Digital Twin for Defence Engineering Support

Digital Technologies have melded over the last two decades to make the virtual world Digital Twin of a physical asset both possible and valuable. A Digital Twin approach can have the benefits of reducing the need for physical assets during design, development and test activities, reducing costs and therefore increase speed to market. They can also optimise a physical asset's maintainability and availability making it possible to do more with less. Typically, 15–25% savings[1] have been identified in different domains including the built environment, transportation and energy. Gartner found that "24% of organizations already use Digital Twins and another 42% plan to use them within the next three years".[2]

Although UK Defence has started to digitise its engineering activities, it could significantly benefit from the systematic use of the Digital Twin approach across the capability life cycle. This is particularly true when considering the need to transform Engineering Support as part of Defence Support Transformation and realise financial and performance benefits across the whole of the Support Network.

Within this joint MOD and Industry paper Team Defence defines what a Digital Twin is within the UK Defence context. It provides examples of the wider UK Industry experience with Digital Twins, their benefits and challenges including culture, skills, tools, processes/procedures, networks, data and acceptance. It suggests what steps need be taken to start realising the savings, improve capability availability and mission effect.

We have an opportunity to make Engineering Support more efficient and effective to close the Defence budget gap. It supports the Defence Support vision of digitisation and better use of data to inform decisions as alluded to in the Engineering Support Transformation Vision paper [3].

1 BCG, Digital in Engineering and Construction, 2016; McKinsey, Construction Productivity
2 How Digital Twins Simplify the IoT – Gartner January 23, 2019 Sarah Hippold
3 Engineering Support Transformation (EST) Discovery, EST Final Report, 28 March 2019

What is a Digital Twin?

Advances in computing power, cloud data storage, and significant increases in real time data that can be captured through the dramatic increase in connectivity, have created a digital eco-system that supports the development of Digital Twins.

As there is no ubiquitous definition available for UK Defence, it is suggested that a "Digital Twin" (Figure 1) be defined as:

"A Digital Twin is a connected data representation of an entity, such as a physical asset, a process or system throughout its lifecycle."

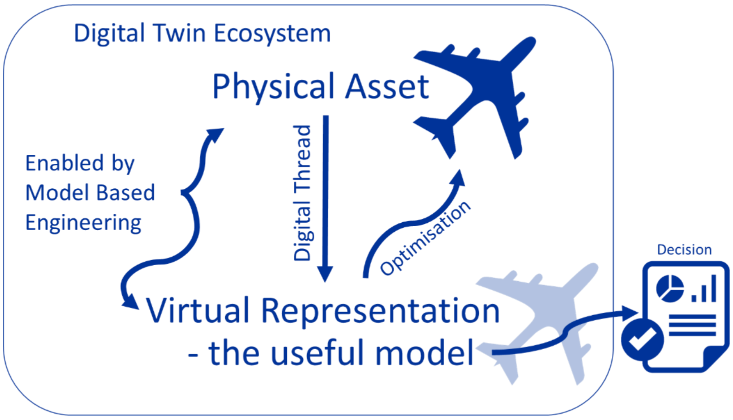

Figure 1 Digital Twin

This Digital Twin represents the design & intent of the entity, its configuration, attributes, characteristics and status within the context of its operating environment over time. The data can be analysed to provide insight into the performance and behaviours of the entity, model and predict future outcomes. This helps to optimise its use and inform decision making about the physical Asset. These opportunities include:

- Rapid Prototyping;
- Digital Design Iteration and Optimisation;
- Virtual Test and Qualification;
- Real-time Evidence based Certification and Safety Demonstration; and
- Optimised Maintenance including Efficient Inspection & Repair.

The Digital Twin *Ecosystem* consists of the interconnected cyber resilient networks, data stores, processes, methods, and tools used to manage, analyse and visualise the evolving data and models.

The Digital *Thread* links the data-information-knowledge system. The related sets of models and data build to form a view of the Digital Twin. Multiple Threads can be brought together to provide different insights into multiple aspects of the physical item and its ecosystem forming a Digital Tapestry. This Digital Tapestry sums all these digital models and data that enables greater insights including Engineering Support, System Availability, and Safety.

