Team Defence Information Digital Twin Community of Practice

(DTI-DT CoP)

PART 1

PART 1

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INTRODUCTION

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This document presents the work undertaken in developing the vignettes discussed in the Roadmap and understanding the implementation landscape for digital twins within the defence sector, including in the sections on page 1.

PART 1

Providing an overview of the work undertaken, the results and conclusions drawn;

CONTENTS

This document provides an update on progress from the Defence Digital Twin Community of Practice since the issue of the Defence Digital Twin Implementation Road Map and Development Framework in early 2021.

PART 1

1.

MULTI DOMAIN OPERATIONS

DIGITAL TWINS ARE A KEY ENABLER FOR SENSING, MODELLING, ORCHESTRATION AND SIMULATION OF COMPLEX PHYSICAL AND CYBER SYSTEMS.

This paper sets out a vision for the federation and integration of Digital Twins to support virtual, physical and cognitive Multi-domain Operations.

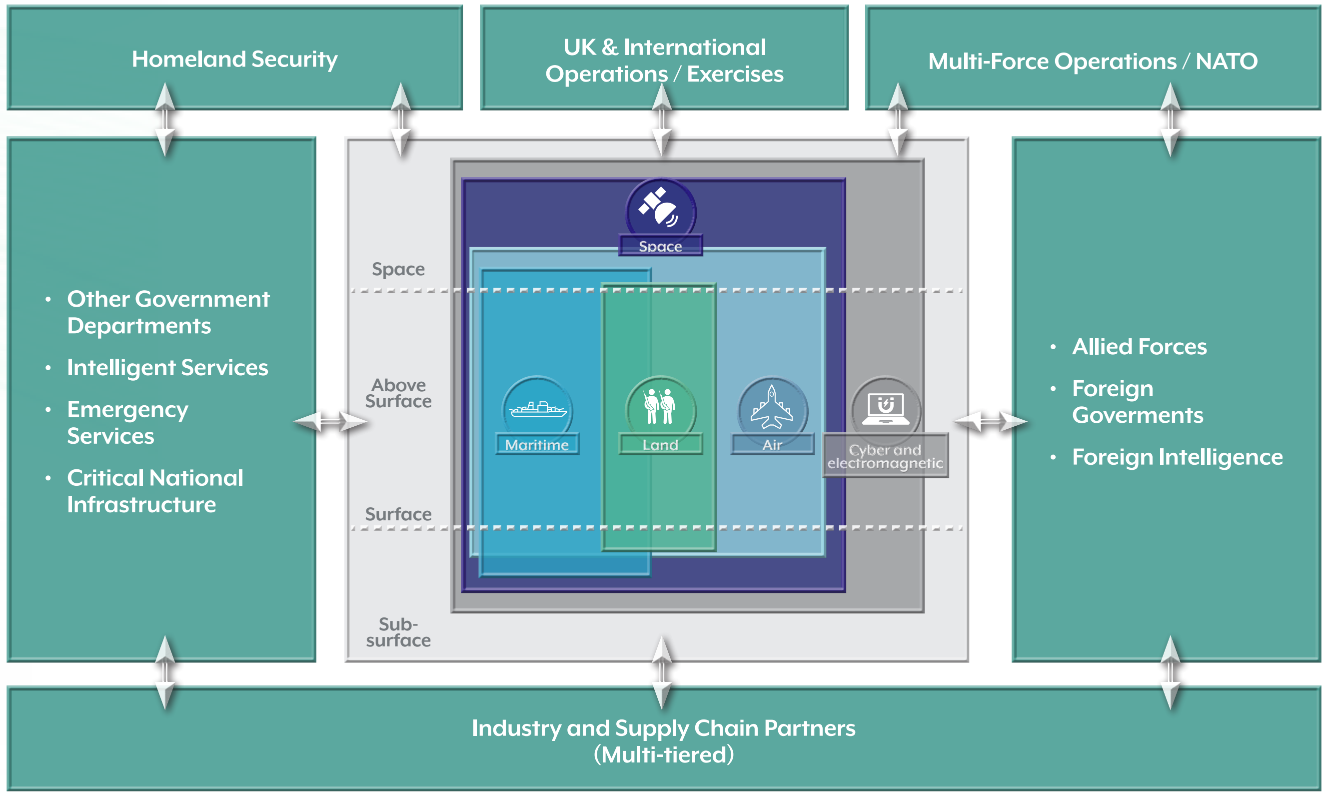
Introduction

To successfully adapt to the Information Age, UK Defence has prioritised the need for Multi-Domain Integration[1] (MDI) across its operating domains (Land, Air, Sea, Space, Cyber and electromagnetic) in order to change the way the UK's Armed Forces operate, war fight and develop capability.

Effective integration of the domains will achieve a multi-domain effect, greatly enhancing the individual effectiveness of each domain with a vision of maintaining advantage in an era of persistent competition

The scope of potential Multi Domain Operations is extremely broad and scenarios can include working with other agencies and third parties:

Figure 01



[1] UKMoD - MDI Joint Concept Note

Fusion and coherence across domains and interoperability with third party entities is essential to orchestrating effectiveness with a need for continuous, adaptive, decisive and resilient sharing and use of data and digital capabilities at the required tempo. Digital Twins are increasingly recognised as a means to overcoming the challenges faced by MDI.

Vision for Digital Twins to enable Multi-Domain Operations

Digital Twins are an accurate and connected real-time, or near real-time, digital representations of physical entities; they unlock value by enabling improved insights through the use of advanced analytics, modelling and simulation to support better decisions, leading to better outcomes in the physical world. The connected nature of digital twins to the real-life entities they represent provides direct sensory feedback to enable continuous monitoring and adaptive change.

Integration of digital twins to create a dynamic system of systems in the context of Multi-Domain Operations can enable horizontal integration and scaling across government, domains and with allies for different operating environments; and vertical integration through multiple tiers, allowing support to UKMoD operations by industry and support chain partners.

The potential application of Digital Twins is expected to span all elements of MDI across multiple scenarios context. The systems of systems approach will reduce overall complexity and risk, allowing the MDI ambition to be more achievable.

The Team Defence Information Digital Twin Community of Practice sets out a vision for the creation of a federated eco-system of digital twins to support MDI requirements. Digital Twins will be interoperable as part of a system of systems and can be combined to form composite twins. The eco-system will allow individual twins to be developed, deployed and managed independently but shared as part of the collective MDI capability.

The TDI DT-CoP aims to test this vision against various scenarios across the scope of MDI to understand the value and benefits of adopting a digital twins approach. The types of digital twins that can be applied and the considerations that need to be made to enable the vision and realisation of benefits, are for example:

- planning advantages,
- improved integration of responding agencies,
- ability to exercise against scenarios that cannot be undertaken for social reasons such as nuclear, flood or mass evacuation,
- privacy in undertaking anti-terrorist responses,
- improving levels of preparedness and training.

This approach aligns to the UK Government Integrated Review[2] and the Integrated Operating concept that includes development of new cross-cutting capabilities such as the Situation Centre, Counter Terrorism Operations Centre (CTOC), National Cyber Force (NCF) and a national capability in digital twinning to enable an integrated approach to working with others around the world.

Whilst there is ongoing consideration and development of digital twins across UK Defence driving at specific use cases there also needs to be consideration of broader application, understanding the relation between digital twins, their federation and integration, or composition, to support macro-challenges such as MDI; or risk that digital twins become stove-piped in nature with limited path to further exploitation.

Team Defence believe that UK MoD will benefit greatly from a pilot programme to inform the development of an eco-system within the defence domain.

The creation, deployment and management digital twins will create value at the individual twin level and federated as a system of systems in the support of Multi-Domain Operations.

Defining a Multiple-Domain Operations Digital Twins Pilot

The dynamic and diverse nature of MDI means that the requirements cannot be captured through a single set of scenarios, but considered from a capability perspective by defining how the re-use, integration, scaling, orchestration of digital twins, the data flows and interoperability between models in a federated environment can be understood, achieved and tested in defence for enablement of MDI for any envisaged scenario or operation.

The purpose of the pilot is to understand where Digital Twins can take us beyond current capability; how we need the system to perform and the technological capability required to ensure speed of relevance for faster, quicker options analysis and response.

Digital Twins are designed with a specific intent such as technical performance and material state, lifecycle assessment, cost modelling, assembly and disassembly for asset maintenance.

Figure 02 - All Digital Twins Must Have A Clear Purpose, Be Trustworthy and Function Effectively

PURPOSE
Must have clear purpose

BENEFIT
Must be used to deliver genuine benefit in perpetuity

VALUE CREATION
Must enable value creation and performance improvement

INSIGHT
Must provide determinable insights into capabilities

(Source: Centre for Digital Built Britain - National Digital Twin programme)

[2] Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy

Understanding the purpose and value of individual twins and how these twins can be combined to support Multi-Domain Operations is key. This will drive considerations for how twins are created and the environment or eco-system in which they are deployed to provide the levels of flexibility and agility required to be dynamically combined and consolidated to model a given scenario or quickly respond to an emergent threat.

Achieving this will require testing digital twins against a set of principles such as FAIR to assess the Findability, Accessibility, Interoperability, and Reuse of digital assets. The principles emphasise machine-actionability (i.e., the capacity of computational systems to find, access, interoperate, and reuse data with none or minimal human intervention) as we increasingly rely on computational support to deal with data as a result of the increases in volume, complexity, and creation speed of data; a core tenet of MDI enablement.

Another aspect of the pilot will be to explore the intelligence of twins, the attributes and methods that enable interoperability of twins, the flow of intelligence to drive outcomes and to test the extensibility of these attributes and methods to support Multi Domain Operations at the required levels of granularity and completeness to effectively model the operating environment, resources and support functions for the context required.

Figure 03 - The types of Digital Twin that must be considered for Multi-Domain Operations

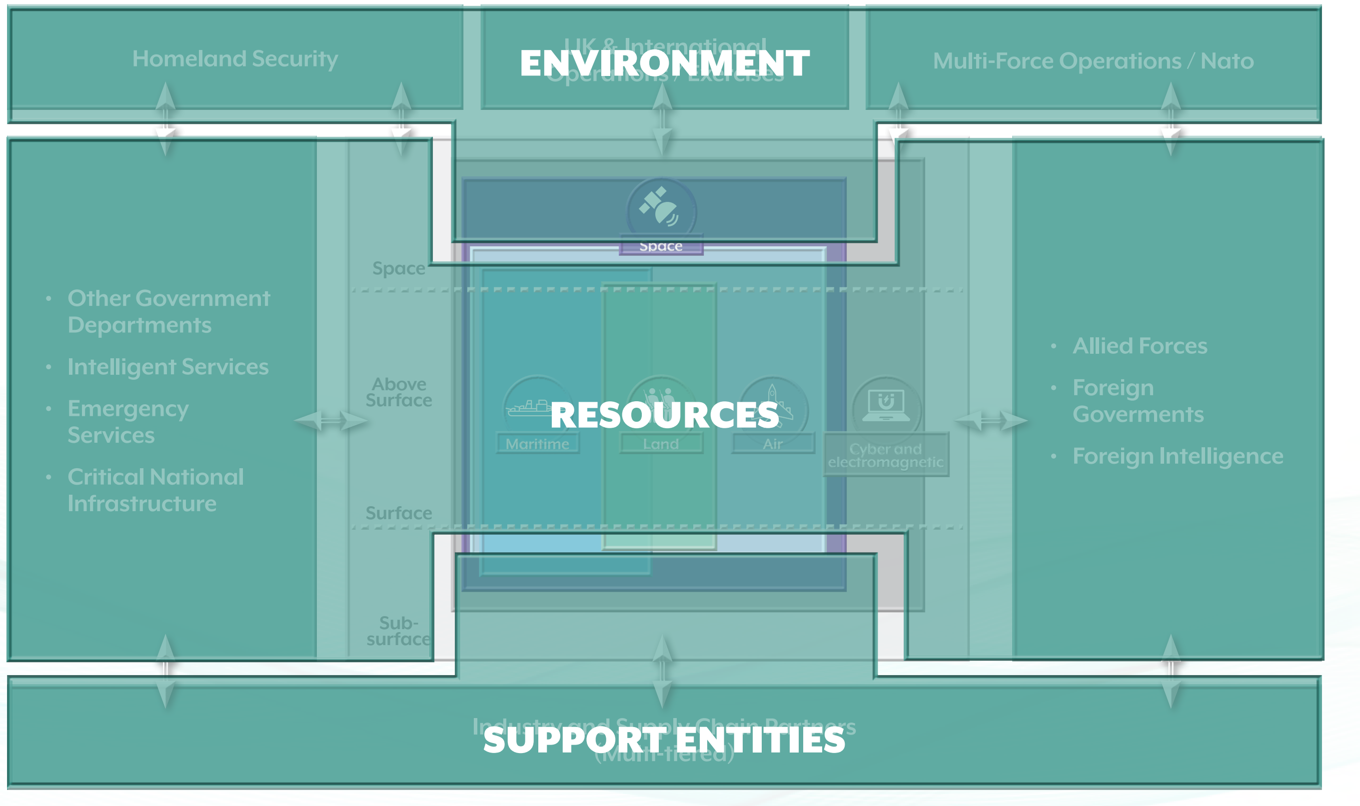
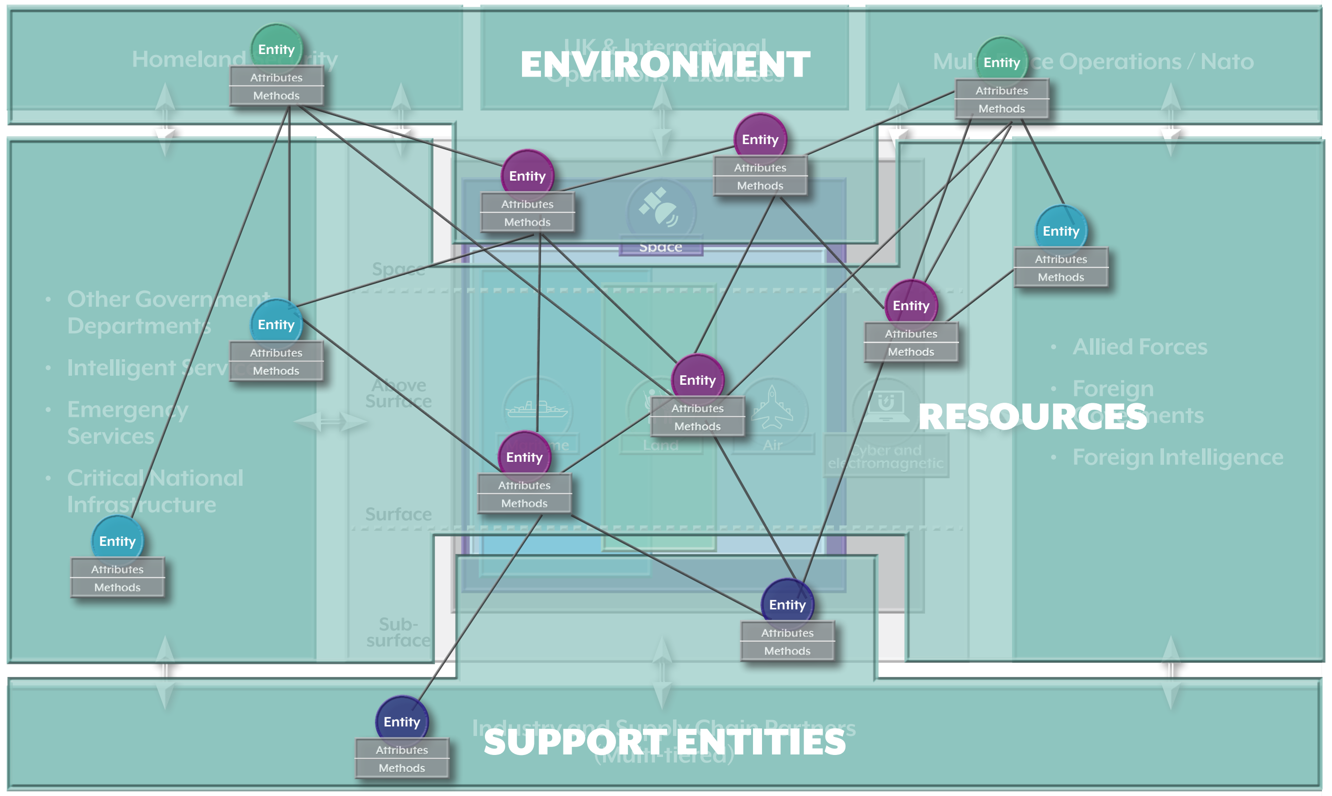


Figure04 - Federation of Digital Twins for a Holistic View of Multi-Domain Operations



To understand this, the pilot will test the ability to combine Digital Twins such as Terrain, Weather, Infrastructure, traffic, Geo-political and people twins that together can define an environment with resource twins such as Platforms and equipment, Military and 3rd party personnel, communications to understand capability, availability and readiness with required support entities such as supply-chain and logistics models to deliver the required effect(s) in the environment.

