Turning data into reality

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Synopsis

This paper looks to expand on the INEC 2016 paper 'The future role of virtual reality within warship support solutions for the Queen Elizabeth Class aircraft carriers' presented by Ross Basketter, Craig Birchmore and Abbi Fisher from BAE Systems in May 2016 and the EAAW VII paper 'Testing the boundaries of virtual reality within ship support' presented by John Newell from BAE Systems and Simon Luck from BMT DSL in June 2017.

BAE Systems and BMT have developed a 3D walkthrough training system that supports the teams working closely with the QEC Aircraft Carriers in Portsmouth and this work was presented at EAAW VII. Since then this work has been extended to demonstrate the art of the possible on Type 26. This latter piece of work is designed to explore the role of 3D immersive environments in the development & fielding of support and training solutions, across the range of support disciplines.

The combined team are looking at how this digital thread leads from design of platforms, both surface and subsurface, through build into in-service support and training. This rich data and ways in which it could be used in the whole lifecycle of the ship, from design and development (used for spatial acceptance, HazID, etc) all the way through to operational support and maintenance (in conjunction with big data coming off from the ship coupled with digital tech docs for maintenance procedures) using constantly developing technologies such as 3D, Virtual Reality, Augmented Reality and Mixed Reality, will be proposed. The drive towards gamification in the training environment to keep younger recruits interested and shortening course lengths will be explored. The paper develops the options and looks to how this technology can be used and where the value proposition lies.

Keywords: 3D, Virtual Reality, VR, Support, Digital thread, Digital Twin, Big Data, Data Analytics, Artificial Intelligence, AI, Augmented Reality, AR, Mixed Reality, MR

1 Introduction

In their INEC 2016 paper and excellent presentation on 'The future role of virtual reality within warship support solutions for the Queen Elizabeth Class aircraft carriers' Ross Basketter, Craig Birchmore and Abbi Fisher from BAE Systems concluded that the availability of consumer VR provided an exciting opportunity to view CAD models, laser scans and training materials from a more realistic perspective at an affordable price. They suggested that a 3D model of the QEC carriers, while also providing a valuable planning tool to simulate the work packages, would be an invaluable tool during training to provide an immersive experience that would provide a safe environment for new starters to familiarise themselves with the layout and navigation within the vessel before boarding, improving their effectiveness while also removing the need for disruptive tours of the vessel help to train staff in emergency procedures with no personal risk to the individual, providing a safer and accessible training environment. Their final conclusion stated that a cost benefit analysis needed to be carried out to support the investment case taking into account the potential savings from the long-term support of the platforms.

The EAAW VII paper 'Testing the boundaries of virtual reality within ship support' presented by John Newell from BAE Systems and Simon Luck from BMT DSL in June 2017 sought to show the work undertaken by BMT to provide an innovative 3D walkthrough training system for the Queen Elizabeth Class (QEC) Aircraft Carriers, supporting the BAE Systems Maritime Services' Industrial Suitably Qualified and Experienced Personnel (SQEP)

Authors' Biographies

John Newell served in the Royal Navy for 38 years, then moved to BAE Systems as Head of Queen Elizabeth Class Aircraft Carrier Support. He is now a Director with Juno Fleet Services Ltd.

Simon Luck joined BMT Defence Services in 2004 as a Systems Analyst, responsible for providing his customers with online information management tools so they could gain insight into their data. Simon now runs the Information Systems Department, delivering core services around software development, data analytics, visualisation and cyber security. His team are responsible for the development of the ENGAGE platform which forms the basis of the immersive QEC Carrier Trainer.

Stewart Leinster-Evans joined BAE Systems in 1995, and has held a range of roles across the Air and Maritime sectors. Since 2015 he has been leading the support team on Type 26, driving the development of a supportable platform for the Royal Navy. Also, he has been a long standing advocate of information exploitation to the benefit of support systems, and consistently explores new ways of improving the efficiency and effectiveness of systems of support.

Training Programme. The authors' aimed to show that the work to date had been primarily focussed on QEC but that this technology could be applied to any Naval platform or task group but also more widely to the whole of the maritime, land or air environments. The paper concluded that 3D, VR and AR technology could be applied to many scenarios with the aim for the future being to stretch and test the boundaries of how we can utilise this technology, not only in training, engineering support, testing operational procedures, business uses and operational planning but also in rapid prototyping and war-gaming.

