasise the importance of MCM operations ensuring the safety of worldwide shipping, both military and commercial. Since World War Two, mines have been the largest cause for warship damage or loss and pose a significant risk to commercial shipping (Navy History, 2018). Figure 2 outlines the US Navy Ship casualties since World War Two against conflict and cause. This highlights that the settings in which navies operate is changing in terms of locations, tempo, ISTAR, etc but what remains, and is a constant threat, is mine warfare. Even though the majority of these mines were deployed many years ago, they are still used today as an affordable cost effective weapon for developing navies.

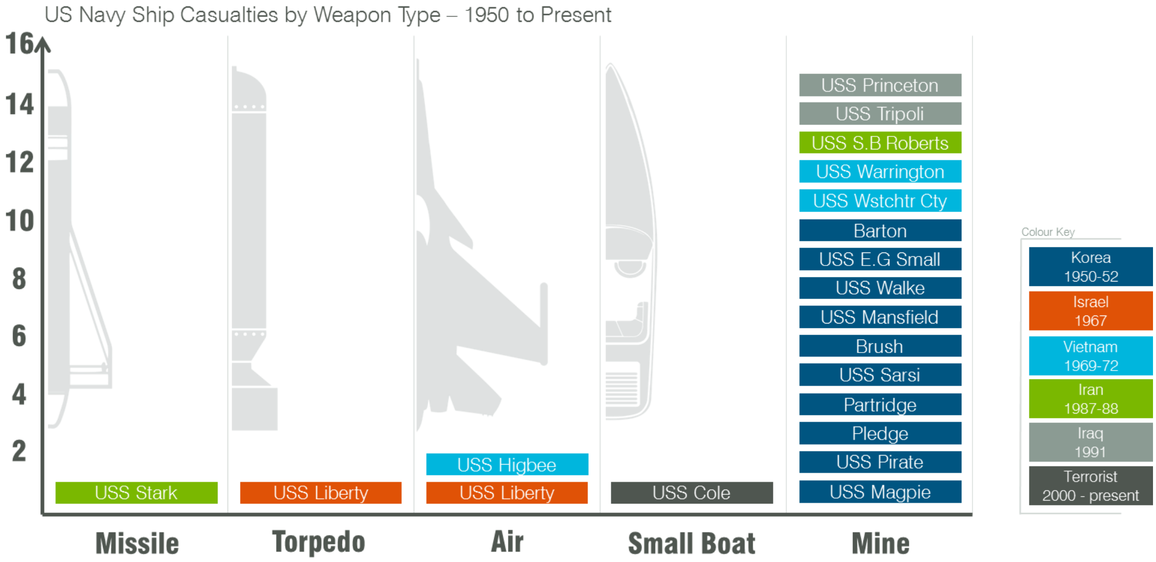

Figure 2 – US Navy Ship Casualties by Weapon Type - 1950 to present (Data from Navy History, 2018)

The image presented in Figure 3 below shows the mine damage sustained by USS Tripoli during Operation Desert Storm (February 1991). The extent of the damage experienced, and the fact that a relatively low-cost mine was able to remove a large Amphibious platform from the line of battle is one example that shows naval mining remains a cost-effective and favoured means of area denial that a Navy will need to counter.

Figure 3 - Damage sustained by USS Tripoli during Operation Desert Storm (1991) due to a naval mine. Image reproduced from Nav Source (2018)

As further evidence that the naval mine is not an outdated weapon, consigned to the history books in a world of cyber threats, Figure 4 shows that sea mines and minefields have been employed around the world during every decade from the 1950s to today. This highlights further the prolific use by both state and non-state actors of this relatively cheap, easy to use and persistent weapon system; delivering a disproportionately higher effect against more expensive Naval platforms, denying areas of operation or deterring opposing forces, or disrupting the flow of commercial trade, food and energy to achieve political goals.

Figure 4 - Active Sea Mining Events since the 1950s, information reproduced from O'Flaherty (2018)

The development of the technology employed in these naval mines has not stood still either. Smart mines built from composite materials, with multiple actuation methods and the ability to recognise and ignore influence sweep counter-measure activity, compound the detection, identification and classification challenges of mine clearance. These smart mines, alongside other examples such as autonomous re-positioning mines and seabed-moored torpedo mines, present a developing threat to naval forces; one that future mine counter-measures will need to meet to remain relevant.

2. Mine Warfare Vessels: Past and Present

Before we can understand the future of Mine Warfare it is first important to understand the past and present. Looking at the selection of Mine Counter Measure Vessels (MCMVs) shown in Figure 5, it is clear that the fundamental attributes of MCM platforms in layout, length, beam and displacement (hence the area available for mission equipment) have remained relatively unchanged in the past 100 years. These attributes are unsuitable for the transition to future capability, due to their limitations in size and displacement against the payload of different vehicles and tools needed to deliver the full range of mine clearance capability required by a modern Navy, to counter the developing threat.

This selection shows that the overall length of these vessels is roughly the same at around 60m. Displacement is often limited to minimise the draught and facilitate the exploration of shallower waters. Beam and displacement are also fairly similar between each example, reflecting the fact that the concepts of operation and equipment required have not changed drastically over time. Since the invention of complex magnetically-actuated underwater mines, the materials have remained consistent; the vessel hulls have been made from either composite materials such as fibreglass, or wood, or made from non-magnetic steel. The use of composite materials can in turn place restrictions on the overall size of the vessel that can be built due to available materials technology and structural strength limitations; the use of expensive non-magnetic steel also introduces significant cost to the vessel.

In order to remain relevant against the developing mine threat, an increased application of autonomous and unmanned technology is being embraced by navies around the world, allied with new concepts of operation. However, this application of autonomous and unmanned systems will disrupt the trend in the size and displacement of current MCM vessels. The attributes in size, layout and space of these current vessels will rapidly become obsolete against the requirements that these new concepts and autonomous technologies will bring.

Figure 5 – A selection of Mine Warfare Vessels past and present. These images, and their associated dimensions, show that MCM vessels have not departed far from a common layout and size over the past 100 years. Autonomous technology and developing doctrine is likely to disrupt this trend, leading to a new breed of MCM platform to counter the developing mine threat.
(Insert Images from Naval Technology, 2017)

3. Concepts of Operation

Working with the wealth of experience brought by mine warfare and autonomous systems industry leaders, along with lessons from Unmanned Warrior 2016, and drawing on the experience of operators from several navies, a range of operational concepts that can be employed to clear a minefield or hunt individual mines were developed. This research identified the advantages, drawbacks and technical limitations of each concept. The spectrum was broken down into four separate concepts of operation:

- Channel Immune
- Channel Avoid
- Channel Standoff
- Area Standoff

For the purpose of the analysis of these concepts of operation and the discussion within this paper, the minefield is assumed to be around 50 nautical miles (nm) deep, the ultimate edges of the minefield are unknown and the mine density, depth of water and bottom-type can vary.

