The challenges in supporting modular capability, today and in the future

A.Harris MPhys CEng MIET, C.Thatcher FdSc BSc MIET

Synopsis

The UK Ministry of Defence recently published the 'Maritime Modularity Concept', outlining the UK's vision for the development and future deployment of modular capability. Whilst the concept of modularity in warships is not necessarily novel, the method of deploying this capability is new to the Royal Navy. Today, 'modularity' is typically seen using block construction during build or weapon system upgrades during deep maintenance periods. Aspects of modularity can also be seen in the installation of Military Task Equipment (MTE) to support specific operations or the on-boarding of specialist teams such as Fleet Air Arm personnel or Royal Marine Commandos. As such, the Maritime Modularity Concept does represent change in how the Royal Navy will deploy capability.

Looking forward, new frigate designs including the Arrowhead 140 and Global Combat Ship, will have dedicated Mission Bays. These Mission Bays are designed to receive a wide range of equipment or facilities packaged within conventional shipping containers. The ability to onboard these containers and integrate them with the platform will deliver a multi-mission modular capability with inherent flexibility, agility, and pace. These vessels are the first step towards the futuristics vision where ships are no-longer designed with distinct roles but provide a platform for "plug and play" capability that is adaptable, versatile, and upgradeable to meet operational needs whilst deployed. The Royal Navy will look to achieve this through the introduction of Persistent Operational Deployment Systems (PODS).

Such an adaptive and versatile capability needs to be maintainable and requires an innovative support solution that ensures modules are available at the point of operational need and enable the platform to remain on task. In this paper the key challenges and characteristics of a support solution that generates, sustains, and recovers modular capability will be explored. This will build on the experience of supporting modular capability today, be that capability upgrades, MTE fits, fleet aviation assets or landing craft. The bounds of this paper will extend to four key areas of in-service support:

- Platform Integration
- Maintenance Management
- Material State Understanding
- Facilities & Infrastructure

The paper concludes that a successful support solution for modularity will address the complexity and challenges of these four areas. This will ensure modular capability is at the centre of force operations, maximising availability of operational assets.

keywords; Modularity, PODS, Support, Capability, Maintenance

Biographies

Amanda Harris is the Lead Systems Engineer within Babcock's Future Programmes team. With a background in systems design within the aerospace industry, Amanda joined Babcock in May 2015, and has experience in through-life support of complex warships and digital innovation. Amanda is a Chartered Engineer with the Institute of Engineering and Technology and holds an Undergraduate Master of Physics (MPhys) degree from the University of Bath

Cleopatra Thatcher is a Supportability Engineer within Babcock's Future Programmes team, with experience in developing in-service support solutions and delivering ILS artefacts for the Royal Navy and Future Customers. Cleopatra joined Babcock in September 2017 as a Higher-Level Apprentice, where she completed a FdSc in Mechanical Engineering, she also has a Maths degree from the University of Plymouth and is working towards Chartered Engineer Status with the Institute of Engineering and Technology.

1. Introduction

Modularity can be defined in different ways, but in essence is breaking down a system of systems into systems or equipment items that can be easily reconfigured or exchanged. There are several different types of modularity used today that we can learn from and inform how modular capability might be supported in the future. Build modularity is where the platform is constructed in blocks to reduce design and build cost. Integral modularity is where ships are designed with specific locations for systems with defined functional and physical boundaries (*Maritime Modularity Concept,* 2023), enabling change during the life of the platform to overcome obsolescence and to adapt to new threats. Such capability upgrades are made by the Alterations and Additions (A&A) process and fitted during maintenance periods. Installed Modularity uses defined interfaces and connections replicated across multiple ship classes to enable operational adaptability and can be described as the payload insertion method. By this definition, Military Task Equipment (MTE) is a type of installed modularity as it can be installed across multiple classes. Containerised mission modules, such as the Royal Navy's Persistent Operational Deployment Systems (PODS) concept, would provide a modular capability, that can be rapidly installed and provide operational adaptability (*Think Differently, [no date]*). Mission or combat team modularity is where the combination of equipment and personnel provides additional specialist capability to a platform, such as Helicopter flights on the T23 Frigates or the Landing Craft with Royal Marines on the Amphibious Class. Each of these different capabilities has its own unique support solution that ensures it is available when needed, that we will consider and learn from for the future support of containerised mission modules or PODS.