A number of other initiatives will also influence how this technology is taken forward in the Defence sector and Maritime in particular. This paper seeks to discuss three key elements. The first is the concept of the digital twin and what we mean by it. The use of this term is becoming more widespread yet do we all have the same understanding of what we mean? Secondly, the paper aims to discuss how best to exploit all the data available and lastly the paper will discuss where the value proposition or compelling business case lies.

2 The digital twin

According to Wikipedia (https://en.wikipedia.org/wiki/Digital_twin), "Digital twin refers to a digital replica of physical assets, processes and systems that can be used for various purposes."

This is a very accurate description in our world of maritime design and support. At BMT and BAE Systems, we continue to invest in the development of intelligent systems to facilitate the design process and the optimisation of in-service support to ensure capability can be delivered as and when required. This includes the relationship-based Digital Twin of assets.

From a design perspective, the Digital Twin should start life as soon as the concept of a new platform, system or equipment is born. It needs to grow with the design iterations and be utilised by all those in the supply chain that are working on the project, acting as the hub for the various systems and tools used to manage the design process as well as the portal into supporting information, such as training, technical documentation and real-time performance analysis. Figure 1 shows the digital twin system testing for the Tide Class.

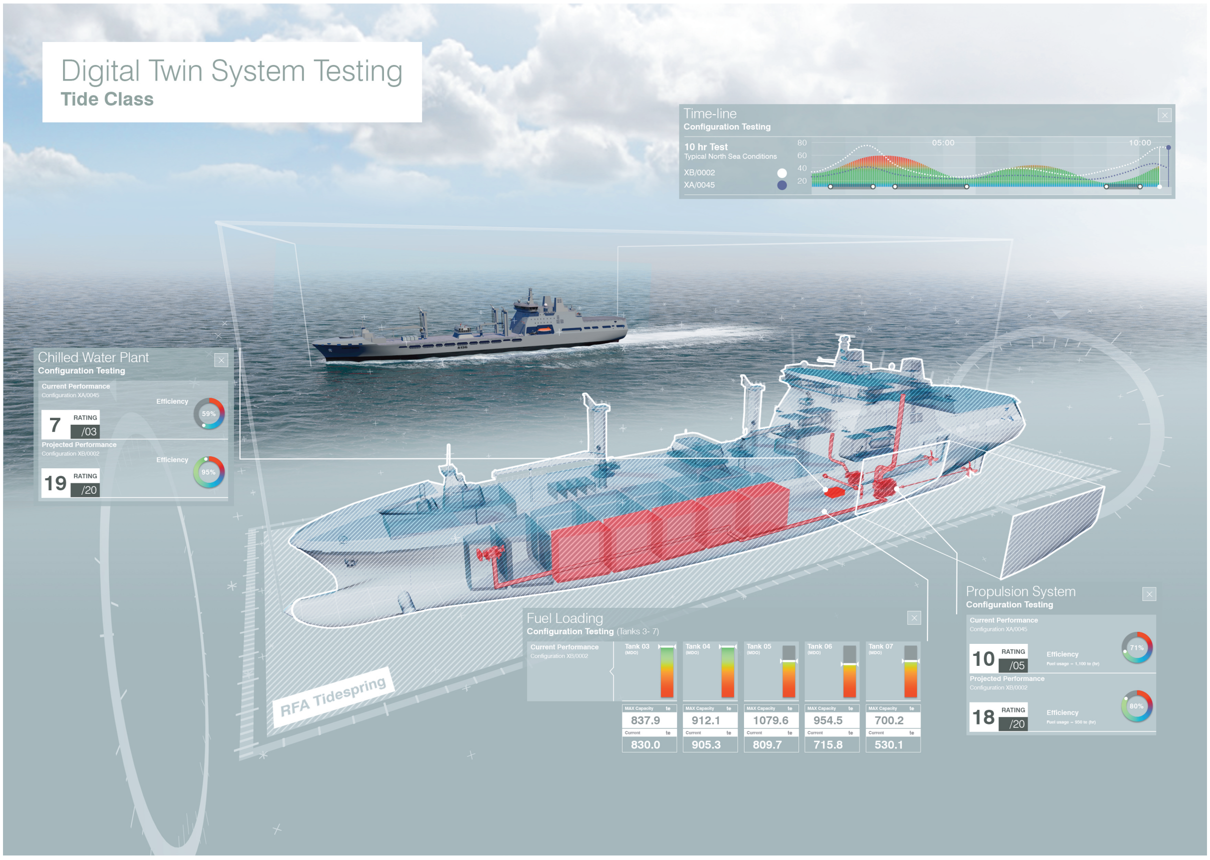

Figure 1: Digital twin system testing for the Tide Class ©BMT 2018.