These assumptions are important in order to model the various MCM scenarios and establish the drivers within these operations against the developing concepts, current / future developing technology and platform design aspects. To prevent bias in the operational analysis, and adding improbable constraints, it is important to use realistic assumptions, especially for the depth of the minefield. 50nm is representative of a mid-sized minefield; comparable to mining within the length of a strategic choke point such as the Straits of Gibraltar, the Dardanelles or the width of the Gulf of Finland, or a defensive minefield laid in the approaches to a port. A deeper minefield (>100nm), such as one that would deny the Straits of Hormuz, or the Malacca Straits, or the freedom of navigation in larger blue/brown-water areas such as the South China Sea, whilst a plausible threat, was not used in this analysis so as not to drive the requirements for a high endurance solution. Please also note that a significant sensitivity analysis was also conducted around this value.

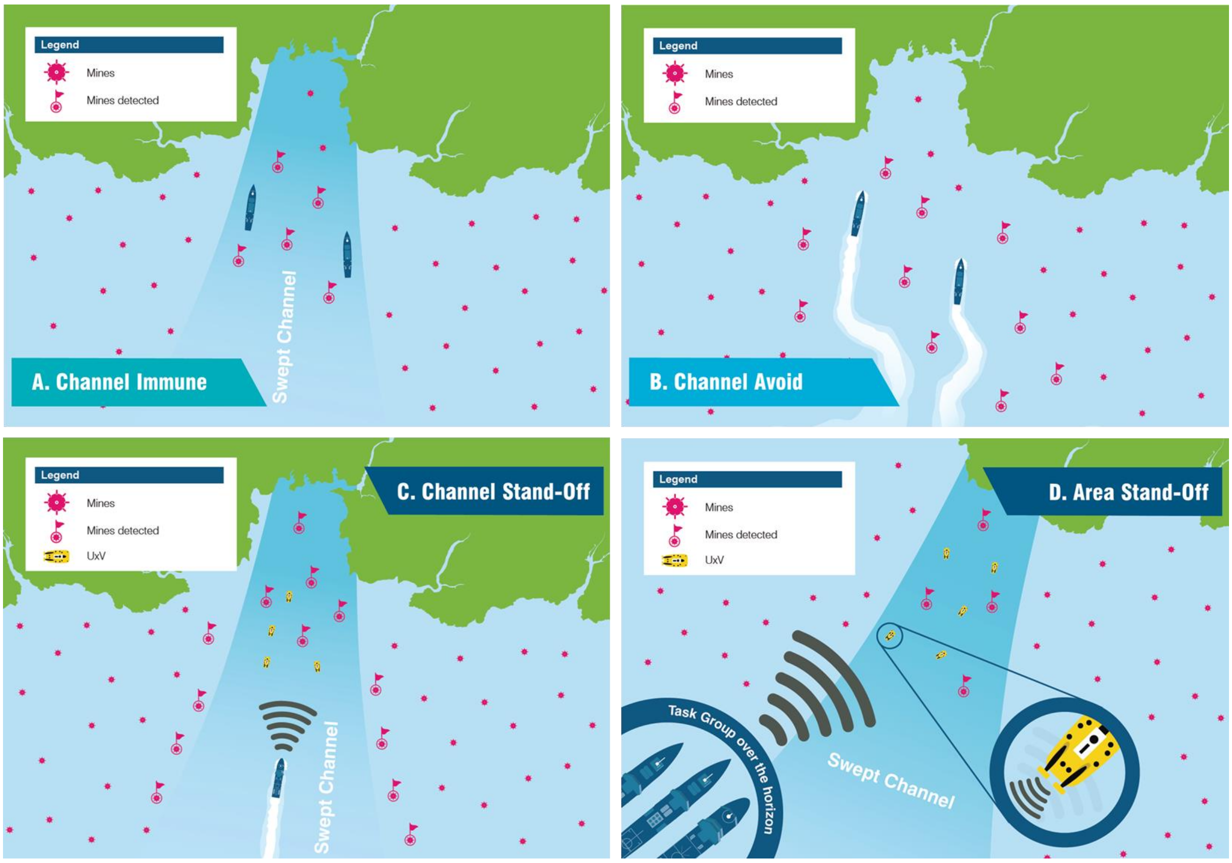

Figure 6 – The four proposed Concepts of Operation for Mine Countermeasure Operations
a. Channel Immune b. Channel Avoid c. Channel Stand-Off d. Area Stand-Off

3.1. Channel Immune

The Channel Immune operating concept as shown in Figure 6A is the same as that currently employed by most of the low signature MCM platforms currently in service. It involves reducing acoustic and magnetic signatures (including use of a non-magnetic hullform) and increasing shock resistance to make the platform largely “immune” to the mine threat, and enables the vessels to operate in the minefield with reduced risk of detonation. This approach can be carried out by one or more platforms, where all would carry out the detection passes until a mine like object is detected, with one platform tasked with classification, localization and neutralization. As discussed, Channel Immune vessels rely on very low magnetic and acoustic signatures and significant resilience against underwater shock; these types of vessel also require accurate navigation, manoeuvrability and position keeping. All of these factors add significant cost to the procurement and maintenance of the vessel in order to reduce the risk to the personnel onboard.

3.2. Channel Avoid

The Channel Avoid concept is presented in Figure 6B. With this concept of operation, the MCMV also enters the minefield but relies more upon sensing and manoeuvrability to maintain separation from mines. The methods of detection, classification, localization and neutralization would be almost identical to Channel Immune. The key difference would be a higher reliance on the accuracy in navigation, position keeping and manoeuvrability. The vessel should be able to navigate around the mines and position-keep in order to maintain a safe distance from the mine. Channel Avoid vessels could afford less onerous magnetic and acoustic signature control than Channel Immune vessels, and hence could allow for a metallic (non-magnetic) hullform, while resilience to underwater shock would be similar. Due to the increased signature of the vessel, if there were any faults or breakdowns in the positioning and detection system the platform would be placed under extremely high risk of damage.

3.3. Channel Stand-Off

The Channel Stand-off concept of operation (as presented in Figure 6C) requires the MCM platform to progress through the cleared channel (up to 50nm in length, under the adopted assumption), using unmanned and autonomous systems to clear mines at an appropriate distance ahead. This concept would utilise a range of offboard systems to search, classify, influence sweep and neutralise the mines. Because the vessel does not need to enter the minefield itself, a lower level of signature (including acoustic) control is required.

