Introduction

In addition to those people within the Defence sector, the intended readership for this Note includes people outside of the sector. The common factor is an interest in the skills needed to support the Defence Digital Transformation program and Digital Twins (DTs) in general.

General Background: The defence sector is introducing 'Digital Transformation', leading to Digital Twins, particularly for procurement and lifecycle of defence equipment. Like anything new, a learning curve is involved. It is the intention to engage with other sectors, the built environment being one and the automotive industry being another, to help with that learning process.

A previous note described the Digital Twin (DT) Lifecycle of a product from the perspective of the defence sector that includes industry (from prime contractors to Small-Medium Enterprises (SMEs)), as well as the various parts of the MOD and the Armed Forces. The Defence Digital Transformation affects all defence stakeholders.

There is a wider purpose in engaging with other sectors. In the event of civil disasters, flooding and Covid are examples, the Armed Forces can be deployed to assist the Civil Forces. For that to be most effective, there is a need for joint training and good communication between the Civil Forces (Fire, Police Ambulance – plus utilities and transportation services) and the Armed Forces. The growing Built Environment is experienced in the use of DTs, and so it will be advantageous for the Armed Forces to have a compatible synthetic environment and DT asset structure to facilitate joint training.

This Note: The defence DT strategy is an upheaval to the defence stakeholders. Like all upheavals, threats and opportunities cause concern, optimism and uncertainty. Having the right level of skills, in the right amount, at the right time are part of this. Other works (e.g. DT Hub, 'Skills and Competency Framework'[i]) have approached this in depth, with specific definitions of job roles, and these are referenced. This note assumes the DT lifecycle model is in-place and, for consistency, is written in the present tense. However, it is intended as a thought provoking piece to launch discussion and sharing of ideas and best practices, not as a definitive work. It attempts to put perspective on what needs to be done at each stage of a DT project, particularly what skills are needed and if/how they may map onto existing skills. It takes cognisance of the current difficulties in Engineering recruitment and suggests where existing skills might be brought to bear.

To repeat, this note does not try to present all of the answers, it is an open invitation for those who have trodden the path in other sectors to contribute to these, and other issues, to help meet the wider joint objectives. Importantly, it aims to bring clarity to a complex construct. Once consolidated, a next step would be to map what training may be needed to bridge current skills into their evolving roles.

Defence Procurement – The Players

A typical current defence procurement process is presented in Figure 1. Government policy dictates objectives and budgets that are interpreted into the Army, Navy, Airforce, Space and Cyber needs by the Front-Line Commands (FLC's - senior Armed Forces personnel).

The Chain of Command, lower ranking officers, engage with other parts of the Ministry of Defence (MOD) to determine detailed specifications. This is generally a task for the Defence Scientific Technical Laboratory (dstl) and implementation is project managed by the Defence Equipment and Support (DE&S) organisation.

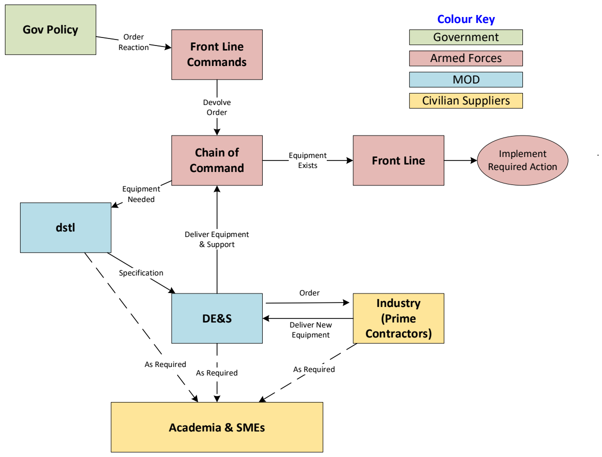

Figure 1 - UK Defence Procurement

Suppliers are drawn from Industry (prime contractors through to Small-Medium Enterprises (SMEs) and Academia) and are subject to commercial contracts.

The UK Armed Forces number about 200,000 people including volunteers, with a budget of around £42bn[ii]. The MOD (DE&S) employ about 60,000 to run the projects[iii]. Given these numbers, responsibilities can easily become blurred between the Services and MOD departments, with the processes being be highly bureaucratic. Introducing change into this structure is challenging! The Public Accounts Committee has consistently claimed that the organisation needs to get a grip'[iv] and is 'broken'[v].