The processes surrounding the Digital Twin are a fundamental element and need to ensure that it is maintained in an effective and efficient manner. This is made especially challenging when multiple parties are involved in the design or integration of assets. The provenance of the data needs to be clear to end users to engender trust in what they are seeing and can understand the ‘state’ of these data elements and how likely they are to change and what impact that change is likely to have.

Equally fundamental are the standards adhered to in terms of what information about these assets is captured and maintained, the interfaces and architectures used to transfer this data and also the levels of fidelity of the models produced. This governance should be driven by common quality management systems and information standards in use across the industry.

The Digital Twin can be exploited across all the Defence Lines of Development (DLoD) and can help shape how the asset will be supported once built. A systems model of the asset will develop interfaces into each of the DLoDs and will identify the inputs and outputs required by each line.

As the design matures, simulation can be used to test performance characteristics of the model, from human factors and ergonomics, through to mechanical representation of delivered capability. This information can be stored within the Digital Twin to inform and enhance the design, allow significant analysis to be performed which should ultimately reduce design iterations and minimise re-work at the physical development stage.

The same Digital Twin can be used to develop training needs analyses and early training delivery. This in turn may result in design changes as objectives are tested in the simulated environment in a range of conditions that may be difficult to replicate efficiently in the real world.

Once the asset is in service, real-time data can be viewed through the Digital Twin to allow for operational analysis and comparisons made to the original design intention. Further analytics can be performed within the Digital Twin, combining with data sources that aren’t available on the physical platform to understand wider impacts and make informed decisions on operational constraints or opportunities. Scenarios can be created to allow for a variety of courses of action to be assessed, whether this is within maintenance, delivery of effect or even impact of a reduced support service.

The Digital Twin must be exploited by as many areas as possible, during the life of the asset, in order to make the significant investment in creating and maintaining it in the first place worthwhile. It should be controlled by a Design Authority, and elements made available via common standards/interfaces to relevant stakeholders and the supply chain and wider eco-system. This will support their role in the maintenance and delivery of the asset and enhance the overall availability and effectiveness of the capability.

The presentation method of the Digital Twin is key and so the standards need to facilitate multiple methods of viewing, whether this is through traditional drawing packages, technical documentation management systems, training applications using virtual reality or platform operator/maintainer systems that use Augmented Reality. The fidelity and information exposed to the users must be designed from the outset from a human-centred perspective to ensure the objectives of those users can be delivered as effectively as possible. In order to achieve this, we need to embrace the technological advances of the commercial sector.

3 Exploitation of commercial technologies

To support the Digital Twin, we need to consider the requirements of maintaining the data throughout the life of the asset and what devices and technologies are required to support the provision, processing and visualisation of this data. Traditional visualisation technologies are still very much in use within the design phase and the industry is already making use of relatively recent visualisation technologies for training (VR) and we are witnessing the emerging of useable augmented reality (AR) technologies to support maintainers.

Capturing data relies on there being well-established, understood and used, standards and open architectures as described in the previous section. From the outset, we must ensure that the defence market exploits the tools and technologies that utilise these standards so we are able to use our valuable design data cost-effectively and maintain it, within the supply chain, throughout the life of the asset. Most industries are making use of low-cost connected sensors (Industrial Internet of Things) embedded within assets which need to be designed in from the outset, as-does the security of using such sensors within the defence context. The interconnectivity of such sensors, coupled with other data sources facilitates powerful analytics which can be carried out within the Digital Twin, allowing a range of simulations to be considered prior to making decisions on the real-world platform or asset, minimising the disruption of delivering capability.

In order to understand the data and provide insights, we must make use of rapidly advancing data analytics and artificial intelligence capabilities that are developing in the commercial sectors. The MOD makes use of existing open-source big data platforms, such as the Apache Hadoop stack, which provides standard interfaces to ingest and process billions of data points. Connecting the Digital Twin to such platforms provides analysts with a common and intuitive view into platform performance and allows insights to be inferred through the aggregation of seemingly disparate data sets. Figure 2 hints at the means by which humans can understand complex systems.