If it were possible to assume that the mine hunting and sweeping operations by these systems were 100% effective, there would be no requirement for any shock hardening above that required by any other naval vessel that would subsequently need to traverse the cleared channel. However, as it is assumed that this vessel will be required to operate continuously in a high risk environment, a level of additional underwater shock hardening should be provided to counter any mines missed by the search, or mines in the uncleared regions either side of the swept channel as the host platform manoeuvres.

Improved manoeuvrability and position keeping should be provided to keep the vessel within the cleared channel in all environmental conditions, and to allow the vessel to position and manoeuvre to react to an inbound threat. This improved manoeuvrability is also required in order to launch/recover/restore/refuel the large offboard systems in the wide range of demanding environmental conditions without endangering the MCMV. An additional outcome of the increased survivability and manoeuvrability is that it allows the platform to approach the minefield in order to deploy and support clearance divers. In the short to medium timeframe, mine clearance divers may still be required for a particular situation that is beyond the capability of the offboard systems in identification, classification and disposal. The cleared channel width must allow for sufficient room to manoeuvre in the event of an emergency, enemy action or in extreme weather conditions.

3.4. Area Stand-Off

The Area Stand-Off concept of operation (as presented in Figure 6D) is predicated on the total use of offboard systems deployed over the horizon from the host platform. These offboard assets would clear a channel ahead to permit theatre access. The host vessel would remain out of the channel until it had been cleared and would then proceed in company with the other vessels. As the offboard systems are the only MCM vehicles that enter the area of the minefield, the host platform does not require the same level of survivability in areas such as shock and signatures. This means that the host platform could be a commercial ship, or a capability hosted in a larger naval platform with another primary role, or deployed from shore over the horizon. However, considering the technology available, this concept of operation has a number of drawbacks that would need to be overcome:

- If a minefield is assumed to be 50nm deep, and considering the requirement to keep a commercial or non-optimised naval host platform a safe distance 'over the horizon' from the nebulous leading edge, the systems would have to be deployed over a significant distance to clear the entire channel. Current technology cannot support the deployment of unmanned vehicles without a secure and assured communications bridge (Santamarta, 2014), with the required network bandwidth to transmit considerable sonar plot data or target identification & classification data to the host platform over the required range; whilst also remaining covert from opposing forces detection, interception or coercion and permitting required man-in-the-loop positive control over disposal activity at range.
- Autonomous surface vehicles deployed over the horizon and up-threat will require surveillance and protection. These offboard systems, with their deployed sensors and onboard automated target recognition processing, represent a significant expenditure which will be vulnerable to opposing forces that seek to preserve the minefield, or to capture such technology, therefore denying theatre entry conditions. The vehicles would need to be protected from threats ranging from missiles / aircraft, to helicopters or Fast Inshore Attack Craft (FIAC) and other asymmetric threats. A solution could include the installation of self-defence weapons on the unmanned vehicles themselves but this compounds the communications challenge with the additional requirements to identify, target and neutralise enemy forces with positive manned control; granting the autonomous vehicle the ability to make these force protection decisions itself raises significant ethical issues if facing a human opponent.
- Due to the significant distances involved, this concept pushes unmanned vehicles (UxVs) beyond their current operational range limits and would significantly increase the time required to clear the minefield

due to the increased transit time (UK Marine Alliance, 2018). For example, the majority of underwater unmanned vehicles (UUVs) currently employed for search and classification roles have a top speed of 6 knots and a maximum endurance of around 10 hours (not accounting for tidal stream), precluding them from use in this concept. Using an unmanned surface vehicle as a taxi to and from the area of operations would go some way to resolving this issue, however this will push up the required size, capacity and cost of the USV, and serves to place all of the MCM 'eggs in one basket', considering the aforementioned communications and self-defence issues.

- The technology for operating autonomous vehicles under COLREGs (Deketelaere, 2017) and other regulations over these significant ranges is insufficiently mature to offer a viable solution at this time.

3.4. Operational Analysis

Operational Analysis, using agent based modelling, was conducted to investigate the feasibility of the different CONOPS and determine the number of offboard systems required.

Two different types of UxV were modelled within the analysis of these concepts, covering the main roles of search, identification, classification and disposal.

1. A Survey Unit: Used to survey the area and search for mines.

2. A Classification/ Neutralisation Unit: Used to classify mines once identified by survey vehicle & launch mine identification & disposal systems.

Using the Channel Stand-Off Scenario, the recommended operational mission payload was calculated to be 2 Survey Units plus 2 Classification Units. These are operational numbers and will need to be increased to allow for reliability and maintenance therefore giving a total payload of 2-4 Survey Units and 2-3 Classification Units. Further details of the analysis are provided in Appendix A.

3.5. Summary

In summary, of the four different concepts of operation, only three are considered feasible in the short to medium timeframe. The Area Standoff solution offers a very attractive solution but due to technical limitations to be overcome it is only likely to be feasible in the long term.

In the short to medium term, navies are faced with three options; the conventional and high cost Channel Immune/Avoid concepts employed currently or adopting the new range of offboard systems in a Channel Standoff solution. Channel Stand-off is the most practical option of the three, as it effectively utilises the technology of autonomous systems within an affordable and flexible platform. The Channel Standoff scenario requires a dedicated ship design that can launch/recover off board UxVs, has situational control and has high shock resistance/survivability. These shock/survivability capability requirements have also been subject to additional, commercially sensitive, analysis. The shock requirement would be expected to be less than the current Channel Avoid vessels, but in reality may be harder to achieve depending on the sensitivity of on-board vehicles and equipment.

4. Transition to Future Mine Countermeasure Capabilities

It is easy to get carried away by the recent successful trials of autonomous systems or the adoption of individual systems with a single utility into service, and decide that the technology is ready to be employed for the full range of MCM operations. However, against the requirements of live operations the transition to Future Mine Countermeasure Capability will only be achieved in graduated steps, as technology develops and confidence in their use in real-world operations against a determined opposing force grows. This can be summarised as a four step process from the current to the future capability as presented in Figure 7 below.