2. Developing a support solution

The aim of any in-service support solution is to ensure the platform, system and equipment is safe, and available, while remaining affordable. Figure 1 below shows the typical life cycle of a naval platform, which can be broken into product development, through life management and end of life. During Product Development, the concept of operation and the maintenance philosophy will be defined before supportability analysis is conducted during the detailed design. This defines how the platform will be supported, the maintenance activities required and who, where and when they will be conducted. Once the platform enters service, it will cycle through the generate, sustain, and recover phases before reaching the end of life, where platforms are decommissioned for disposal or prepared for second owners.

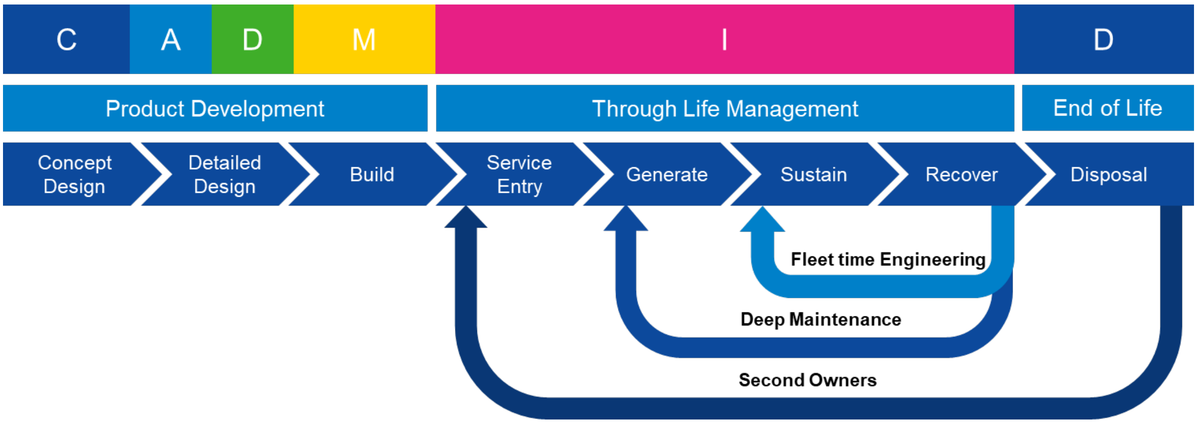

Figure 1: Naval Platform Lifecycle

Any design change to the platform, such as new modular capability, will have its own product lifecycle. This includes product development of the modular capability before implementation, usually as an Alteration or Addition (A&A) as part of a Capability Insertion Period (CIP), Fleet Time Support Period (FTSP) or Deep Maintenance to facilitate acceptance activities. Overlayed on the lifecycle model in Figure 2 are the different types of modularity, showing which phase of the Platform's lifecycle they are typically involved in.