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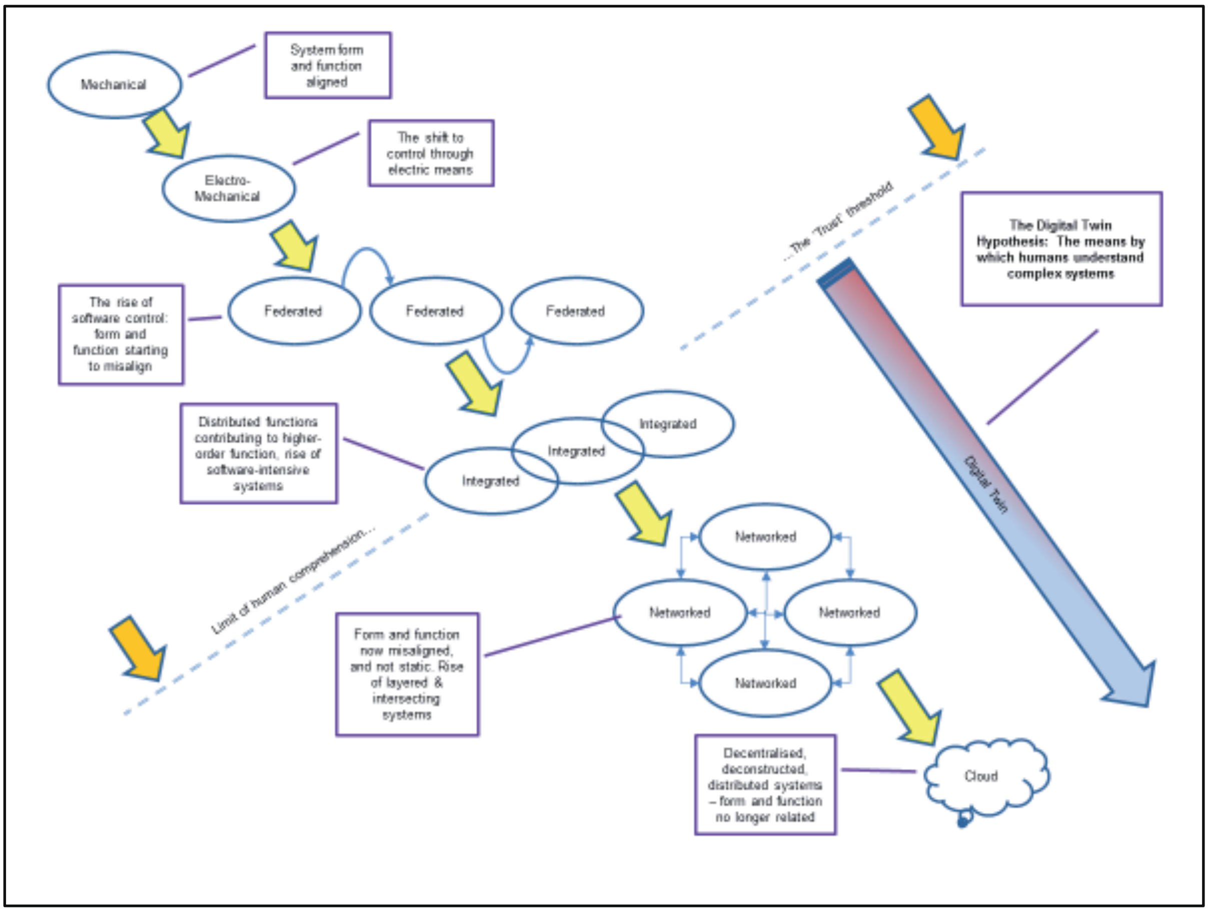

Figure 2: The evolution of complex systems and the digital twin.

Deep neural networks can be used to process these large data sets and construct a model which can be applied to the real-time data channels to manage issues such as potential system failures before they happen. Such an intelligent system can simply provide alerts to operators or be trained to carry out actions to respond to these potential issues autonomously. This is a task which an operator or team of operators can no longer perform effectively due to the significant rate and size of data associated with modern assets. The visualisation of such amounts of data and its origin would result in significant cognitive overload of the analyst and we must therefore present the output of automated findings in a different manner.

The User Experience is going to become a term that will be used more often at all levels of an enterprise, focusing the design of both the asset and the Digital Twin around the objectives of the roles of end users and how they interface with the asset to perform these required objectives.