Establishing the principles for an effective pilot is essential, but context is also required to provide relevance and understand how the concepts for digital twins can be applied and tested against different Multi Domain Operations and requirements such as:

- Pro-Active capability – Forward planning and capability development
- On-going capability – monitoring and intervention
- Reactiveness – the ability to quickly respond to an emergent threat or situation – particularly at a command and control level – including communication with effectors
- Complexities and challenges of combining our environment with those of allies and/or civil forces
- The ability to accurately identify opportunities and threats
- How to extract and apply 'lessons learned' for example: SEMP (Strategic Effects Management Process) and OMSE (Orchestration of Military Strategic Effects)

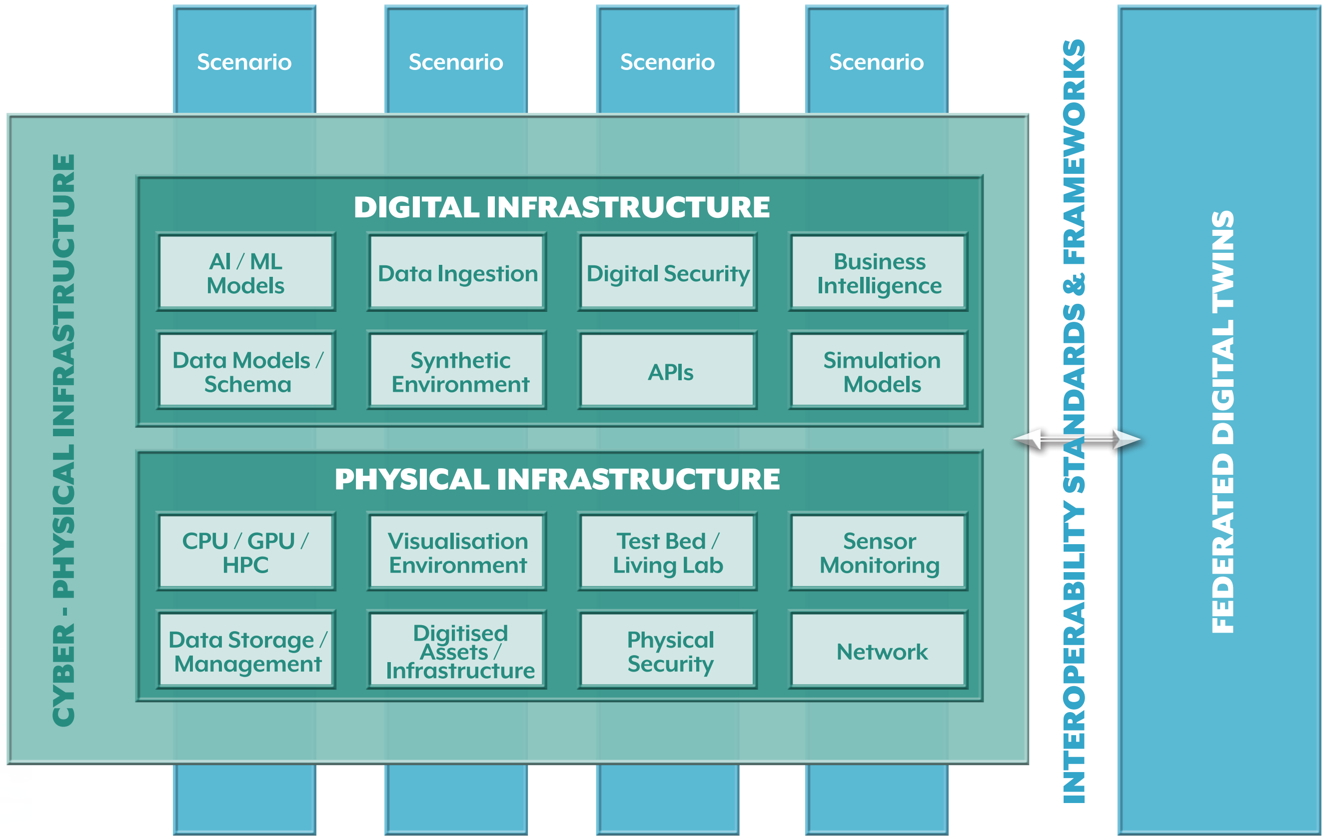
It is important to recognise that we are not breaking new ground, the difference for Multi-Domain Operations is scale and complexity adding to the known value of digital twins: the adaptation and interaction of digital twins to create an effect on an environment. Considerations of automation and applied intelligence to these interactions, and recognition of being able to bring together models from different environments in context of a scenario, at required levels of adaption, need to be accounted for. This places greater emphasis on adoption of standards and common ontologies at a foundational level to allow democratisation of the eco-system itself and the architecture of the core building blocks of the system of systems required for Multi Domain Integration; defining these will be a key output of the pilot.

Enablers for Digital Twins within Defence

Developing a pilot must also consider the technical environment and any dependencies for the creation, testing, hosting, management, integration and orchestration of Digital Twins; the data flows between interoperable digital twins; and connectivity and interaction with the physical entities and environment they represent.

These considerations need to be tested at the physical level to provide the fundamental compute, storage and communications infrastructure as well as the required digital enablers for modelling and synthetics, advanced analytics and integration through open architectures and Application Programmable Interfaces (APIs); all with appropriate security and access controls.

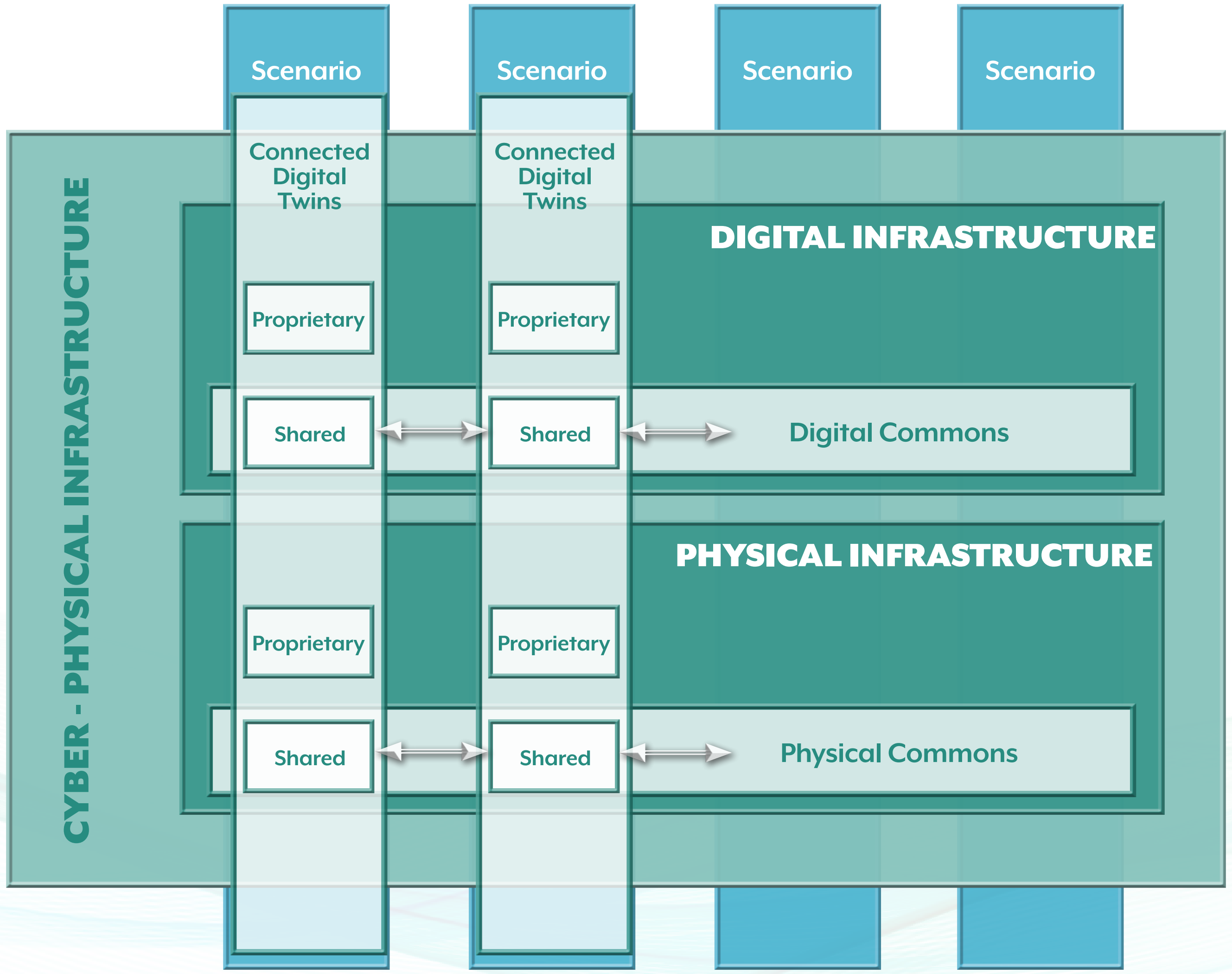
Figure 05 - The Relationship Between Digital And Physical Infrastructure



How the enablers are utilised needs to be considered across the broader Defence Enterprise, recognising digital twins will be developed by different parties, and how these capabilities can be made interoperable with broader government, allied partners and other organisations required in Multi Domain Operations.

The pilot will consider these aspects and the digital commons that can be leveraged within the defence domain for the creation of a Digital Twins eco-system for Defence that can scale to meet the requirements for MDI.

Figure 06 - The Impact Of Federated Digital Twins Across The Physical And Digital Infrastructure



This will include the Defence Digital Backbone, the Digital Foundry and Defence-Synthetics Platform Environment (D-SEP) along with required Interoperability Standards and Frameworks for Shared Content (D-SEP) and Standardised Digital Twins to optimise re-use and scaling; and how these can be utilised in conjunction with open source and proprietary capability and models, such as commercial models or IP protected capability, as part of the eco-system.

Summary

The proposed next phase of activity is to work with the authority to define a scenario(s) and undertake a pilot for testing the use and application of Digital Twins for Multi-Domain Operations, this will collate and build on existing work to explore challenges specific to MDI and linkages to other work across government such as the Department for Business, Energy & Industrial Strategy (BEIS).

The purpose will be to understand how the use of digital twins can take us beyond current capability to support the tenets of future Multi-domain Operational objectives.

The pilot will also test technical feasibility of digital twins development and deployment in the defence domain, and interoperability of twins across domains to support Multi-domain Operations.

PART 1

2.

IN-SERVICE SUPPORT

DEFENCE SUPPORT DIGITAL TWIN COMMUNITY OF PRACTICE IN-SERVICE ENGINEERING

This report outlines the work of the In Service Engineering work stream for the Team Defence Information Digital Twin Community of Practice and is intended as supporting information to the 'Defence Digital Twin – EST' Presentation on 20th October 2021.

The Working Group has focussed on the how adopting digital twins can provide insight to improve performance and outcomes for engineering decisions in the in service phase of the product lifecycle. This report outlines the type of benefits that can be obtained and uses the BSI PAS 280 standard to help guide the identification of improvement areas and the value that this can bring to the MoD as the end customer, as well as for the organisations involved.

The report sets out the Vision Mission and Objectives of adopting digital twins for performance improvement in In-Service Engineering and goes on to consider the types of use case where a digital twin approach could be beneficially applied, and framing these against a standard lifecycle model.
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1. Scope and Purpose

The focus of this task is to consider the in service phase of the life-cycle and particularly engineering activities within that phase, which includes maintenance, upgrade and modification.

The intent of the activity is to identify where the use of digital twins would be applicable and provide a positive impact on efficiency and cost compared with the current approach. Specifically the group was asked to look at in service engineering decision making and has considered areas from single component reliability through to fleet life optimisation
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2 Vision, Mission and Objectives

Vision

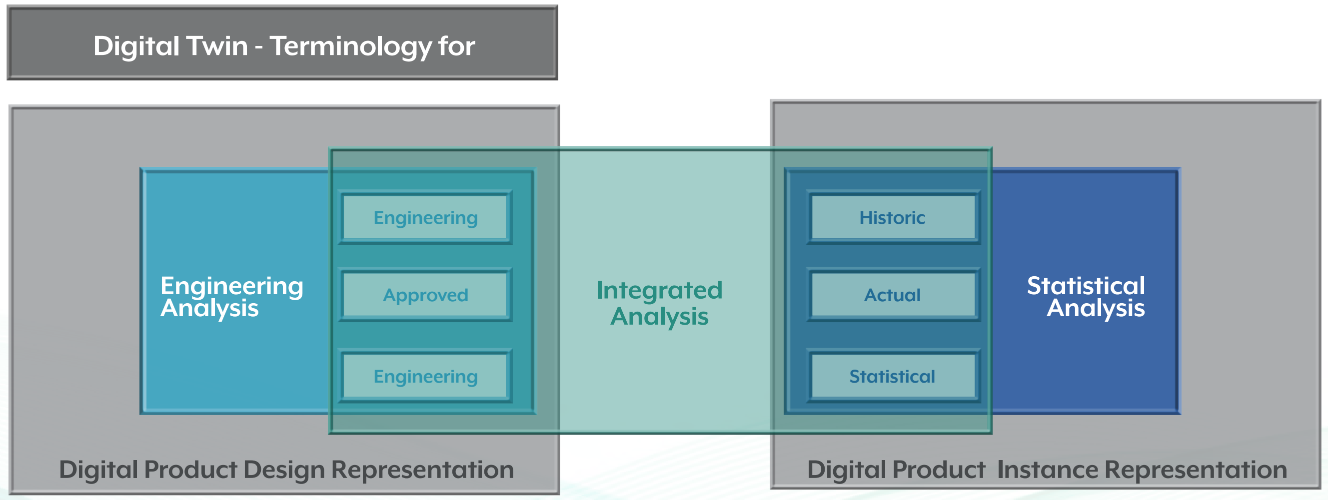
Federated digital twins are supporting a continually improving proactive and predictive support "service", ensuring the most effective, economic, safe and secure operation of military capability

Mission

Prove by the implementation of a number of MVPs on key projects across defence how federated digital twins will deliver continually improving support engineering decisions,

Objectives:

- Define the framework and approach for digital twin adoption in support of engineering decision making in defence through life
- Contribute to the defence standards and policy for digital twins, including understanding how the MoD would contract for digital twins for both new and legacy platforms
- Model the significant transactions in support engineering activity,
- Continually improve predictions via the use of in-service feedback, Increase in allowable life
- Achieve full transparency of equipment condition for predictive maintenance at fleet, platform and component level, enable pro-active and predictive modelling of a dynamic service and enable the most economic provisioning of resources.