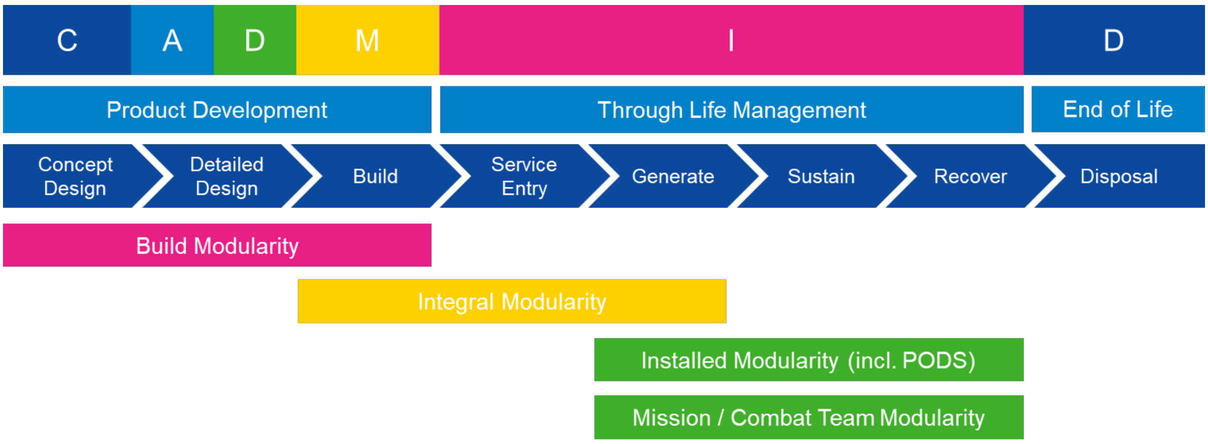

Figure 2 : Naval Platform Lifecycle with types of modularity overlaid

At the heart of the in-service support solution is the Generate, Sustain and Recover cycle, that applies to both the platform and modular capability. During Generate, it is prepared for active operations, during Sustain it is kept operational through routine maintenance and repairs and during Recover it is assessed and restored following active operations. These activities can take place concurrently or independently depending on the level of integration between the modular capability and the platform.

3. In-service support

3.1 Platform integration

When introducing a new modular capability, it is important that it does not adversely impact the performance or the design intent of existing systems, be that the operation, security, or safety of the platform. The level of risk will vary depending on the type of equipment and level of integration to the platform.

3.1.1 Physical integration

There are two key principles that should be followed to ease the physical integration to the platform. The first is reducing the number of interfaces to platform services, for example reducing the interfaces to power and data and containing its own Heating Ventilation and Air Conditioning and fire detection and suppression systems. The second is to follow common standards for interfaces and connectors, such as the NATO Standard ANEP-99 Design and Interface Standards for Containerised Mission Modules *(NATO ANEP-99, 2020)*, which defines a range of requirements to enable interoperability of containerised modules. This approach would allow modules to be interchangeable and used across multiple classes of ships. Currently the physical integration of A&As is designed for each class, and as vessels age and configuration diverges, is adapted for each ship. For MTE, while the equipment can be transferred between classes, there is a class specific installation solution, fitting is a two-stage process, normally spread over two FTSPs, the first to implement the Fit-To-Receive A&A and the second to install and commission the MTE.

3.1.2 Functional integration

Where functional integration is required either to the Combat Management System (CMS), Integrated Platform Management System (IPMS) or ships communication systems it should be treated as a complex A&A and managed by the appropriate design authority. The level of integration required will depend on whether the module only publishes data to the platform (i.e. sensors), consumes data from the platform (i.e. alarms or effectors), or is in dialogue with the host platform. The impact on the host platform, also needs to be considered, as additional modules may require changes to the CMS or IPMS system, and the opportunities to do so will be limited by the operational profile and maintenance periods of the platform. Typically, each class of ship have different CMS and IPMS systems, therefore functional integration, acceptance activities and security accreditation would need to be class specific, even if modules are used across multiple classes, as per MTE today. An open architecture, or standardised data interfaces, would aid the design and integrations of Modules.

3.1.3 Margins and signature management

The wider impact on the host platform also needs to be considered when integrating new modules. An early assessment of the change impact on margins and signatures will help mitigate the problems by providing time to make alterations to the host platform. An example of this could be increasing the power or cooling capacity to a compartment or area of the ship.