Augmented Reality is maturing rapidly, with significantly technological developments in areas such as light field displays, and it's through use of this technology that we can start to enhance the human performance as part of the Digital Twin solution. Through expert human-centred design, we are able to provide the insights to the right person(s), at the right time, and in the right place, allowing them to perform some sort of action – whether this is mechanical or simply acknowledgement of an autonomous system's task.

In order to facilitate this data processing from the birth of the Digital Twin, there is a requirement for secure transit between parties throughout the supply chain. There is significant investment in technologies such as blockchain to provide this level of traceability and integrity thanks to the developments of modern crypto-currencies such as Bitcoin. Blockchain technologies are being developed to support a much wider range of applications outside the financial market largely due to the need for supply chains to work far more effectively in sharing and managing information around assets within business applications. The Defence Industry needs to be involved in how this technology is developed to ensure that it can be used in our highly regulated and secure operating environment, with the optimisation of the supply chain being the long-term goal.

4 Information exploitation (an eco-system view)

By their very nature, complex military assets require a complex business ecosystem (https://cambridgeservicealliance.eng.cam.ac.uk/Research/Ecosystems) to produce and support them. For example, in the UK Naval complex warship arena, the Surface Ships Support Alliance [SSSA] exists to deliver maintenance and support to a range of classes. This alliance consists of DE&S (The UK MoD's Defence Equipment and Support organisation), Babcock Marine, and BAE Systems as the prime organisations, but in reality, the ecosystem is much wider and includes other MoD organisations, and a wide and deep system of supply. All of the firms and government bodies involved in this ecosystem must collaborate effectively to deliver maintenance and support in a timely and cost-effective manner.

Looking back in time, these ecosystems relied on the movement of paper around them in order to deliver this support. This paper covered everything from design information, certification, drawings and the like, all the way through to maintenance instructions, diagnostic aids and training packages. As time has moved on, the ecosystem has (or probably more correctly, is) moving through the electronic era – this can be characterised by the 'paper' being represented in electronic form, such as Portable Document Format (pdf) files – but in essence this is 'just' the same thing as paper in a different form. But looking to the future, the digital (or information age (https://en.wikipedia.org/wiki/Information_Age)) is upon us, and the ecosystem is on the cusp of moving into another era. If anything, the digital age can be characterised by the movement of knowledge through the ecosystem, represented by discrete packages of information and data. In the world of so-called 'Big Data' the movement of these packages have properties of volume, variety, velocity, and veracity (http://www.ibmbigdatahub.com/infographic/four-vs-big-data) - these type of properties (loosely termed the 4 Vs) make the ability of the human to comprehend and assimilate such information a challenging task. And when this is extended across the type of ecosystems present in the support of naval vessels, the challenge becomes even greater.

With this comes a new language – as described earlier, the talk now is one of Digital Twins and Digital Threads as a means of providing some human level meaningful language archetypes to express the digital world. Thus, Digital Twins become the mirror of the real-world object, a representation of it that encapsulates the 4 Vs of big data, pan-ecosystem, and the Digital Thread becomes the path that this Twin traverses through its life. This means that the Digital Twin is 'born' during the development and creation of asset (such as a naval vessel), and continues to grow (in volume, variety, velocity and veracity terms) throughout the service life of the asset (its Digital Thread). The Digital Twin hypothesis is therefore that the Twin encapsulates all the knowledge and experience relevant to the real-world asset. In essence, The Digital Twin becomes the means by which humans understand increasingly complex systems.

The big challenge, hiding in all this, is how to bring the virtual Digital Twin to life in the real world that people (maintainers, operators, designers, etc) live in, and how to make this work with efficacy across the complex ecosystems (and increasingly complex systems!) involved in the support of naval vessels. Part of the answer, at least, lies in the technology of bringing the virtual world to the human world with A/V/MR. In the precursors to this paper, reference is made to the use of immersive technologies to deliver training solutions, and some 'art-of-the-possible' experimentation that looked at other uses of this class of technologies in the support of naval vessels. So far, this has only scratched the surface.

Bringing a bit of systems thinking to the problem, one can consider this virtual universe as a set of layers, namely:

- **A Presentation layer**: The A/V/MR solution used to deliver the information to the user (which could be operator, maintainer, etc).
- **An Integration or Executive layer**: The layer the brings together the various sources of data and information into a coherent (and approved!) set for presentation.
- **An Object layer**: The layer that contains the sources (and sinks) of information and data used to create (or report on) the presentation layer.