Without a Digital Thread, the Digital Twin merely reflects a moment in time of the physical instantiation it represents. The digital thread enables continuous synchronisation between the physical and digital worlds, and for the two to interact.

New life cycle model for new thinking?

The "Vee" life cycle model was created in the early 1990s by the German MOD and separately US Government and remains a useful representation. More recently, Boeing has suggested that this could be extended to show how Model Based Systems Engineering and Digital Twins could be represented. The Boeing Diamond[4] representation could be adapted for UK Defence capability acquisition and support across the life cycle. Virtual world design iterations, changes and digital testing precede the physical world activities to reduce risk, time and cost.

However, to support a fail fast iterative development approach enabled by the Digital Twin Prototype, other models have been developed. An example being Figure 2 the BAE Systems and UK Partners "Race Track" approach used on new projects.

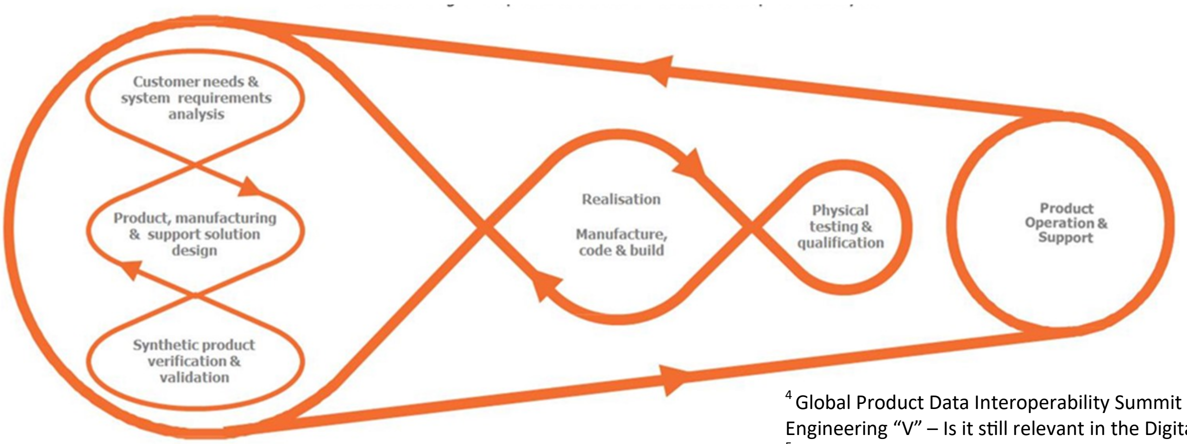

Figure 2 Smart Product Development Lifecycle

[4] Global Product Data Interoperability Summit 2018 – The System Engineering "V" – Is it still relevant in the Digital Age?
[5] Such as ISO 19650 international standard for managing information over the whole life cycle of a built asset using BIM

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Digital Twin Standards and Good Practice

As Digital Twin technologies such as the Building Information Modelling (BIM) and Industry 4.0 - factory of the future - are rapidly advancing, standards and good practice[5] are being established and could be readily adapted with Security elements for Defence. Another opportunity is the Reference Architectural Model Industries (RAMI) 4.0 [6] which defines the service-oriented architecture and supporting standards being implemented by Industry 4.0.

Learning from Industry Experience

Car Industry[7]

Problem: The annual warranty bill within an automotive manufacturer can be well above £0.5bn. Increasing vehicle complexity required more multifaceted validation techniques and a need to understand customer usage profiles in increasing detail.

The challenge was to understand the size of the task and where to prioritise, as:

- The fault/warranty data was fragmented.
- To fix the ever-increasing complex systems more detailed field data was required to reduce warranty costs.

Solution: A digital twinning solution has been evolving since 2005 to solve this problem. The build configuration, warranty, and physical entity data are being remotely harvested and stored for further analysis. This analysis is prioritised according to customer dissatisfaction and or cost.

Benefits: It provides *Efficient Inspection and Repair* with the vehicle owner inconvenience drastically reduced. Vehicles are diagnosed, data is collected, and software upgraded without the need for a dedicated service bay and no requirement for a technician to attend. Tens of millions (£) are saved per annum on resolving issues. Maintenance Technicians are fully utilised on non-software upgrade tasks.