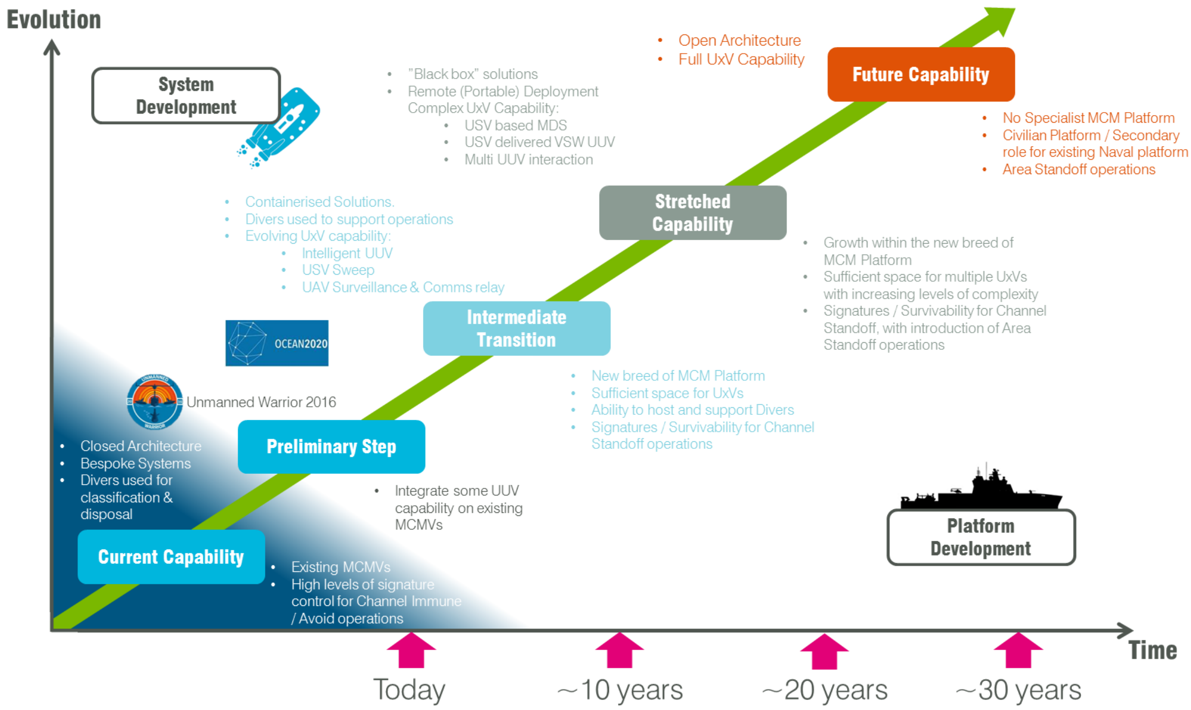

Figure 7 - Transition to Future Mine Counter Measure Capabilities

4.1. Preliminary Step

The first is a Preliminary Step from the current capability of the legacy vessels highlighted in Section 2 above. The current vessels employ the Channel Immune/Avoid concepts of operation, relying on high levels of signature and positioning control. They utilise legacy bespoke-built closed architecture mission systems, making system integration of additional capabilities complex and costly. This first preliminary step, already taken by some navies, is to integrate some UUV capability on existing vessels while still maintaining the primary search/survey capability onboard the ship.

An example of these new unmanned systems being implemented, and as part of the preliminary step, is the 'Unmanned Warrior' exercise which took place in October 2016 where industry, academia and allied nations came together to test and demonstrate offboard systems capabilities. The Unmanned Warrior operation involved 50 different systems that could operate in all domains. The operation successfully demonstrated the maturity of many of the systems and showed how the roles and information from these vehicles could be integrated within traditional warships. However, this successful trial did not mean that the entire system of systems (unmanned vehicles, command and control, communications and policies & doctrine) required for future MCM is now ready for deployment in real-world operations. For example, in order to allow the squads of different Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs) and Unmanned Underwater Vehicles (UUVs) to communicate, a simple Wi-Fi network was used; this was successful in the exercise and proved the unmanned squad concept. However this operation took place over relatively short distances of around a mile, and would not be suitable as a secure and covert communications solution over the distances required in live MCM operations.

4.2. Intermediate Transition

Whilst the existing MCM platforms are able to host a handful of smaller offboard systems, used for individual roles such as classification or disposal, in order to progress to the next step the range of systems required for the full spectrum of MCM capability are required. This includes the USVs, UAVs and UUVs employed to conduct search, localisation, classification, influence sweep and disposal activity within acceptable operational timescales, with additional systems to provide redundancy and allow for maintenance. The current MCM platform designs described in Section 2 lack the real-estate to store, operate and maintain these systems, and the stability and buoyancy to launch & recover them in adverse weather conditions. This leads to the requirement for a new breed of MCM platform, described in greater detail later in this paper and at Appendix B. Additionally, due to the current limitations of the technology (e.g. communications range), and policy in areas such as the defence of offboard assets, a Channel Standoff concept is the only viable methodology at this step. Thus, the host platform will be required to follow the offboard assets through the swept channel, supporting the systems up to their maximum range from the host (around 10nm) (UK Marine Alliance, 2018), again assuming a 50nm deep minefield.

This brings platform survivability requirements, necessary to reduce the risk to personnel operating onboard to an acceptable level. These features include shock protection. This is not just in shock mounting for equipment such as main generators and drive motors, but also shock hardening of the fundamental hull structure itself and the associated furniture, including hull valves. The incident in December 2008 when HMS ENDURANCE was almost lost due to the failure of a hull valve, whilst in this case not due to a shock event, showed the impact resulting from failure or damage to even one of these underwater hull features; this precludes the use of a ship built to civilian/commercial standards in a Channel Standoff operation due to the high likelihood of severe flooding following a mine detonation, even at range (due to shock propagation).

The technology behind these autonomous systems is under constant development. During this transition the platform will be expected to adapt to host the developing equipment. Therefore, where possible, containerised or modular systems are recommended to allow the UxVs to be changed regularly with minimal disruption. USVs, deploying search, classification and disposal UUVs, will also be required to act as a communications bridge to the underwater assets, as well as being employed in influence sweep operations. UAVs may be used as a communications relay link to the host platform to increase the capable range. These UAVs will also have a secondary role of threat and surface mine surveillance. This array of offboard assets working in concert requires C2 to enable each squad to act autonomously, according to set mission parameters, without significantly increasing the manpower required onboard. Finally, in this intermediate transition phase, clearance divers will still be required for support and will serve as a backup if the offboard systems cannot handle specialist classification or disposal activities.

4.3. Stretched Capability

As time passes, this new breed of MCM vessel will potentially need to incorporate and support increasing numbers of offboard systems, certainly with increasing complexity or size. The systems are more likely to offer a “black box” off the shelf solution with increased reliability in real-world operations. These new systems will incorporate Remote (Portable) Deployment of Complex UxV Capability including:

- **USV based Mine Disposal Systems (MDS) –** Enabling the mine to be exploded well away from the host platform.
- **UUV based MDS –** Enabling covert mine identification and disposal.
- **USV delivered UUV Survey Vessel –** Allowing surveys to be completed beyond the horizon and further away from the ship.
- **Multi UUV interaction –** Increased autonomy to enable UUVs to interact and work together to efficiently survey the sea bed.