The technology base used to deliver the Presentation Layer is fast moving, driven by innovation in the commercial entertainment and gaming industries. The Object layer is also fast moving – the continuing development Product Lifecycle Management systems for developmental data can be cited as one example, and also (perhaps more pertinently) the rise of the connected machine, coupled the ability to capture, move, and retain usable data. However, when the sources/sinks of data & information are spread across the ecosystem, this in itself presents a major challenge in the orchestration of the movement of data. This challenge comes from looking at the properties required to assure the information at the point of use in the presentation layer.

This gives rise to the major challenge in the Integration/Executive layer. At the point of use, the user (whether that's a maintainer, operator, or any other actor in the ecosystem) needs to be able to trust the material presented for use. This trust can be broken down into several properties which build trust, namely: provenance, authenticity, coherency, and validity – it's the job of the Integration/Executive layer to address the properties so that the user can 'trust' what they are getting. Taking these in turn:

- **Provenance**: This about knowing where the data/information comes from – is the source a 'trusted' actor in the system?
- **Authenticity**: This is about believing the data/information - does it seem authentic?
- **Coherency**: This is about the relationship between items of information presented for use – do they make sense together?
- **Validity**: This is about sense-making – does the data/information make sense in the real world, and does it correlate to real-world experience?

This is one of the grand challenges in this sphere and lays the foundation for further work to needed to really meet the original aim outlined at the start of this section, that being: 'All of the firms and government bodies involved in this ecosystem must collaborate effectively to deliver maintenance and support in a timely and cost-effective manner'. Thus, tacking the challenge of the Integration/Executive layer is at the cornerstone of moving into the Digital Age.

5 The value proposition

A number of initiatives over the last 5 years or so will influence how widely any of this technology will be accepted and used and most importantly funded. It is the authors' view that the following strategies are key:

- The Surface Ship Support Vision.
- The Common Support Model.
- Programme Faraday.
- The Support Improvement Programme.
- The Maritime Engineering Support Information Exploitation (MESIX) Vision.
- The Naval Engineering Strategy 2017.
- Project Selborne.

Taking each of these in turn:

The **Surface Ship Support Vision** (SSSV) published in 2013 described what NCHQ required from the support environment. By influencing and shaping support solutions it aimed to place the on-board maintainer at the heart of support. It includes 10 Key Support Principles including the need to "exploit the organic capabilities and knowledge of Ships' Staff to sustain Operational Capability…".

An updated Support Strategy for the Ships Operating Centre (OC) within DE&S was written by John Newell in 2013 and it articulated how the Ships OC intended to take forward support to complex Royal Navy surface warships over the next 2 decades. It articulated a direction of travel for how the MOD team and its Industry Participants within the Surface Ship Support Alliance (SSSA) would collectively transform and improve the support to ships and aimed to deliver a support environment that met the Royal Navy's operating requirements articulated in its Surface Ship Support Vision and associated Key Support Principles. Once endorsed, it was formally launched as the **Common Support Model** (CSM) programme. The principle of Operate, Maintain, Diagnose and Repair (OMDR) was first alluded to in the CSM.

The **Programme Faraday** was initiated to oversee the engineering branch recovery plan in order to sustain a cadre which was to be ready for future challenges through a number of strands including the provision of improved training.

The **Support Improvement Programme** (SIP) is a combined DE&S and NCHQ approach to target efforts on solving the Royal Navy's most pressing support issues.

The **Maritime Engineering Support Information Exploitation** (MESIX) Vision aims to enable, equip and empower the support enterprise through digital transformation. It will bring together design principles of Defence Support Network (Information Services) with other guiding principles, the Common Support Model (CSM) and new capabilities such as New Style of IT (NSoIT) to provide a direction of travel to guide development of future Engineering Support information based capability.

The **Naval Engineering Strategy 2017** includes a number of actions of which a number are pertinent to this paper. Action 6 emphasises OMDR as a Key Support Principle (KSP) within the SSSV, implemented via the CSM, and aims to exploit the organic capabilities and knowledge of ship's staff. Action 2 states that the training

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pipeline must be minimised through the use of enhanced use of synthetic training methods. It continues to say that novel training solutions and modern information systems will be key enablers. Action 8 recognises that the effectiveness of organic engineering is critically dependent on the quality of information provided to RN maintainers at sea and the ability to exploit the data that the platform generates. The need to invest in Information and Knowledge Management (IKM) and Information Exploitation (IX) is recognised. Action 14 pushes training so that the maintainer can be at the hear of the support solution and Action 15 once again pushes for the ability to deliver OMDR.