Lessons applicable for Defence: The importance of correctly specifying what data should be communicated and retained. The available diagnostic data has increased to the point where it is not possible to store every parameter in case it is required in the future due to storage constraints and the cost of uploaded data. A Systems Engineering approach should be taken to select carefully the most critical data for the appropriate stakeholders to prevent unnecessary waste and to work within the physical system constraints.

It is also clear that an effective warranty system along with competition can be used to incentivise the supply chain to employ technologies to resolve issues.

Finally, the technology can be scaled to large complex problems including world coverage.

In Defence, the advent of performance-based equipment support services is driving the use of this technology and mirroring the incentives we see in the automotive warranty.

Volkswagen

Problem: How to use augmented and virtual reality to help save time and development costs so that each step in the process can be made faster and more efficient?

Solution: Volkswagen are using big data, Industry 4.0, the Internet of Things, connectivity, mobility services and virtual reality in close cooperation to provide *Rapid Prototyping and Virtual Test and Qualification*. Volkswagen incorporates digital twin technology in their entire business processes. This technology has allowed the creation of digital 3D prototypes of their different car models such as the Golf at design stage, they put together digital representations of the vehicles that are used to virtually validate designs from the point of assembly and throughout the lifecycle of the cars to optimise their product designs. They can then virtually assemble the cars to validate manufacture; virtually crash the cars for NCAP (New Car Assessment Programme) scoring; and virtually stress the cars and individual components with real-life load data.

This both speeds up the design process getting products to market quicker and saving £millions in physical prototype iterations. As the software correlation to real-life gets better, manufacturers are more and more able to rely on this technology.

Lessons applicable for Defence: Industry have adopted and demonstrated the viability of the technologies making this a low risk spend-to-save decision.

[5] Such as ISO 19650 international standard for managing information over the whole life cycle of a built asset using BIM
[6] http://i40.semantic-interoperability.org/

[7] Supplied by EES Solutions KMD Ltd

Network Rail

Problem: Need to address the doubling of passenger numbers over the preceding 20-year period, which will continue to grow, and the need to do more with the predominantly Victorian infrastructure and in particular improve planning, safety plus reduce maintenance and upgrade work.

Solution: Network Rail launched its £330m ORBIS programme in 2012 to produce a geospatial based Digital Twin of the railway network to better manage its assets.

The system collects, evaluates, collates, supports analysis, and communicates data across the business; it went live earlier this year and now supports ~17,000 users. ORBIS enables *Efficient Inspection & Repair*, fault management, optimal maintenance and renewal work and timetable management – planning work that would take days now takes minutes.

Lessons applicable for Defence: Consultation with the core users was critical to the project's success. Also recognising that an agile solution building on existing data and applications was required. The Common Support Model in Maritime is taking this approach.

Built Environment

Problem: Relying on drawings for drafting, analysis and construction is inefficient; drawings decay over time and do not keep up with the changes and renovations.

Solution: Building Information Modelling (BIM), a term that first appeared in the early 1990s, although the research and ideas go back to the 1970s. Building Information Models span the whole concept-to-occupation time-span and provide *Digital Design Optimisation*. Building Information Modelling (BIM) is an intelligent, model-based process that gives architecture, engineering, construction and maintenance professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure. It is widely used in the construction and management of complex infrastructure from universities to airports such as Heathrow. Typically, 15–25% savings achieved in design and construction by enabling a single-source of truth through BIM enabling everyone to work together.

Lessons applicable for Defence: BIM is relatively mature with international standards in place and is being developed through a number of dimensions. This approach demonstrates that UK Defence can readily define a road map for the extension of the Digital Twin concept and build on existing good practice once estab-

Oil and Gas[8]

Problem: Many oil & gas platforms continue working beyond design life into a mature phase of operation, raising a number of challenges:

- Ensure the integrity of the platforms for continued safe operation, and that the platforms remain economical.
- Operators are increasingly challenged to demonstrate the viability and compliance of their infrastructure.
- Increasing costs, as the assets age beyond their design life.

Solution: Near real-time structural integrity "one-model" approach, that helps automate inspection analysis workflows from inspection data to same day, full structural analysis. It also supports a fast response to incident resolution using a more automated, data-driven, and physics-based approach that assists the operator in analysing the large amount of inspection data and *Real-time Evidence based Certification and Safety*.