It is important that the new breed of MCM platform is designed from the start with sufficient space and support structures in order to facilitate the anticipated growing number of larger offboard systems. These larger systems, and a reliance on large USVs, will stretch the capability of the platform and launch & recovery arrangements; it is critical that the platform is designed and built from the start to accommodate this development to avoid early obsolescence.

The host platform will still be capable of Channel Standoff operations; however, due to reduced operational risk, increased technical capability and confidence in the offboard systems, Area Standoff may start to become feasible. In this case, the host platform will move further away from the minefield, now deploying systems over the horizon rather than following them through the swept channel.

4.4. Future Capability

This final future capability is the end goal for many navies across the world. It will involve employing the Area Standoff concept in its entirety, with specialist UxVs enabling the performance of the complete MCM role at long range, able to adapt to all the challenges of live operations. The delivered solution will also have to provide commanders with full confidence in the ability of the UxV system to clear the channel for theatre entry ahead of high value Task Group units such as Aircraft Carriers or Amphibious shipping, or ahead of civilian-crewed commercial shipping. As shown in the timeline in Figure 7, at this point in time the new breed of MCM vessel, introduced at the intermediate transition step, would be reaching the end of its operational life. Once the technology is assured, the host platform capability for the Area Standoff concept can be filled with a commercial platform or a secondary role for another naval ship, which means the new breed of MCM platform may in fact be the last breed of specialist MCM platform.

In summary, the key is understanding what steps are necessary to transition from current capability to what is required in the future. Potentially the future military environment will be a congested, cluttered, connected and constrained domain which has an increased reliance on unmanned and/or semi-autonomous platforms for a broad range of military tasks. There will be a need for closer air, land and sea integration with a small number of multi-mission platform types. Ultimately there will be a greater requirement for interoperability, connectivity, team working, information and knowledge sharing, between manned and unmanned assets and an increased need for flexible, adaptable and affordable through-life capability to meet rapidly changing military requirements.

Consequently future military systems will need to offer multi-mission, multi-role, day and night capable systems supplemented with niche platforms. Manned & unmanned systems working in a cohesive partnership supported by agile, interoperable C2 structures; ad hoc teams seamlessly integrated within the battlespace providing resilient operations in non-permissive environments. Ultimately future MCM operations will utilise a common interoperable mission & support system which delivers cost effective, agile, & sustainable capability.

5. Unmanned Autonomous Systems Architecture

As stated previously, the environment in which navies operate in the coming decades will be dramatically different (UK Ministry of Defence DCDC, 2015). The rate of change in the availability of materials, systems and technologies requires the development of new operational concepts to keep pace and new ways of doing business.

Being 'Equipment Agnostic' in the development of future MCM Command systems is key to avoiding mistakes of the past, and integral to the transition to future capability. Equipment agnosticism can be described as providing a sort of technology heaven where any equipment, any software operating on any operating system or any combination of operating system and underlying processor architecture is available. The capacity for any operating device (UxV) to work with various systems without requiring any special adaptations. The term is equally relevant to both the hardware and/or the software in this model.

It is about an unbiased approach to integrating different tools to solve different problems. Not so much one size fits all more all sizes fit all. An equipment agnostic approach (Figure 8) is what allows us to choose the best equipment for the job. The development of equipment agnostic thinking - using open architecture mission systems utilising a central based information model which through common workstations integrates the intelligent applications required to manage systems in the warfighting arena. For some time we have been seeking a way to transition combat systems into an open architecture model that can provide the freedom and flexibility to adapt more easily to meet new challenges and embrace new and emerging technologies and capabilities. A truly open, modular and simple to interface with technology that is not hindered in ability to benefit from new technologies. The concept is not unique but different, a truly OPEN and modular solution.

A MCM architecture should ensure the utilisation of common components and subsystems such as displays, data formats, and commands, operating procedures, maintenance, storage and spares. It should establish the formats, rates, quantity and quality of data as well as interfaces between various communications systems that transfer data to established data bases.

An open and collaborative architecture for MCM enables rapid and affordable technology integration and enhancement, providing increased capability and allows emerging threats and changing environments to be addressed whilst continuing to meet key operational commitments. This architecture, adopted at the intermediate transition step, will grow and adapt to take a navy from the current capability to the objective capability of the future.

This can be achieved through a single, properly integrated Open Architecture Mission System with common interfaces allowing for fewer screens and vehicle operating/tasking systems. The Single ship network integrates the platform with the communications & mission system equipment in order to compile a truly integrated situational awareness picture. Equipment agnostic, mission enabling intelligent applications can also be used to enable effective planning and deployment of the offboard systems (across more than one platform). This in turn can lead to fewer manual operations and operators to drive the equipment and compile the MCM picture. This modular and scalable design means hardware and software can be adapted to specific future needs and requirements. The open architecture enables faster, more affordable upgrades, as well as easy integration of any third-party modules and functionality. Increasing the mission capability of the platform and enabling flexible and effective MCM operations via:

- A Common display capability, presenting a common user experience across the entire system;
- Common functional and technical services, supporting applications and infrastructure in a standardised service-based manner;
- Best fit technologies that enable better performance;
- A decreased dependency on product development thereby reducing risk.