One challenge with the aspiration to change the modules on the platform at any time is the management of the weight and stability. With both the traditional A&As and MTE, there is a relatively known weight, centre of gravity and location. However, each containerised module could vary significantly in weight and be arranged on the platform in numerous ways. One new challenge with the “plug and play” approach to containerised modular capability, is the number of combinations that can be changed between support periods. Options for how this impact is managed include:

- Imposing limits on the design of modules to fit a standardised weight and centre of gravity envelop and providing a not to exceed limits for predesignated areas.
- Having weight and stability calculations for pre-determined configurations.
- Having a dynamic on-board capability to calculate weight and stability, as per commercial container ships.

The impact on the platform’s signatures should also be considered, especially when fitting warm rectangular containers to the deck of a platform. However, this is less problematic when modules are housed within dedicated mission bays.

3.2 Maintenance management

The maintenance philosophy for modular capability needs to consider what maintenance is required and when, where it is conducted, who conducts it and how it is organised, to increase availability and reduce support costs.

3.2.1 Maintenance philosophy

To meet the benefits of capability availability sought through modularity, the equipment and systems must be maintained to a prescribed readiness level, indicative of the operations the capability would support, the availability of the same or similar modules at the required readiness level and the cost implications.

Currently, for integral and installed modularity, the systems and equipment follow the same maintenance cycle as the platform. Frequent maintenance tasks are conducted by the ship's crew, with industry partners conducting fleet time maintenance periods each year and deep maintenance and recertification docking every six years. In order to realise the full potential of modularity, maintenance management for the modules must look to maximise availability of the capabilities. A consideration to optimise availability of PODS is to disconnect its maintenance cycle from the platform's and conduct necessary maintenance and defect rectification off platform when not required for current operations. The benefit of swapping out modules to conduct maintenance is reducing the maintenance burden on ships staff, however a suitable storage and maintenance facility would be required.

3.2.2 Maintenance Management Systems

Whilst modularity allows operational flexibility, there is a significant challenge in ensuring management, access, knowledge and capacity to maintain those capabilities without impeding the benefits sought with modularity. For platform integrated equipment, where the configuration is rigid during operational deployment, the management of maintenance is achieved through ship systems. For example, MTE uses the platforms Maintenance Management System (MSS). The maintenance lies dormant in the ships maintenance schedule until the MTE is transferred to the platform and activated through a standard procedure. In contrast, moveable assets such as Merlin Helicopters have a separate MMS accessed through a laptop that travels with the asset.

As PODS are introduced and capabilities are interchangeable, the MMS must be accessible to all involved in the maintenance of the modules. Likewise, it will have to be adaptable and flexible, in real time, to represent not only the current ships configuration, but the maintenance state of the module as it is installed.

3.2.3 Maintainers

Who conducts routine maintenance while PODS are on board will need to be carefully considered to ensure it is within the capability and capacity of the ship's crew. For Integral modularity, any maintenance burden placed on the crew is assessed during the product development phase. This allows for maintenance task and training needs analysis to be undertaken, specifying the required training courses the crew must undertake to complete the maintenance tasks correctly. Alternatively, helicopters have additional maintainers, known as augmentees, who join the crew with the asset to conduct the additional and specialist maintenance tasks. While some of the routine maintenance tasks for PODS may be within the capability of the crew, each combination of modules will need to be assessed to understand the total maintenance requirement in line with the crew's capacity.

Where possible and the opportunity arises, lengthier or specialist maintenance tasks should be conducted while the modules are off platform by industrial partners, Original Equipment Manufacturers (OEMs) or naval engineers not on deployment to remove additional burden from the ship's crew.

3.3 Understanding material state

To ensure Mission Modules are operational, safe, and well maintained, the material state and defects must be understood and effectively managed by all stakeholders that support the modular capability.