The Royal Navy wishes to continue outsourcing the delivery of its training requirements and is considering ultimately bringing together much of Royal Navy training delivered in the UK within one contract under **Project Selborne**. The required outputs of Project Selborne include innovation in terms of the modernisation of Royal Naval training services including the potential for novel training technology.

Throughout these documents a number of key principles are established which provide a focus for the development of the digital twin and using that data with the technology of 3D, VR, AR and MR. In the authors' view the key strands applicable to this paper are:

- Improved focus on providing the right data in the right format for the support enterprise.
- Provide the tools required for RN personnel to be confident in their ability to deliver OMDR.
- Reduce reliance on OEMs.
- Use of innovation and novel training methods in RN training.

The digital twin that we have discussed in Section 2 above will provide the underpinning data required for the build and support enterprise using the tools which the MOD mandates. We can provide 3D, VR, AR and MR to provide the best experience for ships staff to ensure they are confident in their delivery of the Maintain, Diagnose and Repair elements of OMDR. As the investment in technology continues, we are anticipating higher performing systems and better human factors around the integration of this technology such that the maintainer can diagnose and repair using tools such as Microsoft's Hololens. This technology should allow greater innovation in training. Many initiatives need to progress and be brought together in order to deliver the improvement to OMDR which are possible, as shown in Figure 3.

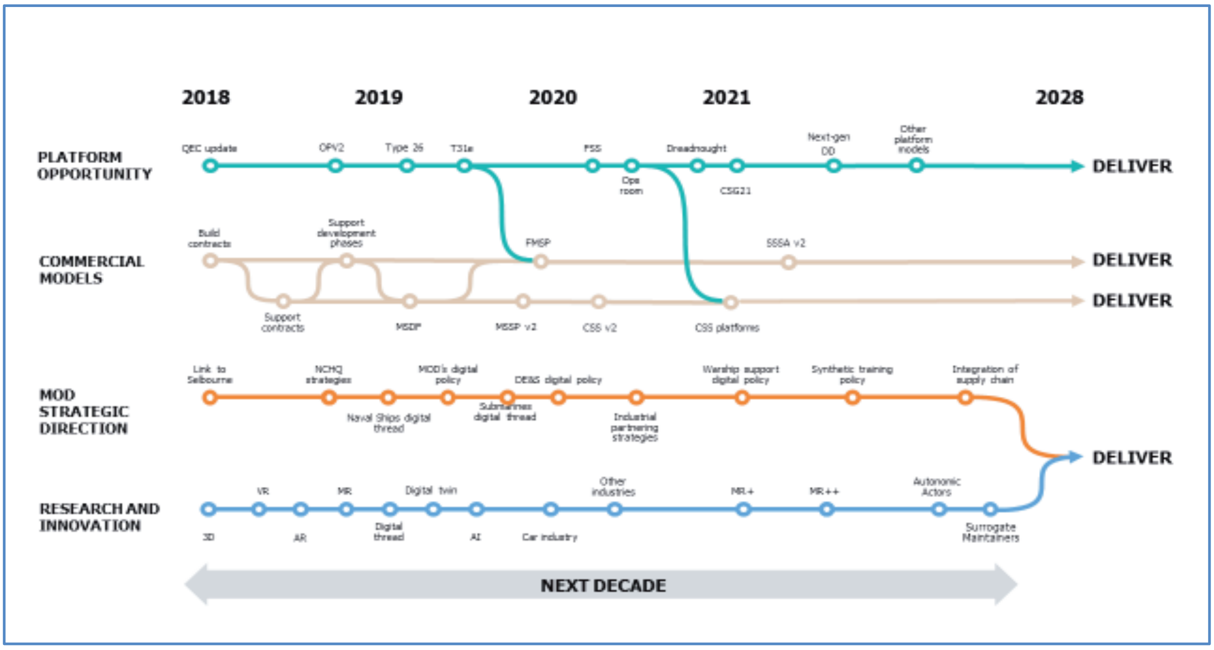

Figure 3: Initiative map.