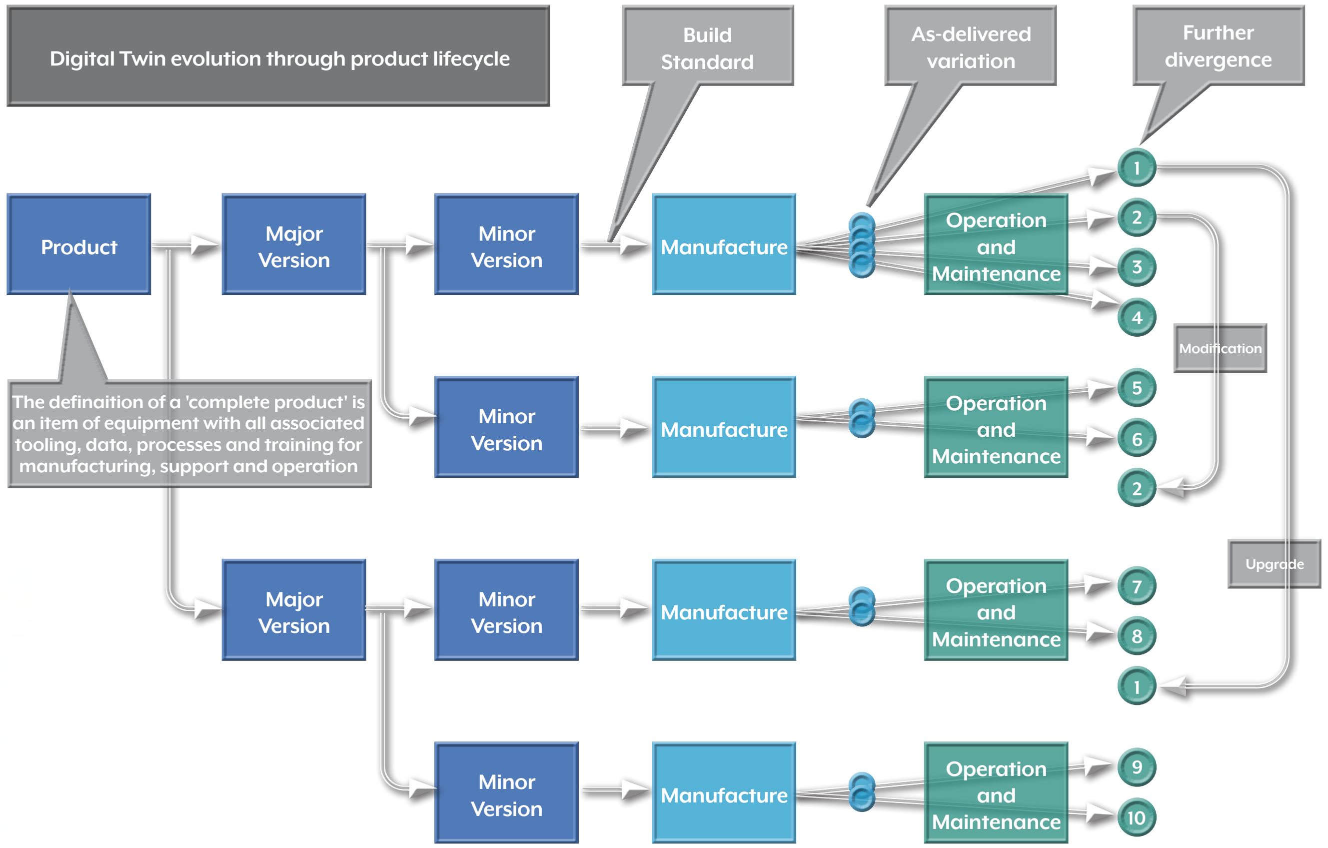
The component parts of a digital twin – Richard Skedd, Nick Webster [BAE SYSTEMS]

3 Digital Twins Through the Life-Cycle

3.1 Digital Twin Evolution

The figure below shows how a digital twin evolves through a typical product life-cycle from a design representation to a representation of a realised product instance and finally to a continually updated reflection of the current state and history of a product in operation.

The figure shows how the individual product instances diverge from each other in service as they are used, repaired, modified and upgraded. All these changes are reflected into the historical data associated with the digital twin to keep it in sync with its real life, physical twin.



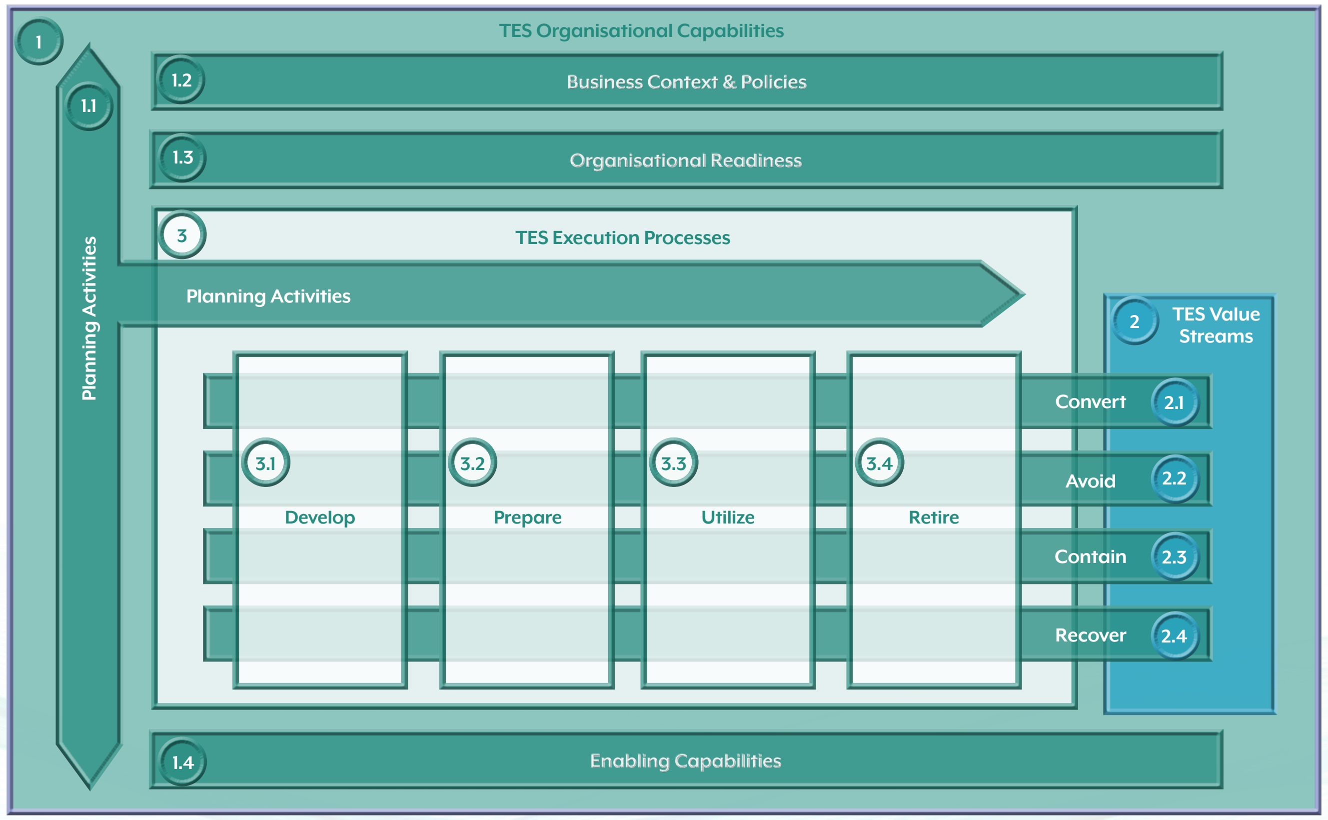
Digital twin evolution through the product lifecycle - Richard Skedd [BAE SYSTEMS]

3.2 Value area Identification

The team used the PAS 280 as a reference model to identify where value could be created. The model provides a common framework for measuring the effectiveness and improvements of Through Life Engineering Services. The standard identifies 4 value streams:

- **Avoid** - Avoid physical degradation of the major asset
- **Contain** - Contain impact
- **Recover** – Recover health
- **Convert** – Convert experience to incremental value

The figure below shows the PAS 280 framework.



PAS 280:2018 standard framework for Through-life Engineering Services

3.3 Use Cases

The team identified six use case areas or categories.

Digital Twin – Value generation area #1

Improved execution of Operation and Maintenance based upon statistical comparison of instances within a fleet.

This would involve Data analysis using statistical techniques enables forecasting of the timing (assuming stable operation) of already modelled events that allows optimisation of fleet operation

Example: Rotating allocation of equipment to tasks to manage life consumption

Value Streams

- **Convert** – Nil
- **Avoid** – Nil
- **Contain** – Minimise life consumption rate
- **Recover** – Nil

Digital Twin – Value generation area #2

Improved execution of Operation and Maintenance based upon engineering / statistical comparison of instance with design

Analysis using engineering models and statistical techniques enables prediction (based on planned operations) of the timing of already modelled events that allows optimisation of the ordering, scheduling and use of resources for an individual instance

Example: Planning timing of significant maintenance activity

Value Streams

- **Convert** – Nil
- **Avoid** – Minimise the cost of TES
- **Contain** – Mitigating operational risk
- **Recover** – Nil

Digital Twin – Value generation area #3

Improved execution of Operation and Maintenance through Engineering / statistical comparison of fleet with design

Analysis using engineering models and statistical techniques enables prediction (based on planned operations) of the timing of already modelled events that allows optimisation of the ordering, scheduling and use of resources across the fleet

Example: Managing the stock, ordering and distribution of spare parts for maintenance activity

Value Streams

- **Convert** – Nil
- **Avoid** – Minimise the cost of TES
- **Contain** – Mitigating operational risk
- **Recover** – Nil

Digital Twin – Value generation #4

Improved Operations and Maintenance through enhanced design representation using fleet data.

Incorporating data from the fleet enables more accurate analysis using existing engineering models and statistical techniques enables prediction (based on planned operations) of the timing of already modelled events that allows optimisation of the ordering, scheduling and use of resources across the fleet

Example: Actual vibration data improves wear modelling to increase the accuracy with which the stock, ordering and distribution of spare parts for maintenance activity can be managed

Value Streams

- **Convert** – Reacting to the emerging reality of cost of support
- **Avoid** – Minimise the cost of TES
- **Contain** – Mitigating operational risk
- **Recover** – Nil

Digital Twin – Value generation #5

Improved design and execution of Operations and Maintenance through enhanced design representation using fleet data

Data from the fleet enables the creation of improved engineering models and a redefinition of the support system to optimise the cost of delivering the required availability

Example: Actual vibration and wear data improves wear modelling to enable a change to less frequent inspections and a longer planned life

Value Streams

- **Convert** – Setting optimum requirements for support policies
- **Avoid** – Minimise the cost of TES
- **Contain** – Monitoring usage and health
- **Recover** – Nil

Digital Twin – Value generation #6

Enhanced product design based upon enhanced design representation using fleet data

Data from the fleet enables the creation of improved engineering models and an improved product design to optimise the cost of delivering the required capability

Example: Actual vibration and wear data improves wear modelling to enable a change to an improved bearing design with repositioned sensors which will result in improved data, less frequent inspections and a longer planned life

Value Streams

- **Convert** – Exploiting opportunity exploitation and setting optimum requirements for support policies
- **Avoid** – Minimising the need for support interventions and the cost of TES
- **Contain** – Monitoring usage and health and monitoring life consumption
- **Recover** – Nil

3.4 Use Case Summary and Application Areas

The summary below shows the scope and subject areas that the team thought would be good candidates from amongst all the potential options.

Use case 1 – component level

Specific improvement: optimise supply chain, operate differently, different maintenance regime, re-design part(s),

- Human integrates between areas and provides insight

Use case 3 - whole platform – or integrated activity

- Potential case study – e.g. T45 whole platform, support organisation design
- More aspirational improvement: automatic integration across components (twins of product or organisational areas), predictive

Use case 5 - fleet level

- Case study – e.g. T45 fleet, FCAS
- Future vision: real time federated data flow – integrated all areas – predictive with some autonomy

Activities that could potentially benefit

- Predictive Maintenance
- Condition Based Maintenance
- Obsolescence Management
- Fleet Maintenance Planning
- Fleet Life Optimisation
- Maintenance Policy Improvement
- Continuing (Air) Worthiness
- Design Change for life or reliability improvement
- Transactional Service Optimisation

These areas were thought to be good candidates as there had been some success in applying data analytics to them in defence contracts.

The team also developed some considerations and specific areas where digital twins may provide benefit.

Predictive Maintenance – Twin of asset

- Statistical prediction of when components would fail to plan avoidance of unplanned maintenance
- Prediction of part life better than we do today with feedback between physical and digital
- Based on historical data and system usage on an individual asset basis
- Make existing analytical solutions more effective or more sophisticated? E.g. Typhoon

Condition Based Maintenance – twin of asset

- Recognising patterns in sensor data that indicate an upcoming issue or failure to intervene before the problem occurs
- Relies on more live data from sensors
- Improve the way we do things today
- Make existing digital twins more effective

Obsolescence Management – twin of asset

- Forecast of obsolescence based on…
- Plan combined maintenance and upgrade more effectively
- Part of supply chain model
- Activities a digital twin allows us to do that can't do today

Fleet Maintenance Planning – twin of fleet / assets

- Scheduling of assets into specific maintenance events
- Attempting to have smooth throughput of maintenance base on current state of assets
- Combination of multiple OEM and customer twins

Fleet Life Optimisation – twin of fleet and assets

- Combination of mission and maintenance optimisation to meet fleet life targets e.g. life extension of fleet
- Combination of multiple OEM and customer twins

Maintenance Policy Improvement – twin of asset

- Using statistical data to suggest optimisation of the maintenance intervals for components

Continuing (Air) Worthiness – twin of asset, twin of organisation

- Improving over the current "manual" process through the use of Digital Twins
- Reliability programme
- Availability impact assessment

Design Change for life or reliability improvement

- Statistical data from asset instances
- Sensor data
- Cost benefit decision modelling

Transactional Service Optimisation

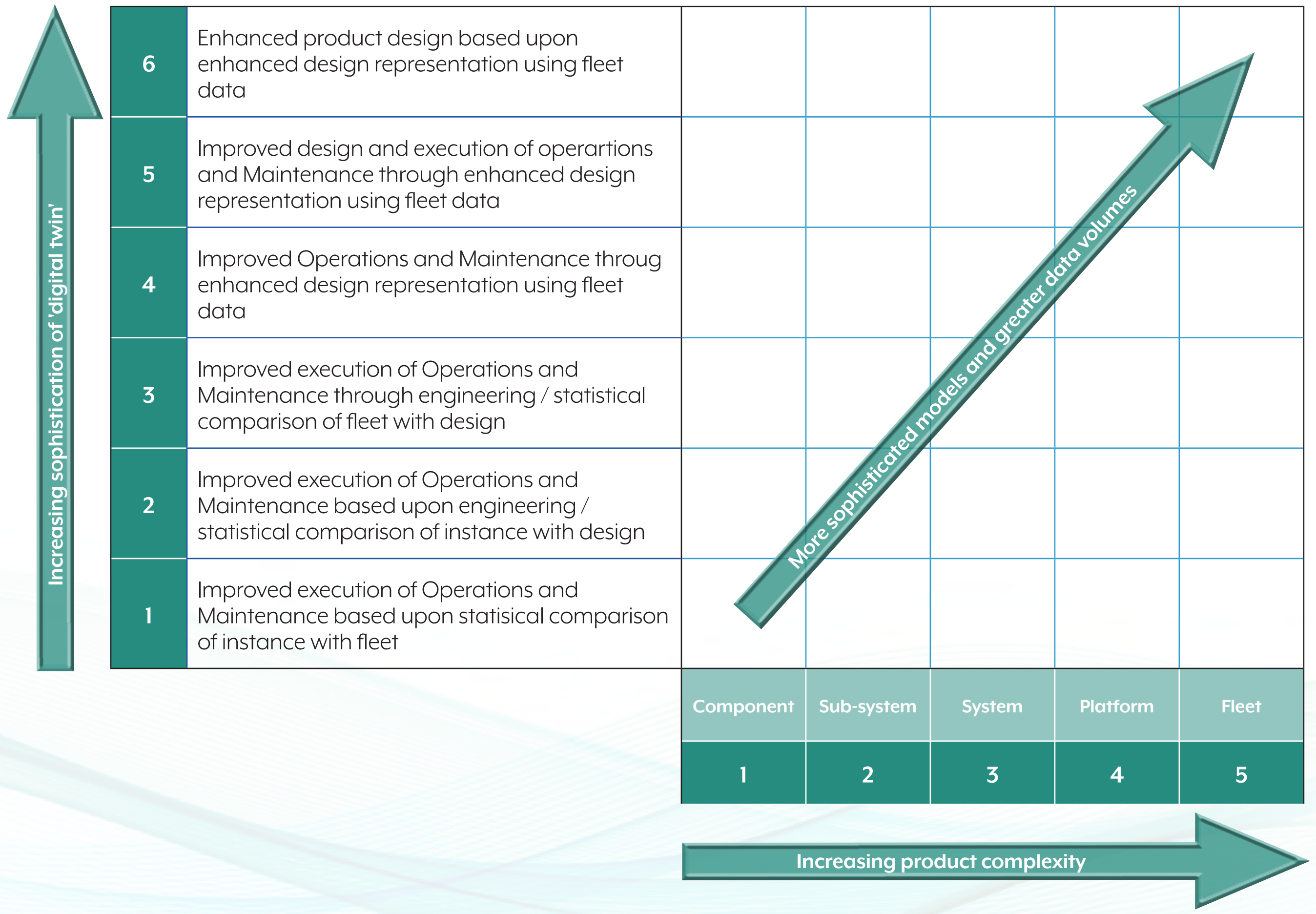
- Modelling and monitoring service design
- Avoid bottlenecks and delays
- e.g. Query answering, information service delivery
- Trend analysis

4 Framework for Classifying the Digital Twin Landscape

The team created a framework for classifying digital twin applications based on two dimensions:

1. **Product or system complexity**
2. **Sophistication of the digital twin**

The figure below contains a "matrix" representation of this framework. It can be seen the cost and amount of effort required to implement the digital twin increases as we increase the complexity of the analysis and the scope and complexity of the "system of interest".