Royal Dutch Shell unlocked 20 years of structural capacity for operated assets in the North Sea – optimised inspection and maintenance, reduced unplanned down time and enhanced fatigue monitoring.

Oil and Gas Technology Centre Team assesses Digital Twins' part in asset savings – Estimates include 45% reductions on equipment down time, 25% in maintenance cost reduction, potential savings per asset ~ £90M.

Lessons applicable for Defence: The use of condition-based Digital Twin incorporating all available design class specifications and inspection data is used to identify parts of the hull that are at risk. It optimizes inspection and provides significant savings in operations expenditure, increased structural life (up to 15 years), reduced inspections, an ability to address 100-year wave loading threats and supports the safety case.

[8]Evidence supplied from Akselos

Industrial Process Equipment

Problem: A supplier of global air and gas handling products typically operates process critical equipment in customer environments, so any unplanned downtime is very costly for the supplier and the customer. Yet for the most part this equipment has been unmonitored.

Solution: A connected field maintenance program that delivers Digital Twins of products to customers and service technicians. The technology enables customers to predict and optimize equipment performance and reduce unplanned downtime, improving customer success and optimizing service and maintenance outcomes, providing *Efficient Inspection & Repair*.

Lessons applicable for Defence: Productionised Digital Twin technologies are already in use in the Industrial space, so enabling proactive and pre-emptive performance analysis to optimise maintenance scheduling and reduce downtime.

Benefits and Challenges for Defence Engineering Support

From these few examples it can be seen that adjacent industries are adopting Digital Twins as they provide savings through increased productivity, performance, reliability and availability and reduce warranty expenditure. They provide ongoing safety verification and are used to extend maintenance cycles.

The developments in sensor technologies that enable a connected environment (Internet of Things) where engineering support information about materials, failures, stresses and strains, usage, maintenance schedules and the life expectancy of parts is potentially at the fingertips of support and maintenance organisations. Through Data Analytics techniques, decisions can be supported and simulations can be run to give accurate representations of how possible changes would affect the capability availability and reliability.

The DE&S expertise and skill mix required to define a Digital Twin solution, are different to those currently available including:

- the creation of the technology dependent business case and requirements;
- specifying the Digital Twin technologies and standards to be adopted;
- ensuring the UK Defence Enterprise infrastructure including networks and big data management support a capable ecosystem; and
- being able to test and evaluate the Digital Twin solution being offered.

As it is possible to make Digital Twins of individual components, complete assets, through to full systems and entire processes. The technology has broad application therefore it is important that a strategic approach be taken.

The need to develop a useful Internet of Military Things (IoMT) could be seen as a significant challenge however UK Defence can build on Defence investments including those in Systems Engineering such as the Guide to Engineering Activities and Reviews (GEAR).

The use of the Digital Twin increases the cyber-attack surface but improving the cyber resilience of both Information Technologies (IT) and Operating Technology (OT) are already subject to UK Defence investment and therefore cyber-risk should not be seen as blocker to using Digital Twins.

Implementation Strategy

As previously recommended[9] MOD needs to engage with Digital Twins and Digital Threads, if only to shape development towards its own needs and long-term strategies.

The following six fundamental elements are necessary to exploit the benefits of Digital Twin for Engineering Support:

- Transform the pan-functional culture and work force to adopt and enable Digital Twin across the life cycle.
- Develop tools, criteria, and business case template that help prioritise Defence Digital Twin investments.
- Provide Digital Systems Engineering processes, procedures, guidance and tools.
- Systematically integrate Digital Twins into the requirements management process from capability audit through scrutineer gate reviews across the life cycle. In particular, the creation of a coherent Defence enterprise digital thread.
- Prepare the supply chain to support wider data availability and coherence. Consider the issues of co-creation, sharing, compatibility and the enabling contracting arrangements.
- Be able to test and evaluate industry Digital Twin solutions in a standardised way. Ensure the development of Regulation and Certification to align to ever greater use of virtual testing and demonstration.

[9]Engineering Support Transformation (EST) Discovery, EST Final Report, 28 March 2019

Route to Implementation and Embedding Savings for Support Engineering

Successes shared and replicated from industry should set the bench marked to help speed up defence adoption and enable the improved Engineering Support and to get early demonstrations of savings.