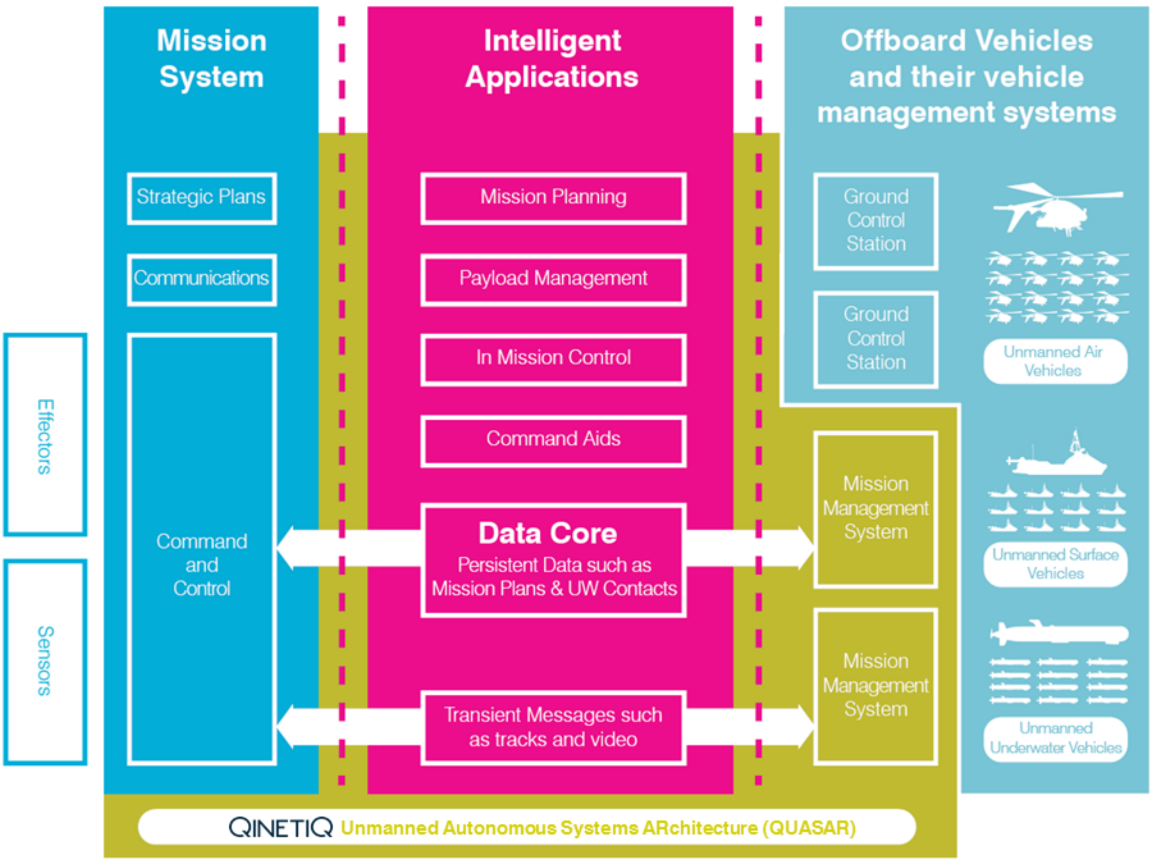

Figure 8 – Unmanned Autonomous Systems Architecture

6. A Ship, Air or Shore Based Capability

With increasing pressure on defence budgets globally, and competing priorities against a variety of extant and developing threats, there is an argument for a (perceived) cheaper, ship-independent containerised MCM module solution using the technology discussed previously (Defence Aerospace, 2018). This is predominately a credible solution when a navy can provide the MCM force with a local secure base of operations ashore. However, to provide a credible expeditionary MCM capability without host nation support, a dedicated ship is required. In a wartime scenario, local safe ports may no longer be available due to a lack of host-nation support or lack of in-theatre over-the-horizon force protection for deployed assets. Reliance on shore-based operations and host-nation support also fundamentally compromises a nation's sovereign capability to assure theatre entry.

Range is also a key restriction to operating solely shore-based MCM solutions. By moving the manned MCM C2 element further away from the minefield the solution becomes reliant on fast surface craft as a 'taxi' to and from the area of operations, and increases operational response times due to longer transit times. The MCM equipment will include high value assets that will need protection; this cannot be provided organically by the MCM UxVs operating at a distance from the coast due to the issues discussed earlier, and cannot be provided economically by air support alone (Babson, 2018). Due to the vehicles' range limitations discussed above operations could be limited to a radius around the host port or shore location, preventing a credible solution if the total area of the minefield to be cleared remains out of range. As an example, current UK Royal Navy MCM operations are not local to a safe host-port, but deployed at range in the Arabian Gulf (Royal Navy, 2018). In order to deploy the MCM vessels at range they also employ a Bay Class (LSD(A)) support vessel as a support /replenishment vessel to prevent the need to return to port, to ensure the endurance of efficient operations (The Military Times, 2018). If this is the case with existing long-endurance dedicated vessels, why would you attempt to send a lower endurance UxV asset further?

A rotary wing air-dropped capability could deploy the smallest MCM UxVs, however this brings additional challenges to recover the deployed UxVs or re-fuel(/charge) / re-arm with mine disposal charges, and this solution would not be suitable for the emerging larger unmanned vehicles. This severely limits the endurance of the mine-clearance effort, requiring a significant uplift in the number of vehicles and aircraft required to maintain the operational tempo.

In summary, navies plan for a worst case scenario; overall force composition and operational requirements are not driven by peacetime local operations. This does not prevent the procurement of additional shore-based mine clearance modules, as described by Defence Aerospace (2018) for certain operations. However, a single navy could not afford a solution that has such operational limitations within opposed operations. In order to deliver a complete capability that provides the necessary operational flexibility against the MCM requirements in all scenarios, from the preliminary step through to the stretched capability, a platform-based solution is the most appropriate. By deploying a ship-based MCM solution the safe launch, recovery and support of the equipment, and adequate support to the significant quantities of transferred data, can be assured.

However, as discussed in Section 2, the current attributes and layout of MCM vessels are unsuitable against the requirements of both the developing technology and developing mine threat. A new breed of MCM vessel, optimised against these requirements and the threat, will allow for the full transition from emerging offboard technologies in Channel Standoff operations to beyond the horizon Area Standoff capability.

7. Conclusion: A New Breed of MCM Platform

It is understandable why a navy would want to make the transition from the current platform-based MCM capability to a future where offboard systems are employed to deliver the full mine clearance capability over the horizon. However a jump from current Channel Immune / Avoid type operations to the proposed Area Standoff solution will require a series of steps as technology develops and confidence in its use grows. Beyond the preliminary step already taken, a Channel Standoff concept is the most appropriate, which will require a new breed of MCM platform to deliver. This platform will take a navy from the capability of today to the complete reliance on offboard systems of the future capability.