3.3.1 Surveys and monitoring technology

Modular capability should allow flexibility in the CONOPS of operational ships, meaning that whilst many modules will spend large amounts of time on board, they will also spend time fleeting between ships, facilities, and storage. One of the biggest risks to equipment when considering modularity, is the risk of damage to equipment during transit. Ensuring equipment arrives at the operational front line, functional and free from defects is critical to ensuring the modularity concept can be realised. This means that traditional time-based surveys and maintenance may be insufficient to ensure equipment is fit for purpose, or inefficient for modules that have spent more time in monitored storage.

Understanding the material state of the module and equipment contained within is a challenge that can be overcome through monitoring technologies such as smart sensors, monitoring in real time, the temperature, humidity, vibration, and security of the module *(Arviem, 2020)*. Similar technologies are utilised in commercial shipping to ensure payloads are secure, in good condition and the whereabouts of any container is known at all times *(Global Infrastructure Hub, 2020)*. A digital database could be developed to monitor the modules in real time and produce reports for the relevant stakeholders, be that Equipment Authorities (EAs), OEMS or others. This would allow for timely repairs when necessary and provide a clear understanding of the availability of any given capability. These sensors could be procured during the procurement of the modules and housing units or retrospectively fitted. The fitting of sensors however presents its own unique challenges. Both the Operational and cyber security requirements will be stringent and considerations for the communications bandwidth demand is likely to result in costs beyond that of simple procurement costs. An analysis of the priced risks of material state understanding must be utilised to understand the cost benefit, or lack thereof, of monitoring sensor technologies.

3.3.2 Location and entity agnostic defect reporting

As modules transit between ships, transportation hubs, storage facilities, industry and OEM facilities, defects need to not only be understood, but be reportable at any given time or location. This will ensure that any impact to availability can be mitigated.

Whilst defect reporting tools are employed on ships currently, the process rarely extends from the operational impact since equipment's are fixed to operational vessels. Modularity introduces the risk of defects occurring outside of the ship, cause delays in providing that capability when required. For example, MTE defects are often only reported once installed on the receiving ship since they will only directly affect operations at this point. Modular capabilities will need to go a step further, ensuring defects can be reported and understood at all times if it is to deliver the flexibility and availability the modularity looks to achieve.

Defect reporting for modular capability needs to include not only operational defects at the platform level, but an ability to report all defects from multiple locations, at multiple times, and provide the level of detail that will allow rectification to be planned to maintain availability and enable the logistical planning. This needs to include the ability of industry to signal that a POD is defective so an alternative can be found to meet the operational needs. A digital, industry accessible defect reporting tool may work to overcome this by providing clearer material state knowledge to all stakeholders.

3.3.3 Defect rectification

When defects are reported, there are logistical considerations when planning the rectification. Since defects should be reported from both ship and shore facilities, planning rectification may include transiting the module from its current location to a desired repair facility. This could include transporting internationally from storage to facility or a ship coming alongside to remove the defective module. The module will need to be transported whilst adhering to any relevant security requirements discussed below. During this time, the capability will be unavailable, but removing a defective module from a ship for repair will allow the ship to continue operations, either with a replacement, or without the capability.

3.4 Facilities and infrastructure

The ability to accommodate, generate, sustain, and recover future modular capability may require specialised infrastructure and facilities depending on security classification.

3.4.1 Storage, maintenance and training facilities

Since space within a mission bay will be limited, it will be necessary to store modules that are non-operational in a secure and accessible location. The storage requirement will be dependent on the environmental conditions, security requirements and the number and types of modules, which is likely to grow as the MOD delivers on their modular vision.

Whilst in storage, the opportunity for maintenance, repair and regeneration should be taken and the storage location should include suitable facilities. Since maximising availability will mean maintaining equipment to specific readiness states, facilities must be capable of not only providing the necessary facilities to conduct that maintenance, but the relevant systems to assure its readiness. An example for this would be a simulated combat management system. Maintenance will be conducted by multiple parties, specific for each module and equipment or system. Therefore, these facilities must be accessible to these parties in order to reduce the logistical burden of transporting equipment, further increasing the risk of damage. Potential locations include Naval dockyards, near a military logistics hub, at existing CMS or IMPS shore test facilities or distributed amongst the relevant OEMs and Industrial Partners.