We recommend that we build on the existing Defence activities and look to cohere them. For example, Computer Aided Design, Finite Element Analysis, Computational Fluid Dynamics Models, Systems Flow Models, and Concurrent Design models already exist for many Defence assets. Current in service monitoring and maintenance records are building up a data reservoir that could be exploited through data analytics techniques. Technical Publications are already electronic with automated drill down capabilities. For example mapping of Typhoon composite skins, electronic repair drawings and laser alignment checks all provide data that can be aggregated and analysed. New products such as the F35 provide ever-increasing data that can be exploited to the benefit of both acquisition and in-service support costs.

Making Digital Twin part of the Engineering Support Process

Using the outcome of these projects to create a systematic and repeatable Engineering Support Digital Twins capability and process.

It is likely that the above process would require the creation of rainbow teams drawing on industry expertise to provide knowledge augmentation and start to generate the skilled people within the MOD to enable this technology to be adopted and the savings realised.

Based on the actions required to embed Digital Twin capability for Engineering Support, it is recommended that a UK Defence road map is developed. This should recognise both new and established programmes and the spectrum of implementation. This will be based on the cost effective exploitation of Digital Twins by programme. It should establish the end vision for new programmes and the guidance for exploitation by other programmes.

Defence Repeatable Engineering Support Digital Twins Capability and Process Elements

People: Develop competency definitions for; gain experience and knowledge for key Defence staff, conduct a Training Needs Analysis.

Engineering: Define processes, procedures, industry standards (augmented for Security requirements) and tools including architecting and modelling for Digital Twins captured in DE&S Guidance of Engineering Assessments and Review (GEAR).

Requirements Process: Develop and add Digital Twin Requirements and Acceptance Tube Map content. Team Defence has already done some work in this area that can be rapidly matured.

Policy and Standards: The development of Digital Twin policy for Engineering Support and Defence Standard for Digital Twin using industry good practice, and DEFCONs for Engineering Support data/ information property rights and Data Security levels.

Commercial: Develop guidance for contracting for Digital Twins including business models, Gain Share through warranties, Intellectual Property Rights, Data Ownership and Model Ownership.

Infrastructure: Ensure the Defence Ecosystem is capable of supporting Digital Twins including networks and data management (storage and security).

Demonstrate benefits: including availability optimisation, maintenance savings, parts supply optimisation, reduced testing, and support centric decision making.

Defining Performance Indicators: to measure and judge the success of the Digital Twin focused on cost, process time and availability.

Quick Wins

Spotlight a number of existing Defence programmes from different domains that already deploy or are planning to deploy Digital Twins technologies, develop their digital thread further and systematically capture their benefits and good practice for the whole Defence community in Policy, Standards and Guidance.

The following table identifies the Digital Twin Themes, the supporting industry evidence, suggested Royal Navy and Royal Air Force projects to demonstrate Digital Twin's worth and enable the capture good practice to promote their wider adoption across Defence.

Life Cycle Stage	Digital Twin Theme	Industry Examples	Suggested Projects to provide MOD Good Digital Twin Practice	Demonstrating Digital Twins Worth:
Concept & Assessment	Rapid Prototyping	Volkswagen	Tempest (RAF)	Coherent Digital Thread across the supply chain & Platform
Development	Digital Design Optimisation	Built Environment	Submarine Delivery Agency (RN)	Providing more effective and efficient decision making and improved customer and supplier mapping
Manufacture	Virtual Test & Qualification	Volkswagen	Hawk (RAF)	Life extension and predictive maintenance
Manufacture & In-service	Real-time Evidence based Certification and Safety	Oil & Gas	Type 23 Frigate	Evidence for continuing safety and certification with acceptable deferred defects
In-service	Efficient Inspection & Repair	Car Industry Industrial Process Equipment Network Rail Oil & Gas	Type 23 Frigate Type 45 Destroyer	Intelligent predictive maintenance

Team Defence contributors from the following organisations:

Advanced Manufacturing Research Centre - (AMRC)

Akselos

Army

Atkins part of the SNC Lavalin Group

Babcock International

BAE Systems

Boeing

Conceptare

MOD DATQA

Defence Innovation Cluster

EES Solutions

Leonardo Helicopters

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