Where is the funding, both MOD and commercial? All of this technology needs to be cost neutral at worst and ideally offer potential savings. Having the right data available to ships staff and industry must be able to generate savings in downstream support activities. If the reliance on OEMs can be shown to potentially generate sufficient savings this may provide the funding for technology to assist with OMDR. Project Selborne opportunities include cutting training pipelines, gamification and synthetic/hardware mix allowing less infrastructure/facilities, particularly for new Classes such as the Type 26.

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Although not discussed elsewhere in this paper opportunities within the dreadnought programme must also be significant. Figure 4 hints at where the correct use of the Digital Twin data may deliver benefits and in the authors' view the yellow highlighted boxes are where we feel the biggest return is or where the focus of effort should be.

OMDR	ACTORS	3D BENEFITS	VR BENEFITS	AR BENEFITS	MR BENEFITS
Operate	Trainers Operators	Link between classroom and reality through rehearsal using simulators, familiarisation and gamification	Link between classroom and reality through rehearsal using simulators, familiarisation and gamification	Enhanced situational awareness	Enhanced situational awareness through field of vision integration
Maintain	Maintainers	Visualisation of planned, unplanned, upgrade and update maintenance proposals Maintenance evolution design	Visualisation of planned, unplanned, upgrade and update maintenance proposals. Complex maintenance evolution rehearsals.	Assistance with maintenance processes using tablets	Assistance with maintenance processes using field of vision projection
Diagnose	Maintainers OEMs IPs (Fault Finding Documentation)	Aids system tracing and fault finding. Provides link to digital twin including documentation	Aids system tracing and fault finding. Provides link to digital twin including documentation	Assistance with maintenance processes using tablets	Assistance with maintenance processes using tablets and/or Hololens
Repair	Maintainers OEMs IPs Documentation Spares	Links from model to digital twin and the supply chain	Links from model to digital twin and the supply chain. Visualisation of repair processes	Assistance with repair processes	Assistance with repair processes

Figure 4: Value proposition.

Some of this technology has been tried before with mixed results. In the Submarine sector VR has been used to train personnel in the layout of the platform and to train them in the initial responses required to certain emergencies such as fires and floods. VR was also used to train Contractors on the QEC layout prior to her arrival in Portsmouth Naval Base. In both of these cases the technology was well received. With the Type 45 Destroyer the use of synthetic training was widely adopted and this led to a dilution in the skills of embarked personnel and a programme to reverse the use of this technology in favour of 'hands on' training was initiated. The blend of 3D/VR/AR/MR must add to the hands on experience and not detract from it. As an example, when training for the handling of boats and ISO containers in the Type 26 is developed it must allow the operator to conduct tasks many times in a realistic environment where he must 'feel' as if it were the real environment. Here VR can probably provide a better experience than a shore based trainer which might come at significant cost. When the maintainer has to learn how to move and repair the handling equipment this might be better done with actual equipment rather with the use of AR/MR assisting with the Diagnosis of OMDR.

6 Conclusion

This paper has sought to discuss three key elements. The concept of the digital twin and what we mean by it has been clarified, the paper has discussed how best to exploit all the data available and lastly the paper has discussed where the value proposition or compelling business case lies.

We have suggested that from a design perspective, the Digital Twin should start life as soon as the concept of a new platform, system or equipment is born. It needs to grow with the design iterations and be utilised by all those in the supply chain that are working on the project, acting as the hub for the various systems and tools used to manage the design process as well as the portal into supporting information, such as training, technical documentation and real-time performance analysis.

We have suggested that to support the Digital Twin we need to consider the requirements of maintaining the data throughout the life of the asset and what devices and technologies are required to support the provision, processing and visualisation of this data. Traditional visualisation technologies are still very much in use within the design phase and the industry is already making use of relatively recent visualisation technologies for training (VR) and we are witnessing the emerging of useable augmented reality (AR) technologies to support maintainers.

Having the right data available to ships staff and industry must be able to generate savings in downstream support activities. If the reliance on industry can be shown to potentially generate sufficient savings this may provide the funding for technology to assist with OMDR. Other opportunities include cutting training pipelines, gamification and synthetic/hardware mix allowing less infrastructure/facilities.

To make this work the support ecosystem includes many organisations, and a wide and deep system of supply. All of the firms and government bodies involved in this ecosystem must collaborate effectively to deliver maintenance and support in a timely and cost-effective manner.

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