These facilities would also provide the ability to train personnel on operational, live equipment, with no impact to the operational front line, which is hugely advantageous to the users and maintainers. However, this could only be provided if the facility was able to replicate the ships systems using training simulators.

3.4.2 Transportation

When a capability is required on board, there will be logistical considerations to consider. This includes movement of the module from its current location; on board, in storage or an interim facility, as well as ensuring the capability can be integrated and operational in time to meet the requirement. Meeting this timescale whilst considering factors such as transport, security and integration will be fundamental in the success of modular capability.

The most cost effective and environmentally friendly means to transport containers globally is by sea freight *(Across Logistics, 2022)* through existing military supply chains. However, a key disadvantage in this approach is the shipping time. Experience in supporting maintenance activities overseas has shown that equipment needs to be available three months prior to the planned maintenance period to ensure it arrives in accordance with schedule. This would reduce the speed at which platforms could adapt to unpredictable changes in tasking, such as disaster relief. Alternatively, use of third-party logistics providers, while potentially more expensive may reduce transit times.

Air Freight via military or civilian means is another option for the transport of modules to the required point of departure, if the operational urgence can justify the cost and environmental impact. However, there heightened safety restrictions for air freight requiring items such as explosives, extinguishants, and some batteries to be removed prior to transport which may mean this approach is not some types of modules.

3.4.3 Dockside infrastructure

The introduction of modular capability will impact the shoreside facilities and infrastructure currently employed to maintain naval platforms. It will be necessary to provide the infrastructure capable of lifting and transiting modules on, off, to and from a ship. To achieve many navies' vision to change module configuration during operations anywhere in the world, the dockside infrastructure to load and unload modules must be universal.

There are currently two approaches, dictated by the design of the mission bay. Some platforms, like the T26, Canadian Surface Combatant and Australian Hunter Classes respectively will have an inherent capability, through a Mission Bay Handling System *(DefBrief, 2020)*. While this has less dependency on local infrastructure to load modules through the side of the ship it is dependent on the stand-off distance and tidal limits. This will require an assessment of the berthing arrangements for each wharf and jetty used. Alternatively, platforms like the Iver Huitfeldt, T31 and Miecznik frigates will depend on standard and readily available dockside cranes to load modules through a soft patch in the mission bay deck head.

3.4.4 Security

The security of systems and equipment contained within modules will be subject to all the same security protocols as equipment stored on board a ship and will need to be considered, not only during transit, but whilst modules are in storage too. Given modules will contain different equipment with different security requirements, storage facilities will either need to adhere to the highest level of security accreditation regardless of the module contents, or there will be logistical challenges in ensuring modules only pass-through approved facilities for the equipment contained. The challenge around security extends beyond a specified storage location since the same will be true for any port or logistics hub during the transport process. To maximise operational availability, modules are likely to arrive at a port prior to the ship and therefore must be securely stored until loaded onto the platform. This security requirement may limit where a platform can securely change its module configuration.

3.5 Support organisation

Since PODS will introduce the movement of modules across platforms of different classes as well as globally, access to the modules will be logistically and contractually challenging. With such a wide range of possible modular capabilities, liaison with OEMs, industry partners, small medium enterprises (SMEs), Ministry of Defence (MOD) and other governmental bodies will be paramount to ensure the PODS are available to support the platforms operational programme.