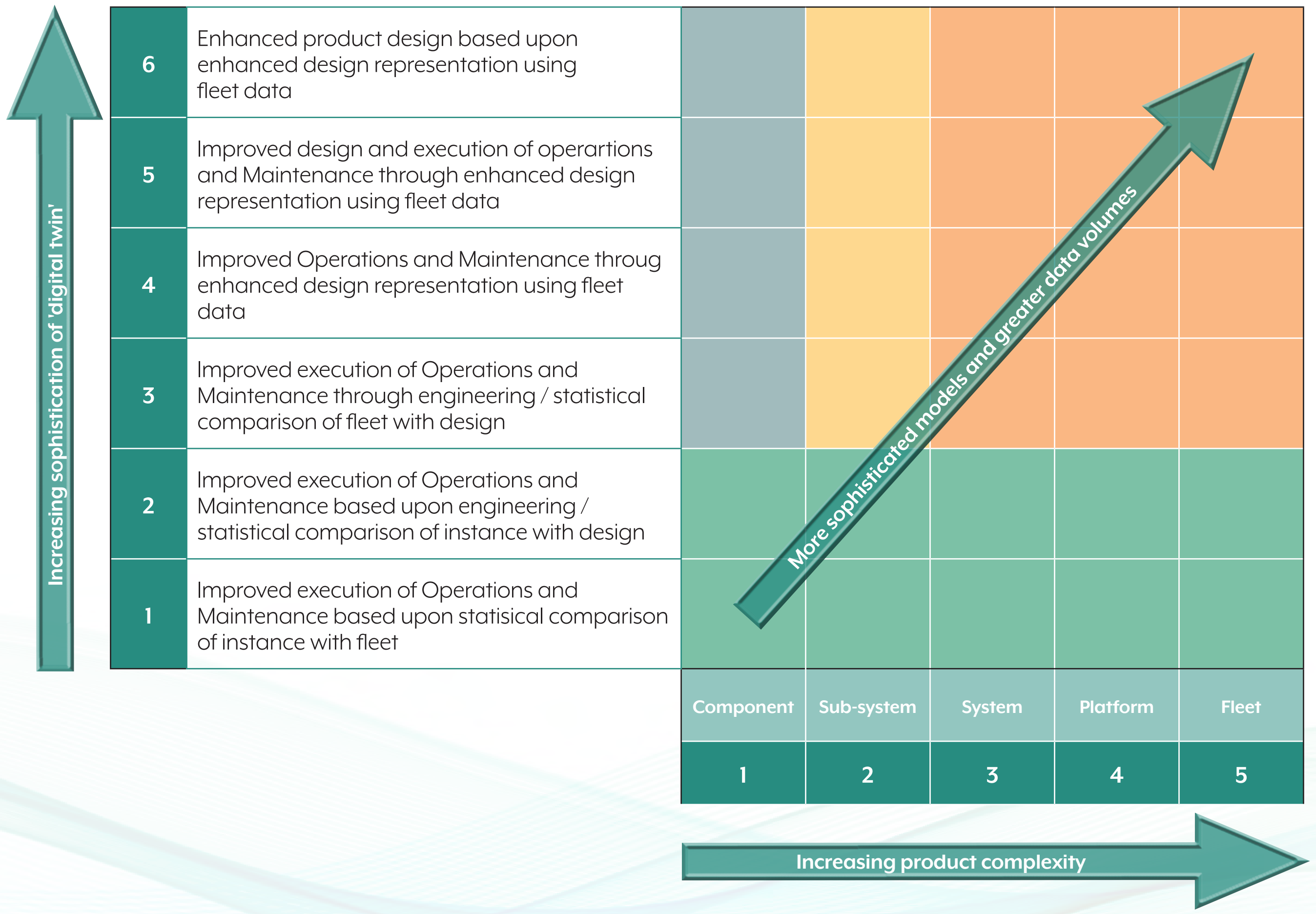
A "matrix" for classifying digital twin complexity in Engineering Support – Richard Skedd [BAE Systems], David Morgareidge [Jacobs]

4.1 Criteria for Selecting Pilot Activities

The team developed a draft set of criteria for selecting pilot activities.

Desirability	**The pilot should:** ▸ be something that both MoD and industry stakeholders would be interested in pursuing ▸ be big enough to be representative of a realistic set of requirements ▸ have clear benefit targets v cost ▸ have a level of sophistication based on availability of data / IT
Deliverability	▸ Need to be able to roll out quickly - especially early pilots ▸ Availability of data ▸ Specific goal / issue to resolve ▸ Commercially acceptable / viable e.g. PFI barriers ▸ Access to real information systems ▸ Effect of data aggregation on security classification ▸ Availability of a MoD environment to run the pilot ▸ Can the pilot be phased to use "easier to access" data initially and move to more sensitive as we progress
Scalability	▸ Multi – platform, multi-programme applicable ▸ Technology concept needs to provide learning for productionisation ▸ Can the technology be location agnostic – transportability including to MoD owned / provided environment ▸ View on tools variability, for modelling, analytics and "digital twin platform", data integration
Relatable to an aspect of digital twinning	▸ Analytics, modelling, predictive or a combination ▸ Linked with data from real physical asset – could be in development but mature enough to be producing representative data ▸ Provides insight into the value of a digital twin approach through life, including the value early phase investment would provide e.g. using modelling predictions in design phase in a virtual environment to inform in service design to get better support service optimisation and have a more cost effective service on day one

The group recommends that to achieve success as early as possible that simple use cases be chosen for the early pilot activities. This approach will build confidence and learning and subsequently can be scaled in complexity as appropriate to the problems to be addressed. This is illustrated with the figure below using the in service digital twin “matrix”, early pilots should map to column one or row one or two, as shown by the green shading on the figure.



Early pilots should be selected from the green areas

5 Summary and Conclusions

5.1 Summary

Generic benefits were considered - these are considerable. The wider benefits, including business transformation, were acknowledged and introduced. It was felt that those benefits identified in this quick-look are, in themselves, sufficient to justify more work. An approach was recommended for selecting and quantifying potential exemplar projects, considering aspects such as time to implement, difficulty, risk, benefits and costs to achieve initial and further benefits.

5.2 Conclusions

- From our research we have seen that there would be a benefit from the use of digital twins, engineering and organisational models combined with asset and operational data, to provide new and faster insights within Support Engineering activities
- A digital twin needs a model and real world data connected together automatically. During the in service phase we already have the models generated during development as well as data on individual assets. This makes in service engineering a strong candidate area for digital twin development and exploitation
- The ability to connect a detailed model(s) (e.g. physics, logistics) to live asset data from specific assets provides us with insights that are not readily attainable from numerical/ statistical analysis of multi-asset data sets
- One of the real values of digital twins is the use of models which have been validated with real world data to predict the future behaviour of systems and operations in environments which are different from the past
- Digital twins can mature over time as the volume and range of data from operation increases and the models are developed to reach their full potential
- The effective development and exploitation of digital twins requires input and collaboration across OEMs, service providers and the MoD

5.3 Recommendations

- Digital twins should be developed for specific problems, with models and datasets appropriate for that purpose
- Model detail and complexity level and the coverage of data should be tailored to be sufficient for the purpose
- We should investigate where the tipping point for digital twins is and what fidelity of models and data is optimum
- General high level models should be used to identify problems which can then be investigated in depth with more sophisticated and detailed twins
- We need to establish commercial and systems frameworks which enable the availability of data, connected directly to the relevant model(s), to generate the twin(s)
- We should also look at joining twins and data across the whole operational landscape and integrate across the various TDI DT teams. This would avoid silos and duplication, opening up wider scenarios such as, the impact of operational environment on spares demand and, the ability of the supply chain to support a surge in mission rates

3.

SUPPLY CHAIN OPTIMISATION

THE VALUE-POTENTIAL OF DIGITAL TWIN TECHNOLOGIES IN OPTIMISING THE PERFORMANCE AND RESILIENCE OF DEFENCE SUPPORT.

A Wicked Problem

The complexity of Defence assets and low cost of developing and operating them makes any promise of efficiency gains and improved performance immensely attractive. Attractiveness increases when we look at those assets that participate in the complicated arena that is the Defence Support Network: varied infrastructure (warehouses/ports/airfields); equipment (assets/materiel/commodities); processes (acquisition/packing/dispatch); movements (scheduling/loading/routing); and the landscape of information systems that support all this. The connection of all assets together is surely the key enabler to the next phase of optimising this network. But we must be careful not to rush into introducing digital technologies, products, and services without fully understanding the end-to-end processes in which they will be used, or the associated behaviours. Joined up thinking is required to make them effective.

Therefore, while individual products and services have their place, significant gains will only come by weaving technologies together and connecting them with data sources, then supporting management and application of that data through project, asset and organisational developments.

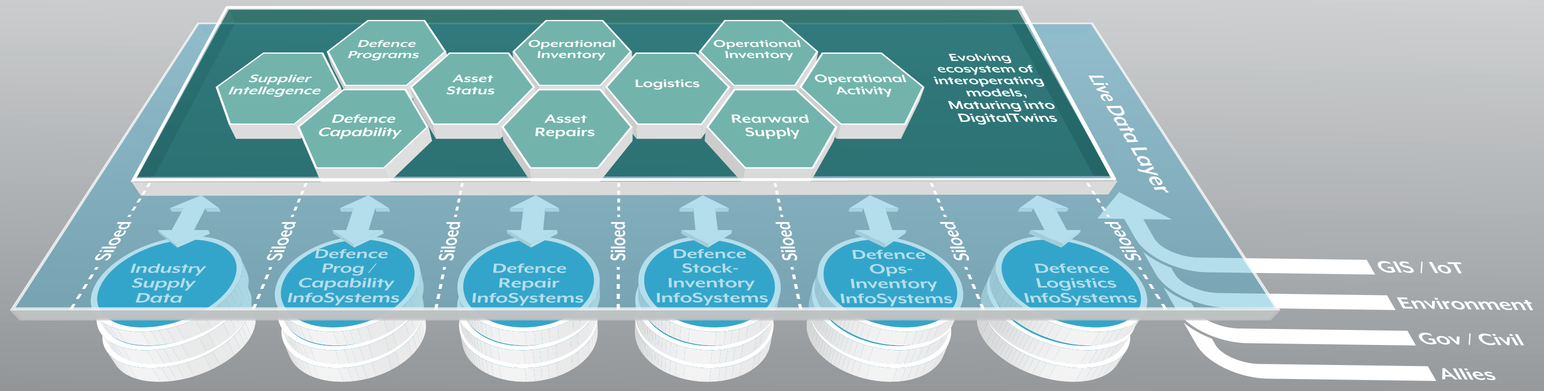
Digital Twin Ecosystem

The vision is to establish and mature an ecosystem of Digital Twins across Defence Support; informed and powered by data from across the defence information systems estate. These would leverage the maturing and expanding Data Layer to enable and evolve the coordinated data-exchange, and federated interoperability of Digital Twins.

Actions and initiatives to facilitate this can be summarised as:

- Auditing and mapping:
- What is already operational in respect to existing Digital Twins (and respective maturity); and
- What existing 'models' in defence have quick-win potential to be evolved or re-purposed into embryonic Digital Twins.
- Combining this with the discovery audit work for the Data Layer to define and document the 'rule book' for future development (i.e. in terms of standards, interoperability and coherence).
- Using these Models to aid the effective targeting of ongoing strategic and tactical investment in improving the quality and confidence in data outputs.
- Continuing to mature the Models into federated ecosystem of Digital Twins

Figure 1 - A Federated Ecosystem of Digital Twins



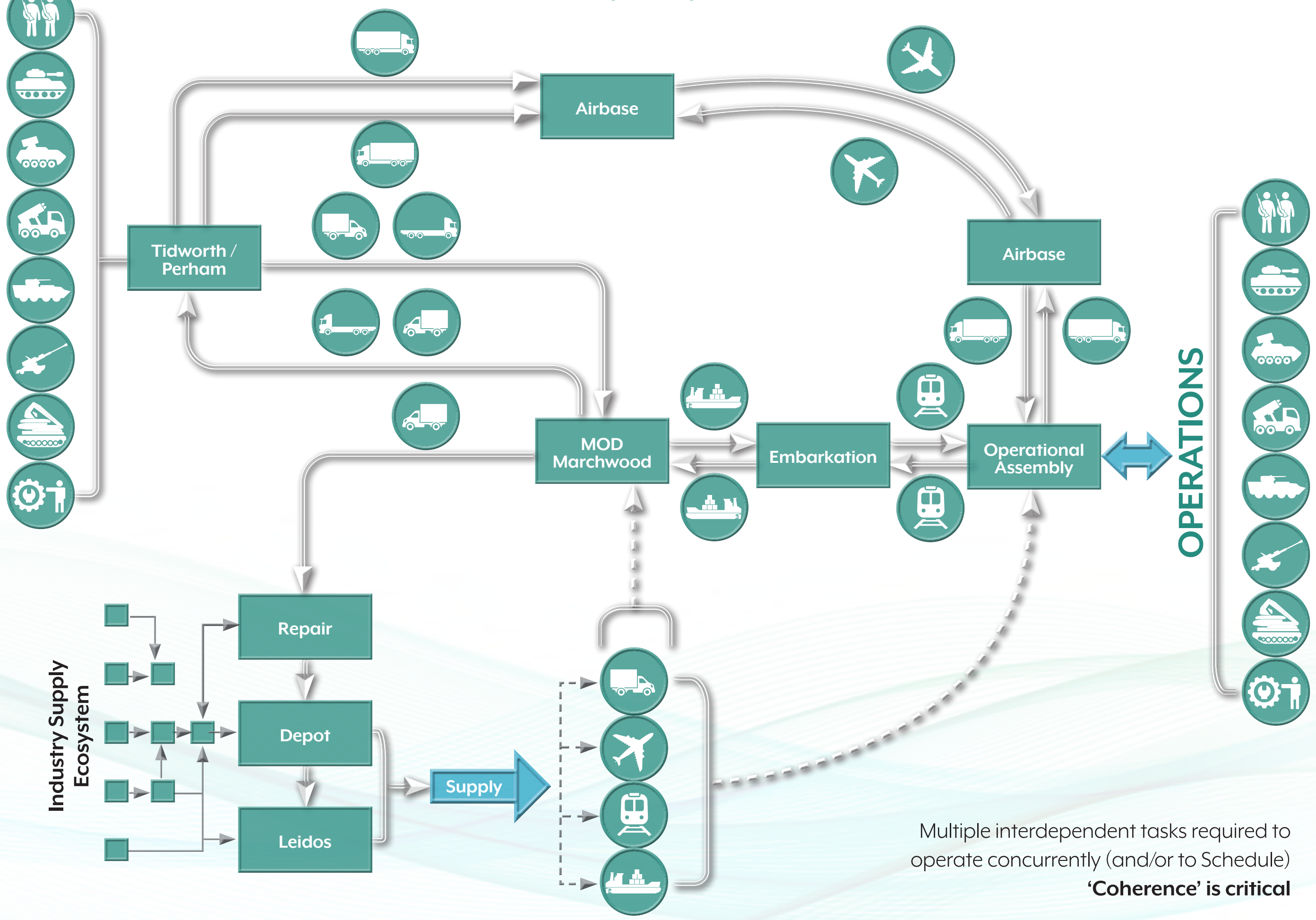
Vignette | StratBase Digital Twin

We have identified a Strategic Base vignette for Digital Twin in DefSp, with a clear path to practical development and demonstrable value-output. The immense complexity involved in enabling and coordinating the Strategic Base is an evident candidate. And the optimisation of the StratBase is clearly aligned with the initiatives of the defence Agile Stance Campaign.