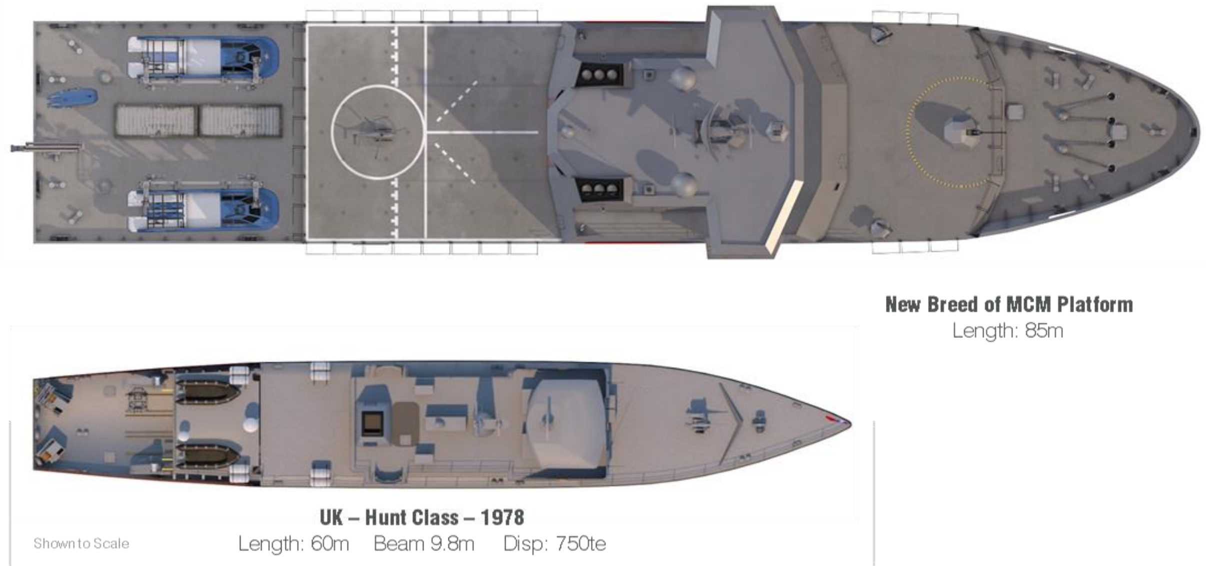

Figure 9 – The new breed of MCM platform and UK Hunt Class Comparison

Appendix B describes in greater detail a selection of the primary changes from the current '100 year' MCMVs (described in section 2 above) that are required to facilitate the new technology, permit Channel Standoff operations, and allow a navy to progress to the next step of MCM doctrine. This new breed of MCM vessel will allow for the full transition from emerging offboard technologies to beyond the horizon Area Standoff capability, as the technology develops and confidence in the ability of the systems grows.

The transition path outlined in this paper shows the steps from the technology of today to the desired future MCM capability, where the complete operation is conducted by offboard assets far ahead of the Fleet; when a commander is content to allow manned ships, including high value units, to enter a theatre of operations wholly cleared of the mine threat by the UxV system over the horizon. The technology, doctrine and policy is not yet in place to achieve this Area Standoff concept, however once the transition is complete this generational shift in MCM technology will deliver a capability that is faster, more efficient, adaptable and inherently safer.

Word Count: 6304

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Appendix A - Operational Analysis and Design Outcome

In order to understand the design requirements of the new breed of MCM platform an Agent Based Modelling simulation using NetLogo software was created. The models can estimate the time required to complete different operational scenarios and was used to optimise the equipment/platform arrangements to support the operations. Two different operating scenarios were modelled, Channel Immune (modelling the current concept of operations) and Channel Stand-Off (modelling the next step in platform design).

Agent based modelling was chosen to generate a simplified but accurate reflection of the operational domain. The model pays close attention to the representation of time and distance in order to calculate speeds and times of the operations. Inter-agent communication was delivered through messaging to allow for a realistic relationship between the different agents. The host platform agent had a coordinating role for all of the other agents thus allowing the scenario to follow the CONOPS process. Modelling assumptions can be changed quickly to suit different off board systems or changes in communication technologies, making the model flexible and agile to design changes. Another benefit of agent based modelling is that the data can all be collected and analysed using MS Excel making it accessible to all users.

Two different types of UxV were modelled, with two distinct roles in order to simply the process:

1. **Survey Unit** - Used to survey the area and search for mines. Could be a UUV, could be a USV with towed sonar, or both.
2. **Classification/ Neutralisation Unit** - Used to classify mines once identified by survey vehicle & launch mine identification & disposal systems. Assumed to be a USV taxi deploying ROVs but could be a large UUV

Figure A1 – Example of Survey Unit, Image courtesy of National Interest (2018)

Figure A2 – Example of Classification/ Neutralisation Unit, Image courtesy of Atlas Elektronik (2018)

Using the Channel Stand-Off simulation model and varying the number of survey and classification vessels between 1 and 6, Figure A3 was created. The figure shows that the knee in the curve and the most cost effective solution is to have 2 classification vessels and either 2 or 4 survey vessels dependant on the width of the swept channel and the effective sonar range. The lines for some of the survey vessel combinations (e.g. 2 / 3 and 4 / 5 / 6) were combined as the difference in the results was negligible.

The calculations in Figure A3 however assume that the surveying/classification work cannot be conducted simultaneously, the full search area needs to be scanned and the data returned and analysed back at the ship. If this assumption is invalid and effective communication between the mother ship and the Survey Units exists then the time can be decreased even further. Figure A4 presents the time to complete a Channel Immune survey of the same area/number of mines against a Channel Stand-Off scenario, with or without the simultaneous working assumption. This not only shows that simultaneous working produces a reduction in the overall operational time but shows that the provision of additional survey units must be proportional to the number of classification units.

Figure A4 also shows that compared to the Channel Immune scenario, the use of offboard autonomous systems offers significant time reductions. As long as the Channel Stand-Off Concept is used instead of the Area Stand-Off, the effect of transporting the survey units (assumed in calculations to be UUVs) to the minefield using USVs (to increase transit speed) has a negligible effect on the overall mission time.

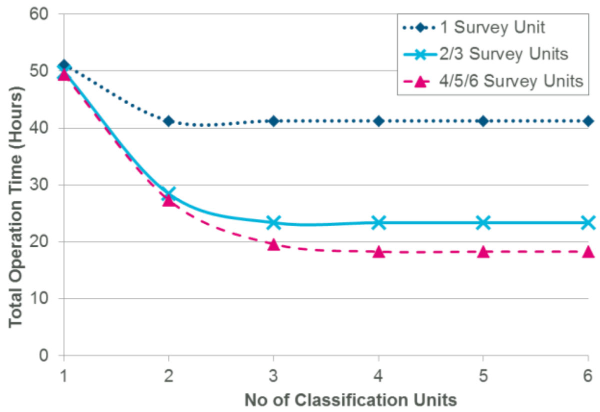

Figure A3 – Channel Stand-Off Operational Time Dependant on UxV configuration.