While there will be a capability sponsor in Navy Command that funds the development and in-service support of PODS, it is not clear who within the current support enterprise would co-ordinate support and logistics activities. If PODS are pan-class, as intended, they would not sit within the current Class Cell model. Existing Equipment Authorities can support and engage OEMs for the maintenance of the equipment within a module, however they do not have the expertise to manage the structure of the modular containers. Therefore the introduction of PODS will require organisational change, whether that is a 'PODS Cell' or 'PODS Authority' to brigade the support activities for a pan-class, pan-equipment capability. This new organisation must collaborate with all stakeholders and co-ordinate transport of modules and maintenance activities to achieve the operational availability and reduced support costs sought with modularity,

4 Conclusion

The PODS concept promises to deliver a platform with plug and play capability that is adaptable, versatile and upgradeable to meet operational needs through life. To enable this benefit, the support solution for PODS will need to be flexible, agile and scalable.

To bring new modular capability into service quickly, we need to simplify platform integration by reducing interfaces and using common standards. However, we also need to recognise that functional integration, acceptance activities and security accreditation would need to be class specific.

To generate modular capability during operations we need a logistics network to securely transport modules to the vessel and infrastructure to transfer containers on and off the platform. The platform also needs to be able to adapt to different configurations of modules, such as variations in weight and CoG. To sustain modular capability throughout operations, the crew needs to have the capability and capacity to conduct the necessary maintenance and repairs. This may mean additional crew will need to be deployed with modules. To recover modules post operations efficiently and effectively, we need to enable better understanding of material state through communication of both operational and lower-level defects through a universal reporting tool and use of monitoring technologies such as smart sensors.

From this paper, it could be argued that a fifth stage should be added to the through life management of containerised modular capability, storage. Time in storage, away from the operational front line provides a unique opportunity for deep maintenance and allows OEMs, and industry partners to support defect repairs. Allowing OEM's and industry partners to maintain modules away from front line operations in a secure storage environment provides an opportunity for the asset to remain available and release RN operator maintainers for deployment. Additionally, it provides opportunity to improve crew capability through training using operational equipment which will assist in achieving readiness when deployed. To achieve these benefits, suitable storage facilities that incorporate maintenance and training facilities would be required in a location that is secure, accessible and minimises transport requirements. To co-ordinate these various efforts coherently, a nominated single capability owner would be required. The capability owner would be responsible for the material state of the modules, owning all Defence Lines of Development and would co-ordinate all stakeholders from maintenance to logistics ensuring that modular capability is maximising availability of operational assets.

Acknowledgements

The authors wish to acknowledge our colleagues at Babcock; Ian Atkins, Steve Brown, Richard Hesleden and Paul Hodgkinson for sharing their experience in delivering support to the Royal Navy and other allied navies.

References

Across Logistics Maritime Transportation. advantages and disadvantages (2022). Available at: https://acrosslogistics.com/blog/en/maritime-transportation-advantages-and-disadvantages (Accessed: 30 July 2023).

Arviem (2020) A smart container or smart device for containers, Arviem Cargo Monitoring. Available at: https://arviem.com/a-smart-container-or-smart-device-for-containers-what-fulfill-your-organizations-need-for-real-time-cargo-monitoring/ (Accessed: 30 July 2023).

DefBrief. Rolls-royce expanding facilities for Canadian Surface Combatant Program work (2020) Available at: https://defbrief.com/2020/02/15/rolls-royce-expanding-facilities-for-canadian-surface-combatant-program-work (Accessed: 30 July 2023).

Global Infrastructure Hub (2020) Smart shipping containers to enhance port productivity, Global Infrastructure Hub - A G20 INITIATIVE. Available at: https://www.gihub.org/infrastructure-technology-use-cases/case-studies/smart-shipping-containers-to-enhance-port-productivity/ (Accessed: 30 July 2023).

Maritime Modularity Concept (2023) Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1134112/Maritime_Modularity_Concept.pdf (Accessed: 26 July 2023).

NATO Standard ANEP-99 Design and Interface Standards For Containerised Mission Modules, Edition A Version 1.

Think Differently (no date) Think differently. Available at: https://www.royalnavy.mod.uk/news-and-latest-activity/features/think-differently (Accessed: 30 July 2023).