Challenge Synopsis

StratBase performance is critical to UK defence capability. It is highly complex; highly inter-dependent, incorporates all forces; traverses defence, industry, and civilian activities; and requires the ability to surge en masse. For example – a high level snapshot as per the diagram below reveals the complex webs of inter-operational dependencies. In practical terms, there are multiple variances and iterations of these flows needing to operate concurrently and coherently to assure performance.

Figure 2 - Vignette



Premise of Capability

Through the lenses of proactive scenario planning and in supporting deployed operations. How can a Digital Twin ecosystem empower StratBase Agile Stance with coherence during complex operations – using real data and change impacts, to inform and support Command and Operational decisions?

There is a real, fundamental, and tangible purpose – being to provision defence personnel with a powerful suite of Digital Twin technologies to support, cohere, and optimise Defence Support, across the lifecycles:

- From Business as Usual;
- To enabling deployments
- Though Operations, the reverse supply chain and re-supply
- Supporting surge demands; and
- Facilitating coordinated withdrawals

Premise of Function

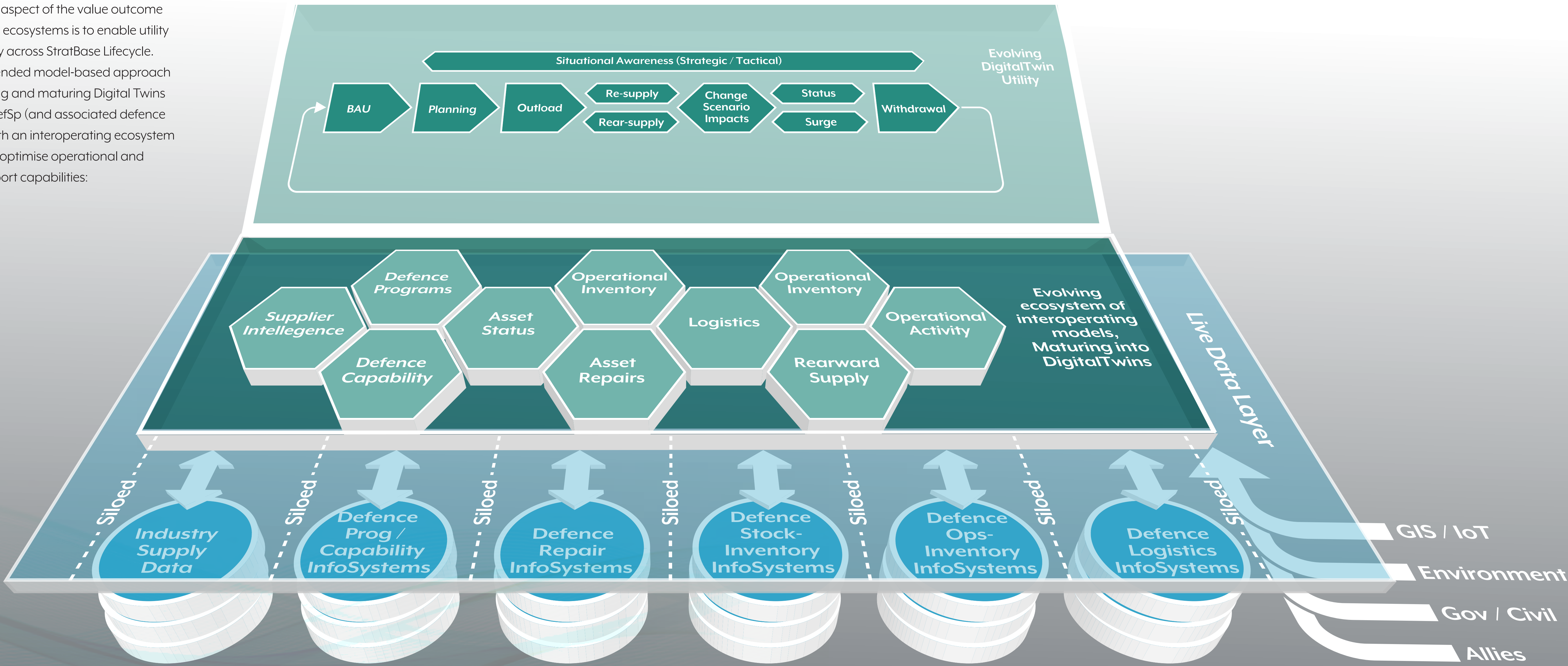
In liaison with defence DefSp/StratCom, we have identified a set of functional propositions for the Digital Twin(s) technologies empowering these capabilities, which may be summarised as follows:

- To support the optimisation of StratBase Agile Stance, not just in outload, but also supporting the coherence in reverse supply and restocking during operations, and ultimately the planning and execution of coordinated withdrawals.
- To support assurance that concepts of capability and readiness to act are validated coherently (i.e. not just by individual stovepipe, but accounting for interdependencies across the DefSp ecosystem)
- To support assurance in logistics coherence – reducing the risks for misalignments and bottlenecking
- To enhance, evolve and mature the collaboration and coherence in interoperability between defence and its supporting organisations, such as industry, emergency services, and other civilian systems and Allies
- To facilitate dynamic, interactive, and role-based dashboards of KPI metrics and decision support-tools (maps/charts/graphs/tables/dependency-networks/ etc.): providing the ability to test, validate, communicate, and action operational capabilities in near-real time – for example:
    - Provisioning commanders with demand and situational awareness – e.g.:
        - Validate progress metrics vs the PJHQ deployment and StratBase Outload plan
        - Surface key activities and the monitor the balanced utilisation of resources
        - To support evidence and impact-based decision making on scenarios i.e.:
            - X activity is possible – go!
            - X activity is possible – BUT here are the potential impacts
            - X activity is NOT possible – BUT here are the potential alternatives
- Provisioning operational and supporting personnel across DefSp (and associated entities) with tools to effectively and collaboratively manage coherent StratBase operations – e.g.:
    - Asset and commodity tracking and distribution
    - Coordination of logistics vs dynamic demands
    - Coordination of Outloads
    - Coordination of operational Re-supply & Reverse Supply
    - Coordination of Withdrawals

Premise of StratBase Lifecycle Utility: BAU | Planning | Ops

An important aspect of the value outcome in Digital Twin ecosystems is to enable utility and capability across StratBase Lifecycle. The recommended model-based approach to empowering and maturing Digital Twins will provide DefSp (and associated defence personnel) with an interoperating ecosystem with which to optimise operational and decision-support capabilities:

Figure 3 - Strategic Base Lifecycle



P.A.C.E

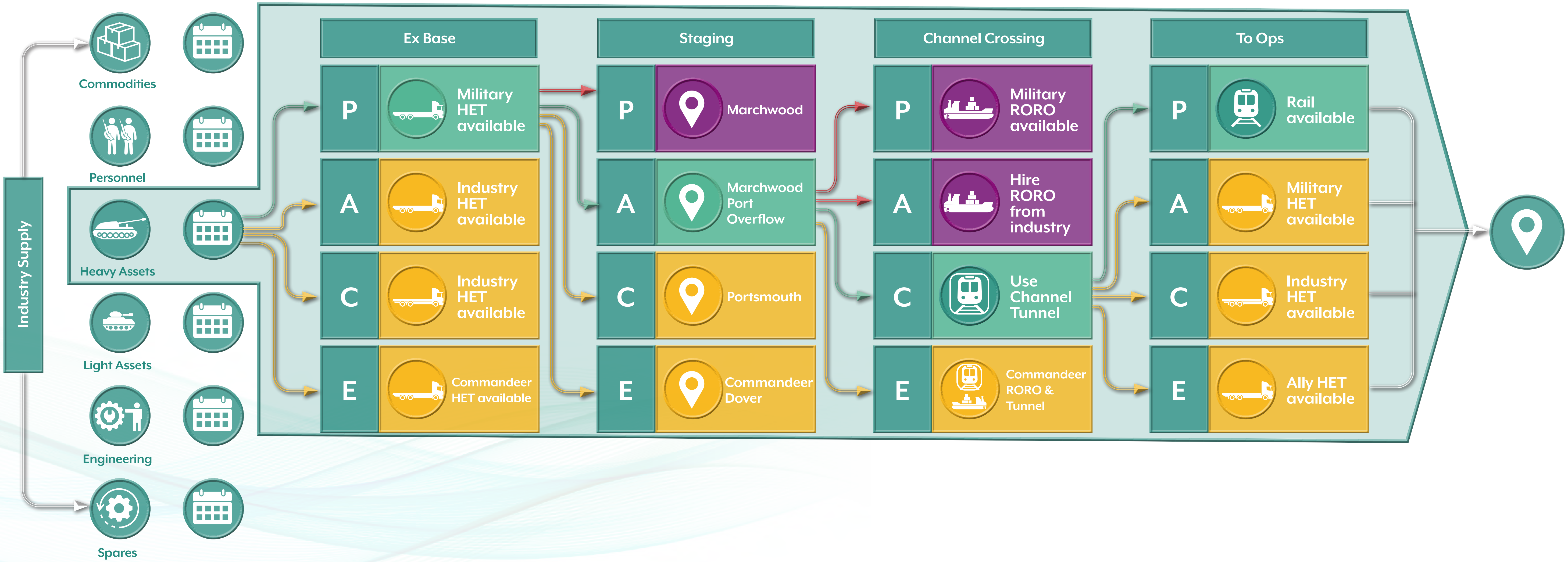
A promising concept is the application of P.A.C.E. modelling within the Digital Twins, where the complex and evolving interdependent 'paths' of operational activities can be visualised for commanders and operational/supporting personnel in respect to their practical availability at any given point in time, i.e.:

- Primary - being the default or preferred course of action
- Alternate - being the alternative course of action
- Contingent - being the back-up action; and
- Emergency - take emergency actions

This approach also lends itself to the phased introduction and application of AI/ML technologies to empower predictive analytics, drive optimisation, and (cautiously) enable aspects of automation.

In practicality - there are multiple tasks required to operate concurrently (and/or schedule). The PACE Models are interwoven to 'test & Validate' capacity (i.e. capacity is variable vs demand - so bottlenecks move) **'Coherence' of inter-dependencies is critical**

Figure 4 - Application of PACE



Data Layer for Federation

The vision is to support an evolving ecosystem of Digital Twins across Defence Support, federating asset, infrastructure, transport and communications, simulations, models and analytics of subsidiary element Digital Twins.

The underlying information estate for defence support is vast, disparate, and incoherent. Given the premise that Digital Twins are entirely reliant on data, this is of course a challenge.

Federating the data-estate is critical to assuring coherence. However, a wholesale 'rip & replacement' of the information system estate is untenable. Likewise, embarking on wholesale inter-systems integration would be extremely expensive; disruptive; time consuming; and bring a fundamental risk of investing in obsolescence.

A practical, cost-effective, and timely approach would be to overlay and evolve a "Data Brokering Layer" (Data Layer) across the legacy information systems estate with which the systems could exchange data, leading to anestate of Digital Twins could communicate and federate.

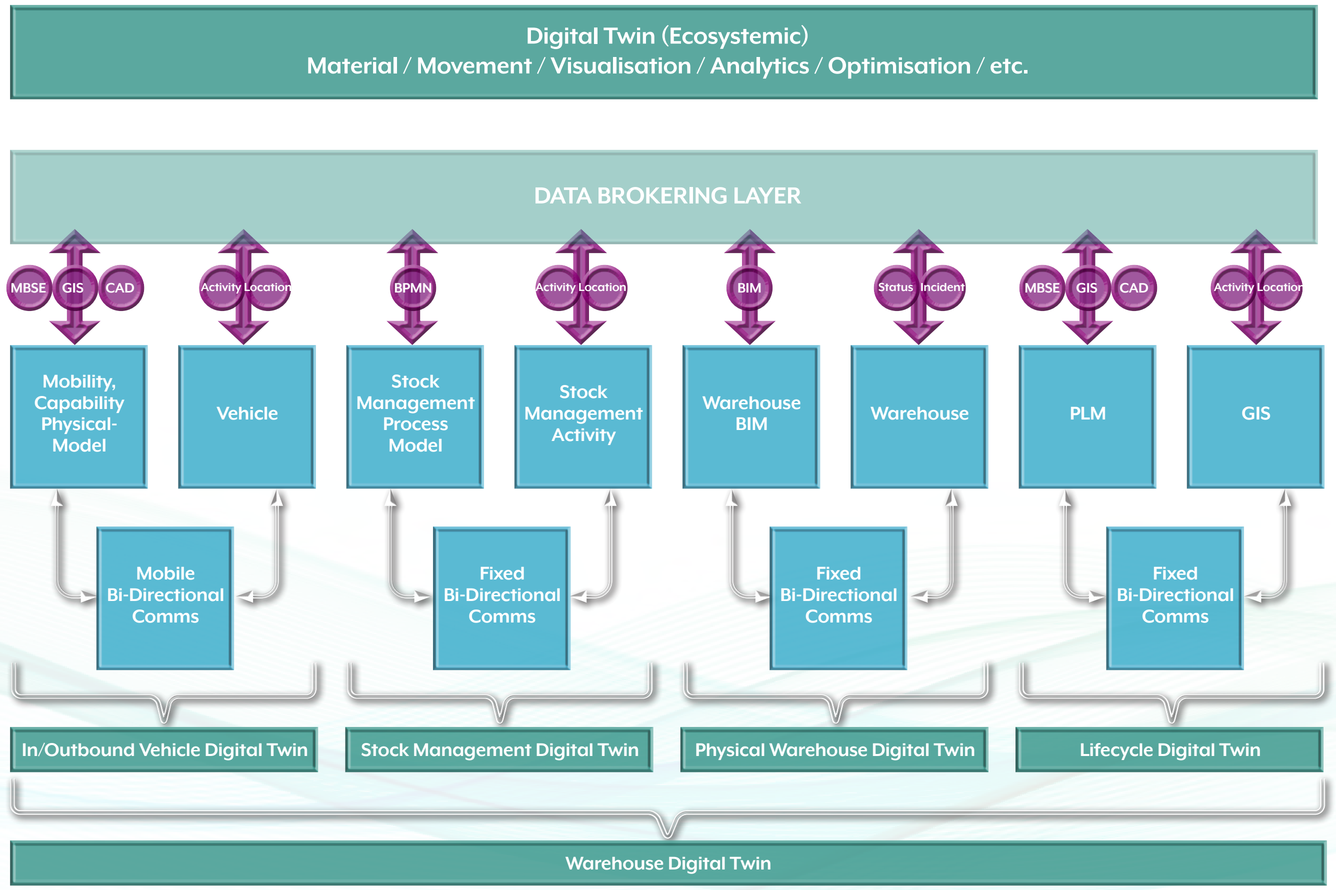


Figure 5 - Example of a Digital Twin Ecosystem for a Warehouse

To achieve this it is necessary to identify the:

- Characteristics of the 'data brokering layer' for enabling the federation / syndication of Digital Twins operating across Defence Support
- Data modelling approach and characteristics for federating support digital twins whilst exploiting appropriate existing standards

Therefore, our objectives are that this federating data layer can be implemented and evolved to support and enable the dynamic operational tempo of Defence Support, encompassing the ability to:

- Discover and exploit data sources;
- Gather information from deployed assets and the Defence Support Infrastructure;
- Transform information into a format which is exploitable by models, synthetic environments and analytics engines;
- Virtualise and manage the routing of information for exploitation.