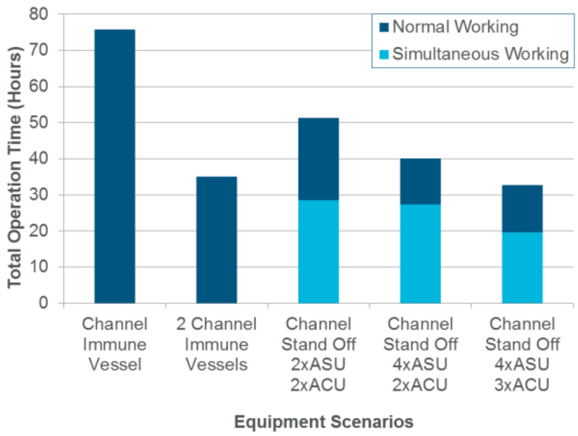

Figure A4 – Comparison of Channel Immune and Channel Stand-Off Operations

In summary, the recommended operational mission payload is therefore 2 Survey Units and 2 Classification Units. These are operational numbers and will need to be increased to allow for reliability and maintenance therefore giving a total payload of 2-4 Survey Units and 2-3 Classification Units.

Please note that this paper selects aspects of the supporting work conducted and does not include all of the work completed. For more information on the full extent of supporting work completed please contact BMT.

Appendix B – Features of the new breed of MCM platform

The following is a selection of the platform features required by the new breed of MCM platform, to deliver the next step in capability and allow Channel Standoff (and eventually Area Standoff) operations against the developing mine threat.

- **Working Areas**
  Over 500m^2 of flexible working deck space is required to store, maintain and operate the number of UxVs necessary to deliver mission timescales. Sufficient working deck space is critical to ensure the platform is not overtaken by developing technology and the increasing size of UxVs, to prevent the platform becoming obsolete within its lifetime. For example, the trials USVs already at sea as demonstrators are around 11m length (15te full load), however the lessons from these trials have led to the next generation of USVs that are around 13m (>20te full load). This size increase already witnessed, to deliver more payload space, power and speed, is likely to continue into the future as more capability is added; the host platform needs to be designed from the start to accommodate this change.
- **Mission Payload**
  A capacity to carry around 500te of payload, to include UxVs and full support to embark and operate clearance divers will be required. This also includes the medical support requirements which accompany a clearance diver capability. As an aside, this payload capacity is equivalent to the overall displacement of a Ton Class MCMV (1951), highlighting a difference to the legacy MCMV.
- **Enhanced Situational Awareness & C2**
  A large, open Command Bridge and separate Mission Operations Rooms / Planning Rooms will allow C2 of multiple UxV squads required for future MCM operations in real-world scenarios and to maintain the required operational tempo. Sensors sufficient to detect threats to the ship and monitor deployed assets will be essential.
- **Deck Handling**
  Deck machinery to handle large UxVs to enable a rapid flow of vehicles on/off the ship will be required. A heavy man-riding crane/davit capacity is required for large UxVs (capacity >20te to satisfy safety standards), with the associated ship structures to support this handling equipment and these heavy loads. While stern ramps appear attractive from an operability point of view, affording offboard assets a rapid launch & recovery capability, they may fall short in future adaptability to accommodate growing systems. Additionally, the stern ramp for a minimum of two USVs, and the required additional buoyancy required for damage stability aft to naval standards, brings a considerable space requirement that is difficult to achieve in a smaller vessel. If a stern ramp is used it will add considerable length overall and cost to the platform.
- **Signatures & Survivability**
  The requirement to manage signatures is not as strict as current concepts of operation (Channel Immune / Avoid) and allows the use of MOTS / COTS equipment rather than specialised non-magnetic systems. However, noise and magnetic signatures still need to be controlled as the platform will be inside the swept channel and may need to manoeuvre close to the edges of the swept area, or may encounter a rogue mine missed by previous searches. Survivability (particularly shock protection) to allow Channel Standoff operations is required, exceeding that provided by a typical OPV. These features include the mounting of equipment, especially propulsion systems, but also the shock hardening of the hull itself. The shock requirement in particular is beyond the capability of a hull and structure designed to commercial standards, precluding the use (at the intermediate transition step at least) of existing oil rig support or similar vessels. Both the signatures and survivability requirements lead to a platform that delivers acceptable levels of risk to the personnel operating onboard in real-world MCM operations.
- **Force Protection**
  Force protection capability needs to be scaled appropriately to the threat against the ship and deployed assets, to deliver acceptable levels of operational risk. Depending on the ORBAT[1] and likely course of action of opposing forces, this could include the provision of an anti-air missile system such as MBDA Sea Ceptor, or a ballistic-based defence. The previous generation of 'whites of the eyes' Close In Weapon Systems (CIWS), such as Phalanx, are unlikely to fulfil this self-defence role unless facing a supersonic threat; their capable range is too short to defend the deployed assets, and the debris resulting

1. Order of Battle; available units, equipment and vehicles of a particular force.

even from a successful engagement will still cause significant damage to a ~85m length platform. Instead, a 40-76mm gun system, with fragmentation ammunition and a range up to 10nm to protect both the assets and the host platform is likely to better satisfy the requirement and cost, provided surveillance, identification and target acquisition requirements are also met. However, any increase in the capability of the force protection systems will have a subsequent impact on the manpower and maintenance required.

- **Flexible Power & Propulsion**
  A diesel-electric architecture would support the variable electrical loads required by different mission profiles and payloads that may be carried on the platform throughout its life; this architecture also provides propulsion redundancy and noise hygiene. Separated engine spaces are required to satisfy Channel Stand-off propulsion survivability requirements, to prevent the platform from becoming stranded or drifting within the narrow swept channel deep inside the minefield from the loss of a single machinery space.

- **Hullform for Stability**

  A beam that is almost double that of existing MCMVs, and a 'full' hullform, is required to allow launch & recovery of large UxVs (>20te) in challenging weather conditions and sea states. Clearance activity or theatre entry conditions for a Task Group cannot be delayed by the MCM force due to adverse weather, and so the 'finer' hullform of an OPV (designed to give an OPV a greater maximum speed for patrol tasking) would not be suitable in a MCM host platform role. Finally, station keeping and low-speed manoeuvrability, critical to maintaining position within the narrow swept channel and reacting to threats, requires a dynamically unstable hullform. The hullforms of a Frigate or OPV are unsuitable for this role in this regard, as these platforms are instead designed hydrodynamically for primary straight line speed and high speed manoeuvrability requirements; these types of platform will not be capable of accurately maintaining position or manoeuvring in confined waters at low speeds in the high sea states required, to provide appropriate levels of safety to the Ship's Company and the vessel. It is also for this reason that large Amphibious platforms will be unsuited to Channel Standoff operations, as they do not possess the manoeuvrability or tactical diameter to deliver the MCM role in these confined waters with an appropriate level of risk.

Figure B1 – Indicative arrangement of the new breed of MCM Platform (Image © BMT 2018)