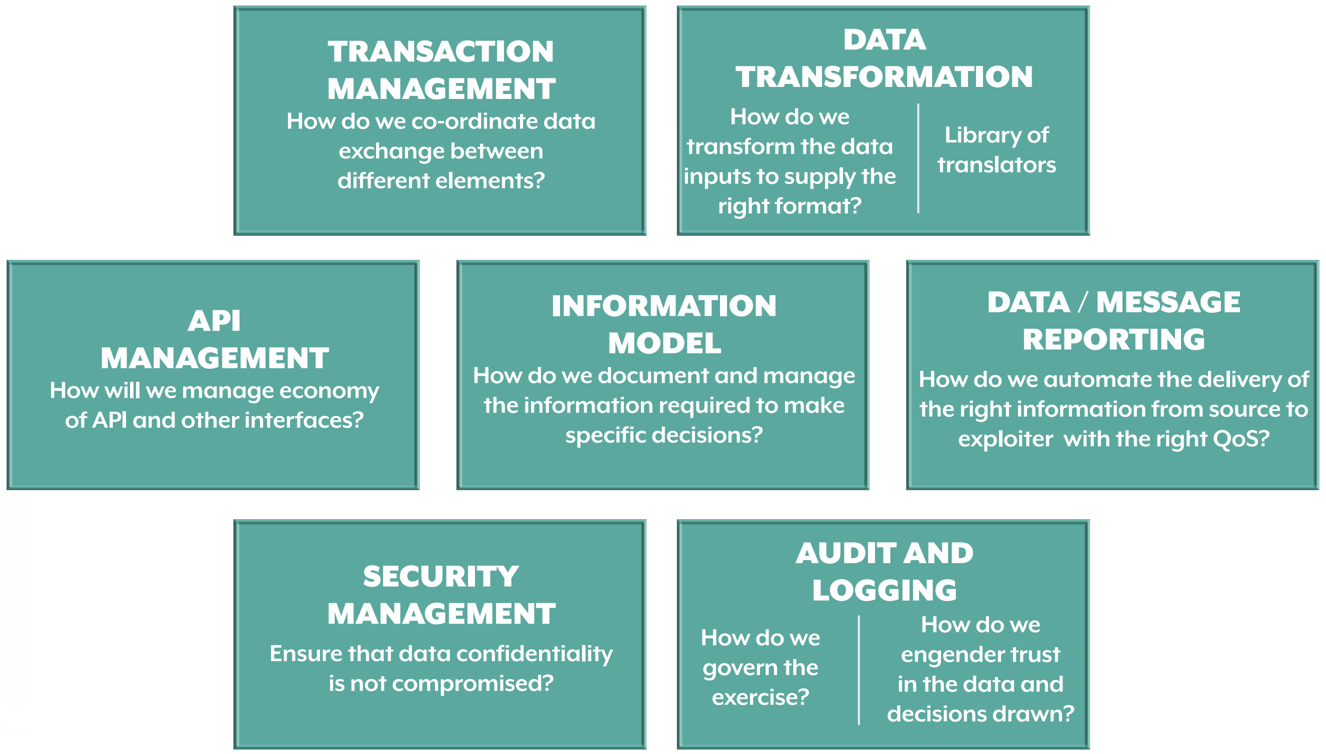
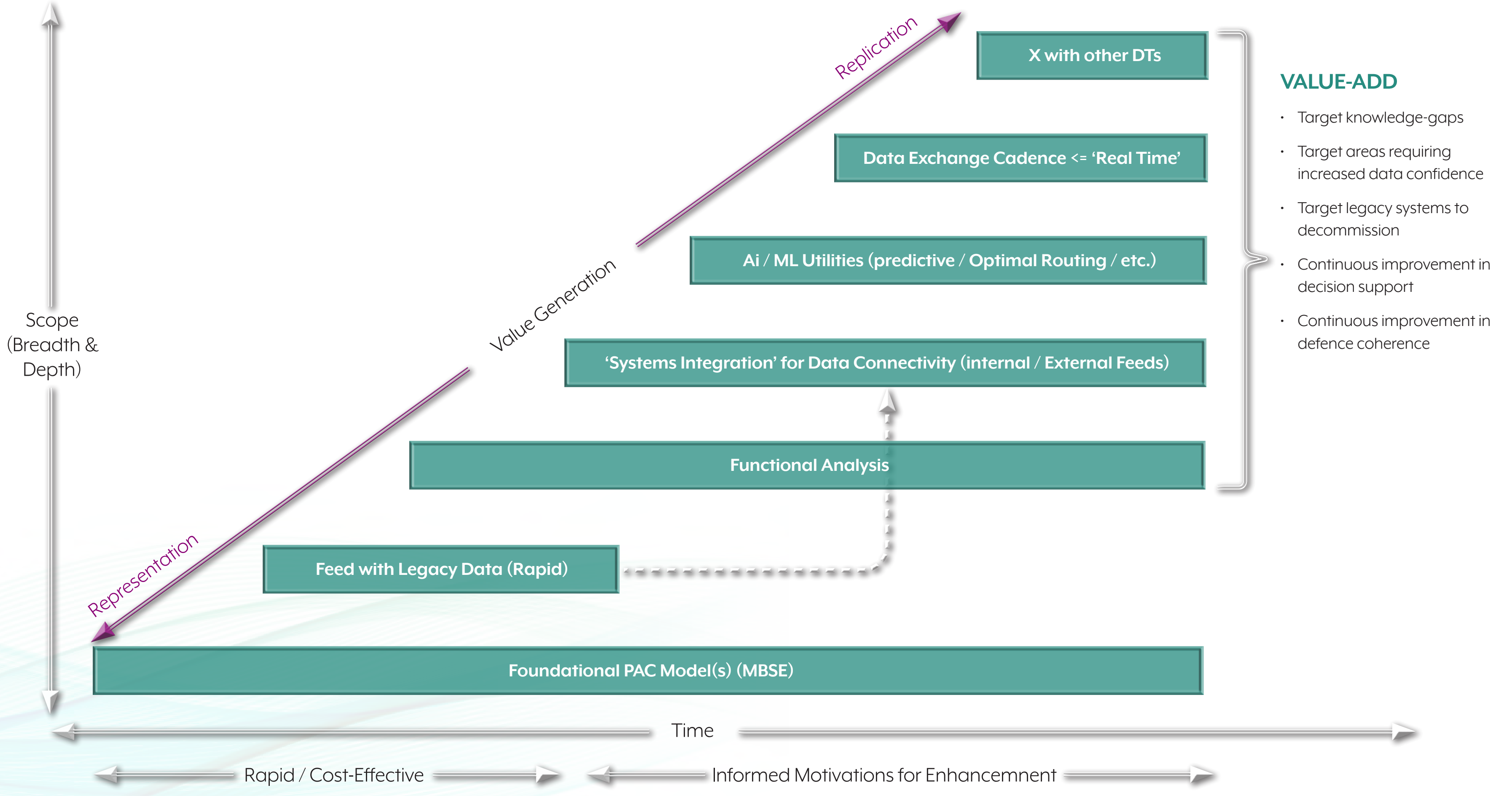


Figure 6 - Capabilities Required of a Federating Data Layer

Data Layer Objectives

- Undertake 'discovery audit' to identify and catalogue the extant information system estate; what data is available; and at what objective level of quality or veracity (system by system).
- Utilise the discovery audit to provide the basis for understanding, developing, and implementing the necessary tools and protocols to enable this data to be 'translated' between the host information systems and the Data Layer. And thereon how to manage the virtualisation and routing of such data exchanges. For example:
  - How to leverage existing APIs and to apply new APIs where there are gaps?
  - How to establish a common format and language which can be applied and exploited?
  - How to establish, coordinate, and manage the varying demands of data exchange cadence e.g. X-data updated monthly / Y-data updated weekly / Z-data updated in near-real-time?
  - Where and how can the introduction of IoT technologies drive rich ecosystemic data feeds?
  - How to establish and enforce management, governance, and auditability?
  - How to enforce and manage security; particularly where the application of Digital Twin is aggregating information and traversing between Official Sensitive and Secret domains vs the roles of the respective userbases?

Figure 7 - Increasing Value Creation over Time



Digital Twin Maturity Curve

In the context of the above, it is important to acknowledge that 'Digital Twins' are the output of evolving modelling and data; which matures from being "representative" to 'replicative'. This concept of 'maturity' is a combination of the breath/depth/fidelity of the underlying Model(s), the quality and cadence (i.e. refresh-rate) of supporting data from the defence information system estate.

Our proposition is to begin at the base of the maturity curve; to scope and deliver a rapid and cost-effective foundational outcome which can then inform and motivate a targeted investment strategy for its ongoing development and maturity (capability/value-output).

Minimum Viable Product

An MVP will focus on a ring-fenced scope of capability; directed by data which is available and of sufficient quality. This will then form the basis for ongoing evolution and maturity of the Digital Twin(s) in terms of scope, capability, and value-generation against broader strategic plans and tactical demands. We will aim to move out on this in a structured but speedy manner. In the next 6 months we will look to initiate a study to look at the quality of existing data across the key nodes in the Defence Support Network – the Joint Support Enablers – and identify the most suitable target for a proof-of-concept, which will be focused on 1 node and likely 1 process against that node. This we plan to develop out in 2022, enabling us to build the learnings that will inform the most fruitful subsequent steps with regard to integration and maturity.

PART 1

4

ENGINEERING & SAFETY DECISIONS

SUMMARY OF ENGINEERING SAFETY DECISIONS

Introduction

This workstream of the Team Defence Information (TDI) - Digital Twin Community of Practice (DefSp TDI DT CoP) had the aim of understanding the current Defence policy and engineering standards and how these could change to support the creation and use of in-service Digital Twins. This was further explored through an in-service safety case example. The intent was to build a picture of the current policy and standards to inform on:

- Defence Policy for digital twins including models and simulation;
- Defence Standards and their promotion of data and models rather than documents; and
- How an in-service safety case could help to define the transformation process required to move from a Document Based Systems Engineering approach through Model Based Systems Engineering (MBSE) into creating and using Digital Twins.

The working group on DT Engineering and Safety was hosted by Team Defence beginning in June 2021 and ending in October 2021.

Problem

Defence engineering, including safety, currently promote the use of a Document Based Systems Engineering approach through its policy and standards, as:

- Document-based artifacts are used to capture much of the system specification and design information, such as requirements, interface control documentation, cases, and system architecture design descriptions.
- This information is often spread across many different documents including text, informal drawings, spreadsheets, and disconnected databases.
- This document-based approach to systems engineering suffers from a lack of precision and has well known configuration management issues.
- Current In-service Safety Cases are Document Based Systems Engineering outputs built on cold data, do not provide real-time visualisations of data for the Duty Holder, and are equipment not user/capability based.

Vision for Engineering Safety Decisions

The vision is that system, people, process, place, and asset data is automatically gathered, collated, and stored to allow in-service engineering (inc. safety) insights through its visualisation to aid better timely decisions.

Objectives

The following objectives were used to focus the workstream's effort:

- Review current policy JSP 939 - Defence policy for modelling and simulation [1] and its promoting of MBSE and Digital Twins;
- Review Knowledge in Defence [2] standards and guidance focusing on its provision of knowledge for MBSE, Models and Simulation, Digital Twins, and related current good practice; and
- Review example safety case and safety standard Defence Standard 00-056 [3] and its promotion of in-service 'data' and 'models' required to manage safe operation through life.

Policy

JSP 939 Defence policy for modelling and simulation and its advisory group provides an excellent platform to promote and enable the use of MBSE and In-service Digital Twins. It can do this by providing agreed Defence Digital Twin Principles, enable the Defence Digital Twin environment. The community of interest considered Gemini Principles and also suggested that these are extended to include:

- Rigour - robustness, trustworthiness, dependability and configuration management;
- Machine learning and Artificial Intelligence; and
- Legislation.

Industry is enabled to influence and support the update of this policy through the Defence Modelling & Simulation Coherence (DMaSC) Industry Advisory Group [4] (DIAG) which provides bi-directional engagement between DMaSC with industry and academia. The group is open to all industry and academia that can contribute to the design and delivery of models and simulations.

[1] JSP 939 - Defence policy for modelling and simulation – April 2020

[2] Knowledge in Defence (KiD) (mil.uk)

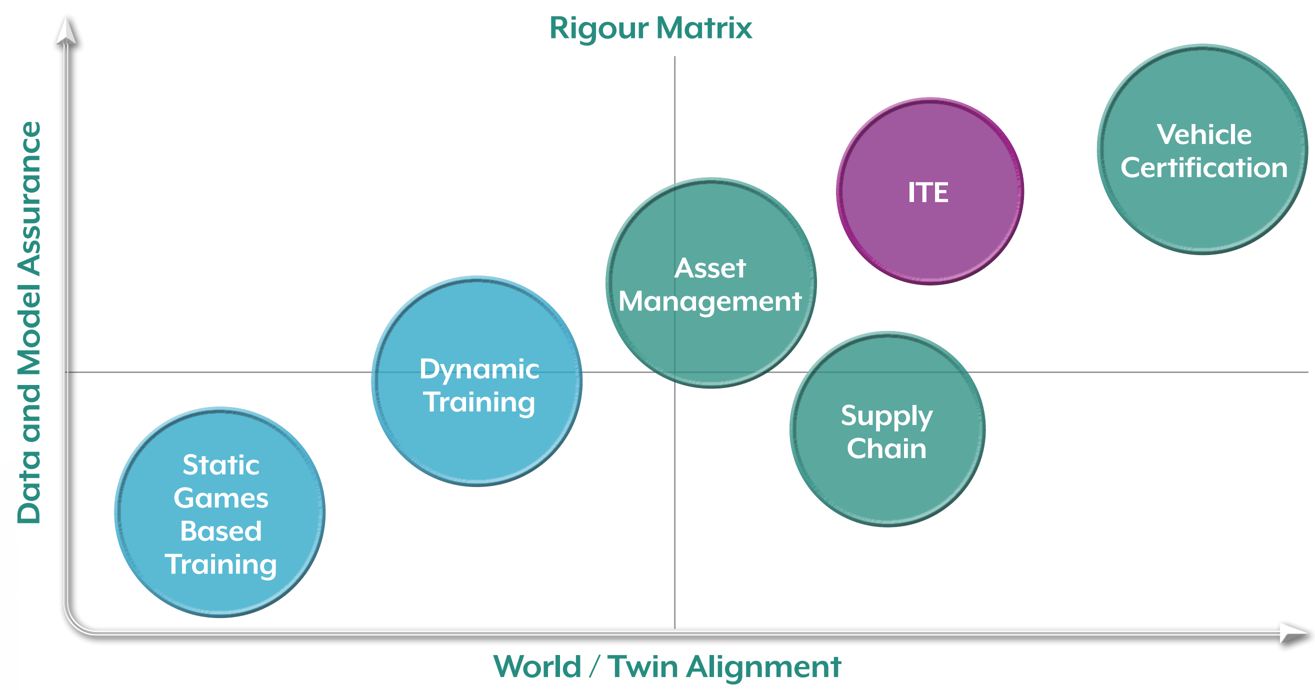
[3] Defence Standard 00-056 - Safety Management Requirements for Defence Systems Part 1: Requirements - Issue 7 Date: 28 February 2017

Defence Standards

Currently Defence Standards are based on the Document Based Systems Engineering approach and have been developed over several decades and include the incorporation of learning from experience. These standards do not prevent the use of digital twin solutions but also do not promote MBSE and Digital Twins. Clearly identifying the data and models' inputs and outputs within the standards through agreed ontologies could aid the adoption of Digital Twins to manage in-service equipment and services.

When considering test, certification and safety, the level of rigour (Figure 1) required when developing and managing Digital Twins should be specified in the standards. Also, the need for configuration management, including safety decision data records, should also be defined particularly for incident and accident reporting. Overall, a risk-based approach to the level of rigour applied to the development of a Digital Twin and its configuration management should be adopted.

Figure 1 - Risk Based Digital Twin Assurance Rigour



[4] Please email PoC: UKStratCom-Cap-C4ISR-JTS-Group@mod.gov.uk if you wish to participate.

In-service Safety Case Vignette

The vignette selected was to consider the use of Digital Twins as the In-service Safety Cases to provide barrier and compliance visualisations (Figure 2) automatically populated with real-time and near real-time data. Thus improving Duty Holder risk understanding, management and decision making.

The vignette discussion further enforced the suggested additions and alterations to policy and standards described above. In addition, a soft system model was discussed to consider the data and its visualisation for three main areas:

- Duty Holder – the operating risk is demonstrated as "As Low As Reasonable Practicable" – the system is safe to use.
- Maintainer can maintain the design intent.
- User can operate the system safely.

Defence Standard 00-0563 was considered and the following key changes suggested:

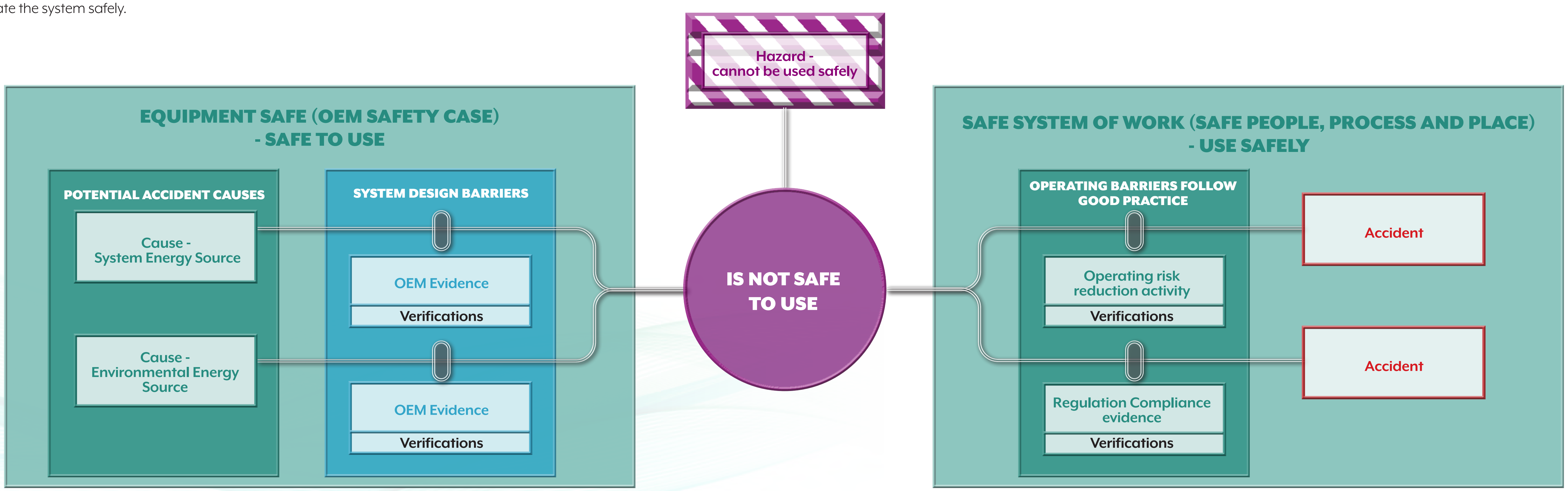
- That the Original Equipment Manufacturer should define the in-service data and models needed to maintain the safe-to-use & use-safely arguments; and
- Use Bowtie hazard representations for system/platform types to aid hazard log understanding and for key active barriers to define the data and models to aid Duty Holder risk management.

The Next Steps

From the group's discussion, the following next steps were developed:

- Rigour - Using this sprint's Digital Twin survey data, categorise the Digital Twins by the potential harm and identify the rigour (standards) that should be applied.
- Industry to support the Defence Modelling & Simulation Coherence (DMaSC) Industry Advisory Group (DIAG).
- Investigate how data visualisations could be connected to existing databases e.g., training, maintenance, Health Utilisation Monitoring System, for example.
- Investigate cyber security of safety involved Digital Twins.
- As Defence Standards go through their update cycle, consider how the move to MBSE and Digital Twins can be promoted and consider the creation of ontologies.

Figure 2 - Safety Visualisation



PART 1

5

FUTURE TEST & EVALUATION

DEFENCE SUPPORT DIGITAL TWIN COMMUNITY OF PRACTICE

MOD TESTING AND EVALUATION VIGNETTE WORK STEAM SUMMARY

Problem Identification

Aberporth was visited a representative of a live range to identify the problems common to the entire enterprise - Is currently a physical or 'real-life, real-time' event range on the coast of Wales where live weapons and people, wildlife and property mix in real-time in a very complex safety critical amalgam. The people, wildlife and property element can never be fully managed, controlled or influenced only the live weapons element which can and does, quite rightly, lead to cancelled, delayed, restricted live testing

- **Safety Trace** – With any 'Live' physical event, on entering the range an invisible area is generated electronically around an aircraft (or any other platform), which indicates the entire envelope for which a weapon system presents a threat to life or property, the size and shape of which is dependent on the type of weapons system. This is managed to ensure the aircraft Safety Trace and people, boats, vessels etc. do not 'physically' overlap with the risk of disastrous consequences. Cause and effect of this is that whole swathes of Cardigan Bay and beyond become 'No-Go' zones for aircraft because of people, floating assets and even wildlife which can delay, cancel, or impede live Testing and Evaluation' at considerable cost and inconvenience for the MOD
- **Weapons life** - When a weapons system is fitted to an aircraft its time-limited 'life' starts to reduce, if too many 'missions' (including those experienced as above for T & E) are delayed or aborted they may need expending to avoid costly de-commissioning
- **Weather** – Poor visibility of any kind can delay, cancel, or impede live events

Vision Mission and Objectives

End to End Vision: 'A Test and Evaluation Enterprise that harnesses the most capable and value for money elements of government, industry and international T&E that is dynamic, agile and primed to deliver Defence's future technological, safety and operational challenges to maintain Operational Advantage.'

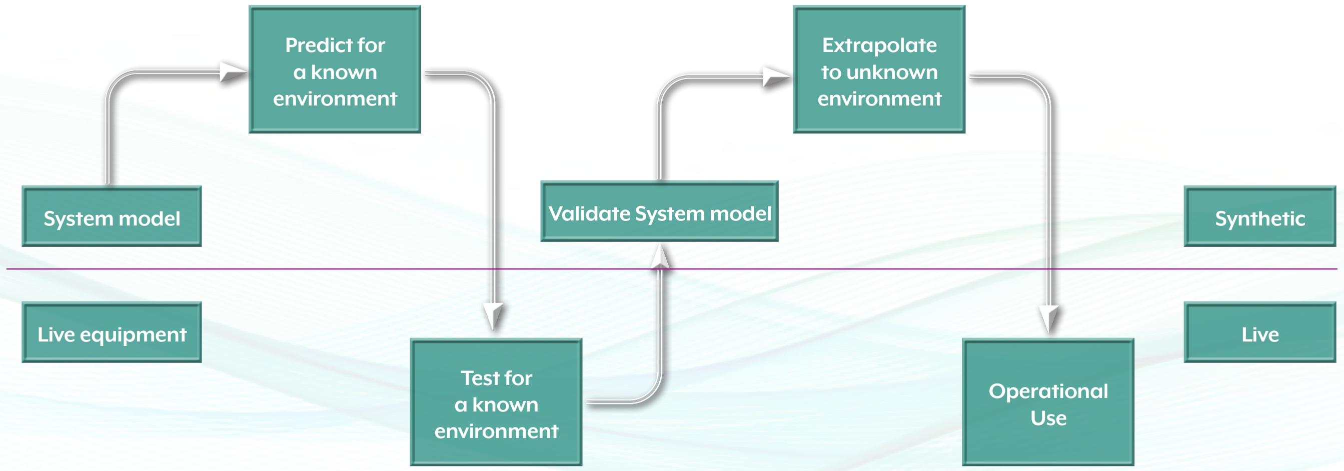
Future mission state and objectives of the test range: The generation of test evidence in the future is going to be more heavily dependent upon the use of M&S (Modelling and Simulation) and will exploit system representations from the system manufacturer. This is a trend that has been developing in the complex weapons arena for several years but will move from being programme specific to something more institutionalised.

If the critical issues associated with the logical integration of these capabilities into a validated M&S T&E system are addressed, which is not a small challenge, such a system would naturally cover many of the challenges raised above; most importantly the potential ability to test in an operationally relevant environment in a secure manner.

The challenge is then to ensure confidence in the performance and capability predictions derived from the use of M&S (driven from a feedback loop). This would then underpin the required cultural change needed to allow the use of such tools as business as usual (witnessed in other sectors such as Automotive/Oil & Gas). The use of M&S for T&E raises different challenges to their use for training, requiring the representation of real-world artifacts, targets and threats that provide accurate stimulation to the sensor models and thus the rest of the system under test.

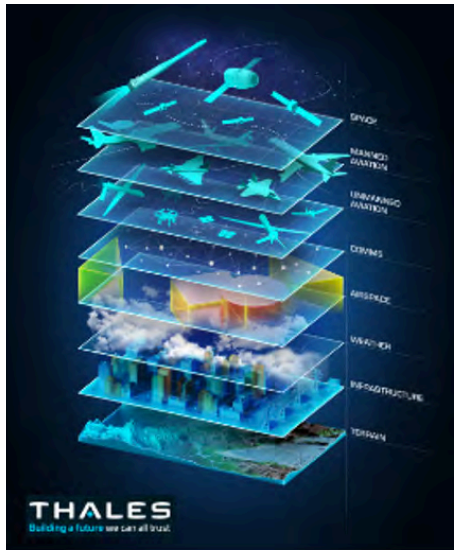
In this context, the role of live T&E is to provide several validations and thus the confidence to use the reference digital test capability to extrapolate system performance to more relevant environments with different targets and threats.

Benefits in summary – Only use live testing for final endorsement or proofs leading to a reduced utilisation of live systems, environmental impact and cost, while improving safety and delivering at pace.



Use Case / Vignette

RAF T&E - Digital Twining/synthetic/simulation will have a positive effect on future T&E and commence the journey to future proofing the range to adapt to new technology. The Head of RAF T&E propose a Vignette using Flares.



Exemplar Examples

- 'Models, Digital Twins and Hybrid Twins' to provide a link between the digital and physical domains– F35 Flight Testing
- Maths and Physics Based Models' limitations in fidelity - **The SimTE** (Simulation for Test and Evaluation) **www.thertdc.com/SimTE/SimTE.mp4**
- 'Standalone Digital Twins' cost effective and expedient in automatically generating a high fidelity – **Oil and Gas, Automotive** (First White Paper September 19)
- 'System Digital Twins' sharing important behaviours and characteristics with their physical counterparts – **ML** (Machine Learning)
- 'Environment Digital Twins' a digital counterpart to a test range to de-risk, monitor, optimise and the need for live trials through reliability – Thales
- 'Hybrid Twins' physics and maths based parameterised models that are calibrated with data from the physical entity - **The Earth's atmosphere and weather**

PART 1

6

ADVANCED CAPABILITY DEVELOPMENT

DEFENCE SUPPORT DIGITAL TWIN COMMUNITY OF PRACTICE

Advanced Capability Development

1 General

This report outlines the work of the Advanced Capability Development work stream for the Team Defence Information Digital Twin Community of Practice.

2 Context

Delivery of future capabilities that create military advantage for the UK require industry consortia, often with international partners, to collaborate integrating complex technological systems while protecting their own intellectual property. Assessing functional and non-functional trade-off and de-risking system integration of cutting-edge technological solutions requirements must be conducted early in the lifecycle.

3 Situation

Historically a document-based approach has been taken and integration issues subsequently found later in the development lifecycle lead to higher cost of redesign and engineering effort.

4 Change of Approach

There is a need for cultural and organisational change integrating an engineering approach that cuts across internal and external business units and also encompasses the Customer and Supplier domain.

While models have been used for many decades in support of product development these have tended to be only loosely coupled with other models (if at all) and targeting a single purpose (for example electrical power consumption or aerodynamic performance).

Enabling all development stakeholders to work on a single digital definition of the product improves collaboration and communication, and provides a clear reference configuration as the foundation for further development.

5 MBSE Across the Lifecycle

Utilising the same model centric approach across the lifecycle will provide the golden thread from concept to capability providing a digital feedback loop through the stages of capability development. However, as the granularity or programme maturity of a paper-based system progresses, the extent and communication of these changes becomes onerous. In a model-based environment these changes are instantly available to all in the programme, removing the enormous activation energy and cost, represented by a mountain of paperwork in need of updating. This Authoritative Source Of the Truth (ASOT) provides rapid access to detailed design data, previously often lost only months after the programme was launched.:

- **Pre-Contract:** includes requirements' capture, assessment of feasibility and preparing a requirement specification (scenarios and a high-level model).
- **Bid:** includes transferring the requirement to bidders and supporting them through the executable requirements process (running scenarios)
- **Implementation:** a successful bidder activity to develop the equipment and a software model that represents its performance.
- **Acceptance:** the activity that confirms to the user that the deliverable equipment meets the intent.
- **In service:** each deliverable equipment will start with a copy of the model (Digital Twin)that will be modified according to the events that affect the real equipment (updates, damage etc.)
- **End of life:** the real equipment will become redundant but much of its model is very likely re-useable for new applications.
- **Inter-Programme:** the software models comprise components, many of which are not application sensitive. For example, elements of a radar equipment will be appropriate for air, land, sea, space and commercial applications. This re-use opportunity can significantly reduce risk and timescale in the development of new equipment.

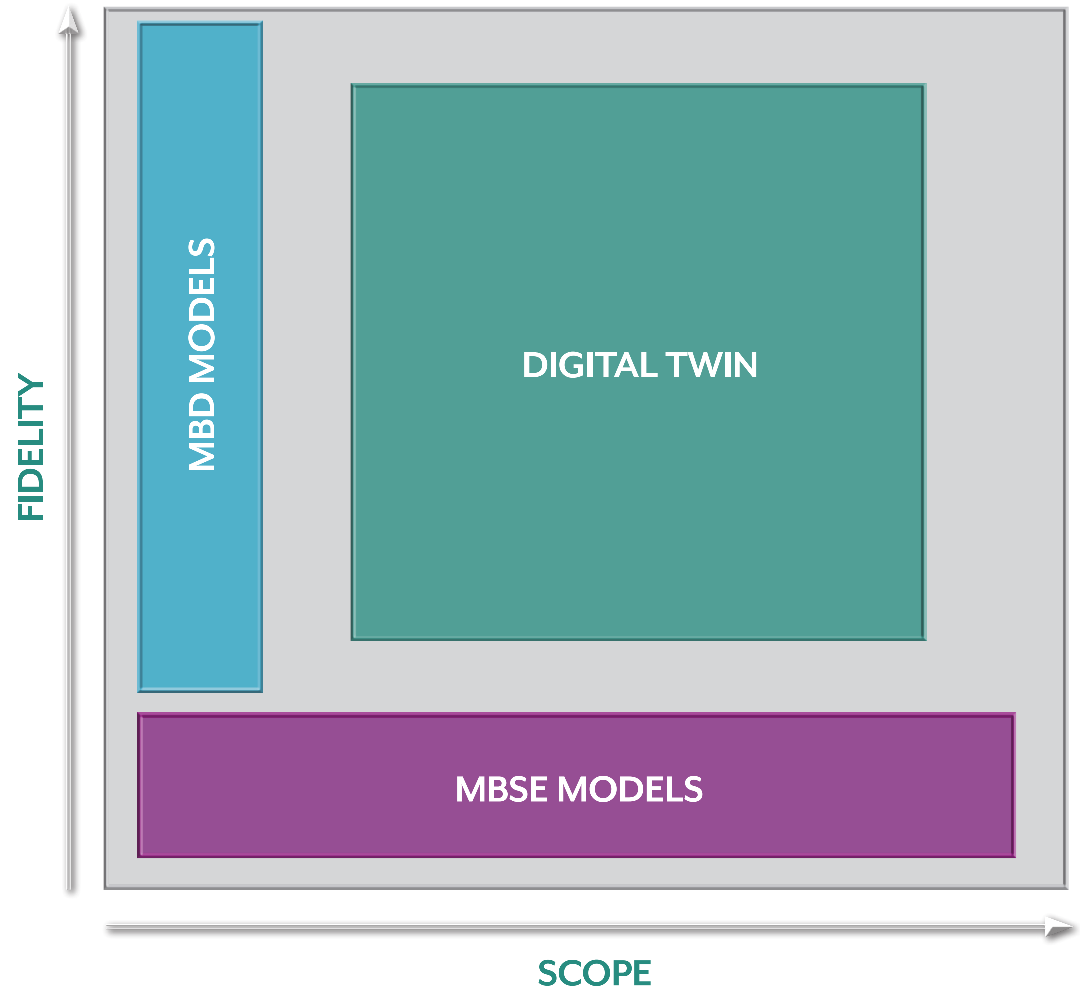
Throughout the product lifecycle, changes to system requirements are not only inevitable but beneficial, by indicating progress towards an acceptable design. However, as the granularity or program maturity of a paper based system progresses, the extent and communication of these changes becomes onerous. In a model based environment these changes are instantly available to all in the program, removing the enormous activation energy and cost, represented by a mountain of paperwork in need of updating. This Authoritative Source Of the Truth (ASOT) provides rapid access to detailed design data, previously often lost only months after the program was launched.

Traditional models are a trade-off between fidelity and scope

- Models with low Fidelity and wide Scope e.g. Model-Based Systems Engineering / Architecture Models
- Models with high Fidelity and narrow Scope e.g. Model-Based Design & Analysis Models

Digital Twins need to be accurate at both the macro and micro level

- Models with both high and low Fidelity and a wide Scope e.g. Digital Twins



6 Federation

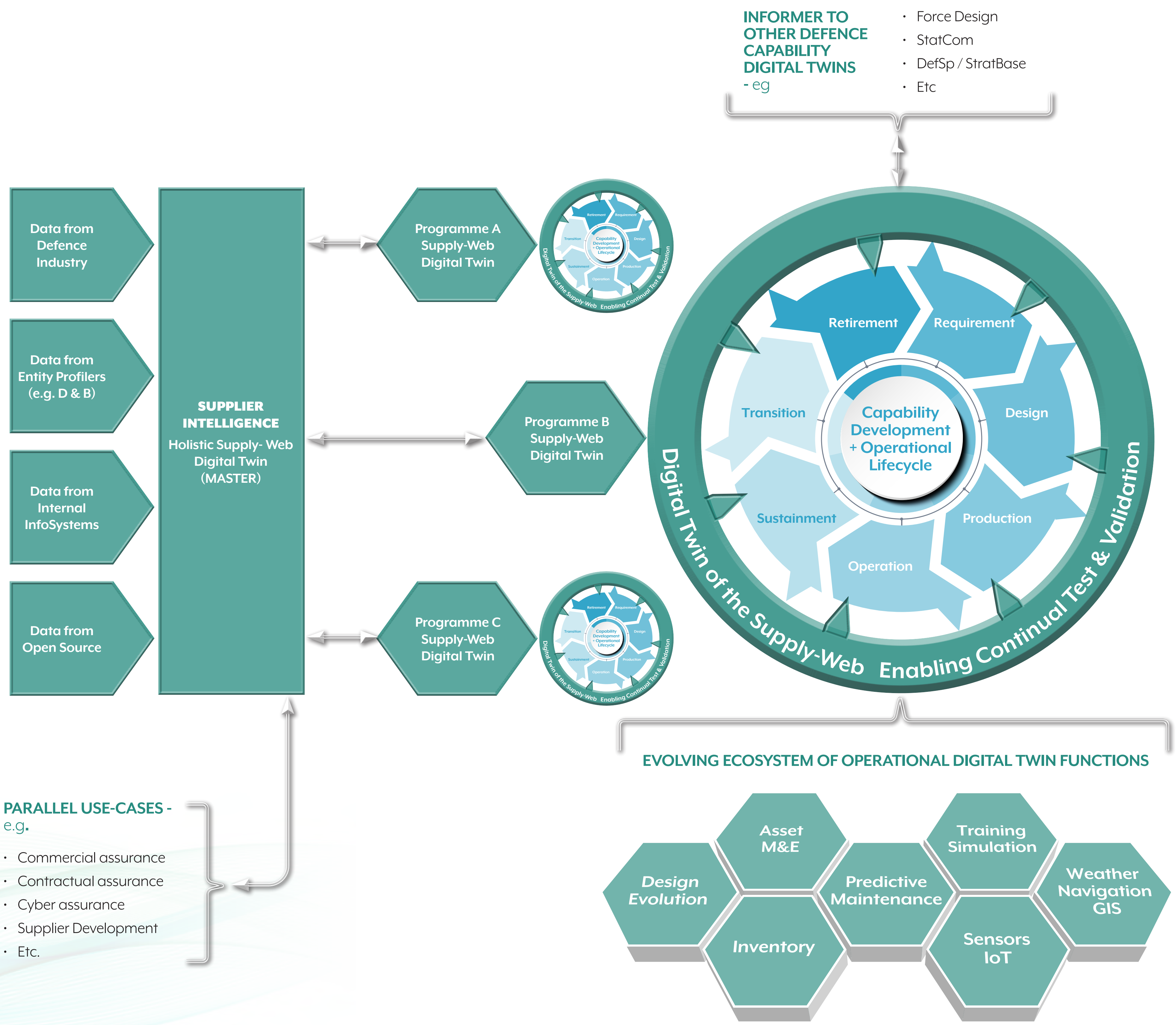
For a Digital Twin to cover the full lifecycle of its physical counterpart, it must exist before the physical product has been produced and may exist even after it has been destroyed. Digital Twins made during the concepting and development lifecycle phases (Digital Twin Prototypes as defined by Grieves[1]) provide the greatest opportunity for accelerating capability development.

Using federated synchronised models enables early verification of the completeness and consistency of the modelling performed in developing the product:

- Stakeholder Needs and Requirements Definition: Working collaboratively with stakeholders and using models in support of understanding and describing their needs, including traceability.
- System Requirements Definition: Using models to correctly create, agree and configure requirements. Best practice is observed to be a mix of collaboratively developed models with a thin layer of requirements to provide context – there is a heritage of using models to illustrate requirements only.
- Design Definition: Using models in support of design characteristics, focussing on collaborative design and data sharing across skills boundaries (systems, software, algorithms, mechanical, electrical, etc.)
- Systems Analysis: Using MBSE as a common language in support of Systems Analysis, linking these MBSE models to those of other skills to support the collection of data and inputs for the purposes of analysis, including physical models, representation models and analytical models.
- System Integration & Verification: Using models for progressive integration of the developed system, with use of representative models in early stages (digital prototype), progressively replaced by equipment as development progresses. Includes critical checkpoints to provide assurance of correct behaviour and operation of interfaces.

Federating model-based systems engineering through the support network (supply-webs) will deliver significant value to defence capability development. Digital Twin Models of the supply-webs can be leveraged for multiple value-propositions across defence including the assurance in capability development and operations.

Mapping/visualising/analysing the complex webs of supply-web risks and dependencies throughout capability lifecycles will support enhanced evidence-based decision making across both capability development and operational lifecycles. It empowers the support community and operators with access to previously unseen connections and hidden dependencies.



[1] Grieves, Michael. (2016). Origins of the Digital Twin Concept.

7 Benefits

Potential benefits of applying MBSE across the lifecycle include:

1. **Validation and Verification:** Creating a cross-domain ASOT for complex programs reduces the risks associated with requirement and design changes; while offering a long-term, easily accessible and up-to-date source of knowledge of the system.
2. **Reduced re-work:** the clarification of the requirements and constraints of the expected scenario results improve communication at all levels, including the development team.
3. **Flexible product:** the deliverable is better understood and the models facilitate running 'will it do this..' and 'what if..' experiments. This encourages product extensions and modifications in situations where a new design might otherwise be the alternative.
4. **Improved implementation:** the implementation process remains well focussed with less temptation for requirements bloat or missed requirements.
5. **Effective and efficient training:** the models and scenario approach allows potential users to contribute at early stages of the lifecycle. It also means that training aids are available prior to delivery and as part of it, not an afterthought.
6. **Improved maintenance:** maintaining the digital twins and the information that can be derived from that supports predictive and preventative maintenance. Where necessary, replacement part design is more easily identified.
7. **Supply-Web Risk Mitigation:** Operating a maturing ecosystem of Supply-Web Digital Twin(s) will enable defence with effective resilience against evolving risk factors; and reveal the complex relationships of demand and capability between disparate capability programs.
8. **IP Retention:** With MBSE, lower tier partners can create a model representative of the full performance envelope of their component, sub-system or system to the OEM; providing a perfect shop window for their technology. The OEM, in turn, can deploy the model in their "environment" to explore the behaviour of the system as a whole without the need for an prototyping effort.

8 Conclusions

The increased tempo of development and integration of complex systems of systems will require federation of digital models to manage upgrade and technological insertion.

Many artifacts to create these modes already exist, albeit narrow and unfederated, early in the lifecycle.

Applying a Model Based Systems Engineering approach will not only support accelerated development of advanced capability, but if applied throughout the capability development lifecycle has potential to realise many additional benefits

PART 1

7

DIGITAL TWIN KNOWLEDGE BASE

UNDERSTANDING THE IMPLEMENTATION LANDSCAPE FOR DIGITAL TWINS WITHIN THE DEFENCE SECTOR

Executive Summary

Within this workstream of the Team Defence Information (TDI) - Digital Twin Community of Practice (DefSp TDI DT CoP) the aim has been to create a knowledge base of Digital Twin (DT) Implementation projects. The intent has been to build a picture of the current and future digital twin activities and to inform on: i) the nature of DT projects; ii) DT application areas; iii) challenges experienced in DT design and development; and iv) capture reflections on return on investment.

The working group on DT mapping was hosted by Prof. John Erkoyuncu at Cranfield University and an online survey was launched on the 23rd of June 2021. To date, 99 responses have been collated from 49 organisations. The survey was filled out by people in a variety of roles such as: C-level Executives, VPs, Directors, Head of Units, and Consultants.

The survey gave us the status of DT projects within the defence sector and other related areas. The industrial engagement has shown significant and growing interest in DTs. Subsequent to the online survey we interviewed experts from 10 organisations who have participated in the survey to get more detailed insights in to the design and development of DT processes.

The knowledge base that has been developed is important as it offers the first of its kind to reflect on the current interests in DTs in terms of application areas, and to capture the level of benefit that maybe achieved from DT projects. By making the knowledge base publicly available we aim to assist organisations in identifying and developing the most impactful DT applications. In the current version of the knowledge base there are a number of key messages that can be drawn out, including:

- The size of DT projects varies significantly. Whilst medium sized DTs have received the largest interest with 38% of DT projects in this category, there is roughly even interest across large (30%), medium and small sized DTs (32%). This means that DTs are considered to be flexible in terms of the scale of problem that they can handle.
- 49 organisations that filled the survey came from very broad backgrounds, whether it be solution providers, consultancies, OEMs, customers, or tier 3 suppliers. This indicates that the potential benefits of DTs have been acknowledged across the supply network. The DTs suggested are primarily to improve the asset performance outcomes between the provider/OEM and customer, and currently there are no DTs focused on supply chain integration.
- The DT development horizon indicates that the theme is largely a growing initiative that is in development or planned. 27% of the DT projects presented have been completed with outcomes available, which illustrates some level of maturity in DTs implementation has been achieved. Currently, the largest emphasis is on live DT development projects with 41% in this category. This shows that there are numerous new DT examples that will become available in the short to medium term.
- 27% of projects have full DT operating capability, and 17% have initial operating capability, indicating that over 40% of projects already have some degree of DT capability, and the rest are either at a conceptual (28%), proof of value (14%) or prototype stage (17%). Although, there is a growing amount of maturity in DTs, there is still a significant opportunity to develop the maturity in DTs.
- The common intended outcome of DTs has been to improve asset performance, where an asset has typically been a high value complex engineered asset. Furthermore, there have been a very small number of DTs focusing on the delivery mechanisms considering the integration of internal processes or organisational functional units.
- DTs have been considered across the asset life cycle with an emphasis on the in-service phase. The main DT application areas have been in 'asset performance optimisation', 'maintenance, repair and overhaul' and 'test and evaluation'.

- The breakeven point for DT investment has been less than 2 years for the completed DT projects. Furthermore, among the completed projects, the breakeven point for large projects has been just under 4 years, and 2 years for small projects. This indicates that investment in DT has commonly provided a relatively quick return within the project areas that it has been applied to.

We have identified numerous challenges through the detailed interviews that have been undertaken. A set of quotes are provided below to illustrate some of the main areas identified:

- "[...] The biggest problem is bringing the **data together** in a way that would support the development of a DT. [...]"
- "[...] I think the **integration** of all these different components is a bit of a headache, [...] but is fundamental for the development of a DT. [...]"
- "[...] The issue that twining turns on his head is that we really have no idea how much **waste** is in the **current standard** way of behaving around assets [...]"
- "[...] I think our failing so far around DTs is **organisational culture**, I don't think we lack the technologies to produce a models, simulations or service solutions, is more a cultural issue with the acceptance of DTs within the decision making part of the business. [...] and really understanding what DTs are [...]"
- "[...] This is where **good architecture** comes in, because what you want to be doing is extend the boundaries because there is more information you can get, which helps with decision making. It's not to move the boundaries because I can but because I need to. [...]"

The knowledge base that has been developed as a DT database is accessible through MS Excel. We expect the use of this to be primarily to assist organisations or individuals in their journeys with designing and developing DTs. This resource will offer lessons learnt and will enable to minimise waste in DT activities. The knowledge base is structured in a way that makes data search intuitive, and analytics feasible to evaluate key information. It is also designed in a way that allows to monitor changes in DT projects, and to add new propositions.

The knowledge base will be updated in a controlled manner with specific timeframes and stakeholders allowed to be able to make modifications. Moving forward we believe it will be critical to ensure that the knowledge base evolves over time by adding new projects and tracking the progress of existing and planned projects. Our plan for future actions centres on enabling the continuous evolution of the knowledge base. This will be achieved through the following activities:

- Twice a year an online survey will be launched to capture updates on existing and planned DT projects
- The knowledge base will be continuously updated with a major overhaul twice a year based on the new surveys conducted. The results will be made available to view and analyse through the TDI webpage
- Further interviews will be organised in batches of twice a year to reflect on the detailed DT design and development activities, which will help to iteratively enhance the guidance provided
- An annual white paper will be published to reflect on the emerging trends and set out further propositions for future work
- Dissemination events will be organised to share updates on the DT progress

The annex below provides the detailed results from the online survey.

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