The Digital Transformation Program[vi] is being introduced as approach to improving the situation. It is challenge to do this against the existing behemoth of a structure, requiring some thought about a pragmatic approach to its implementation. The following explores the area of skills to achieve suitably qualified and experienced people (SQEPs) that fit into a clear and defined structure.

The DT Process

A common understanding of the DT lifecycle is a necessary for meaningful discussion. A previous note provides a lifecycle overview of the stages, whereas here what happens at each stage is considered.

The defence sector's implementation model was previously represented by the CADMID lifecycle model[vii] and variants of it. CADMID is the acronym for Concept, Analysis, Design, Manufacture, In-Service and Decommissioning – a linear flow. The DT approach replaces this with variants of Model, Analyse, Build, Deploy[viii], also a linear flow but more challenging to convert to an acronym!

As depicted in Figure 2, the implementation may use agile development, with incremental deliveries, to replace the less popular traditional 'big-bang' option. Clearly, the diagram can be readily adapted to support the traditional approach – there would be just one (very complex) iteration.

DT
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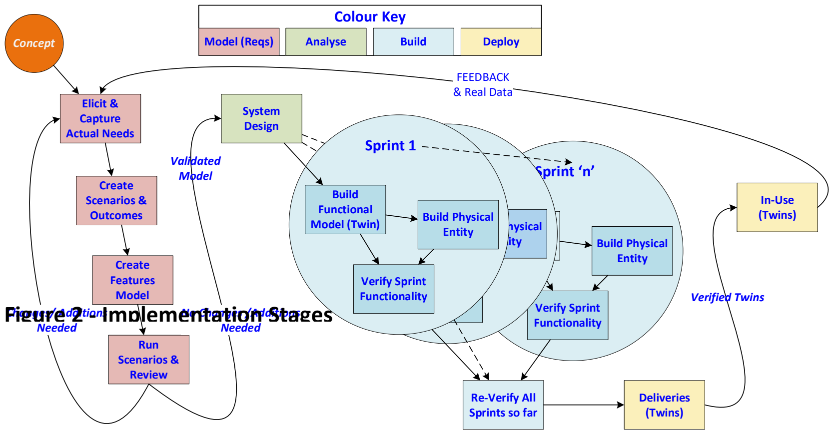

Figure 2 – Implementation Stages

Following the establishment of a need, the modelling stage is used to elicit and capture requirements. The analysis stage provides the systems design to meet the requirements and the build stages produce the physical entity and the 'as-delivered' digital twin(s). The deployment stage ('in-Service' or 'deployment' in defence language) provides feedback to inform equipment updates, future designs and to support the maintenance of the physical entity, as described later.

The first step towards successful implementation of the strategy requires all stakeholders to agree the process, then to understand who has responsibility for each stage. More work can then be done, by the stakeholders, to define the responsibilities, clarify and define individual inputs and outputs to ensure the required overall outcomes. This should be an inclusive stakeholder activity but coordinated by those responsible for the strategy. It has not yet happened, so the premise of this note is not yet been clarified or ratified.

Modelling Stage

Compared to the traditional approach, the DT method of product delivery requires more work, up-front in the lifecycle, to define scenarios that the new product is intended to meet. 'Product' could be equipment (new or updated) or operational changes. The up-front modelling activity is completed when the customer cannot think of other needs and the (validated) Features' Model will run the identified scenarios to produce the expected outcomes. This 'Features' Model' will then form the specification, an executable reference model, against which the performance of all subsequent project deliveries will be compared (verified). The Features' Model will produce the required outcomes for the range of encountered conditions by simple high-level-of-abstraction code, not how they could/should be achieved – that comes much later. This model's key feature is that it needs to lend itself to quick and easy modification to support interaction and development of intentions.

Given a small handful of scenarios, a Features' Model can be started. What is important is prioritisation of deliverables, so that best value for money is delivered.

So, what skills are needed at this stage? Does it require those difficult-to-obtain Engineering skills?

The people who know what is needed, see Figure 1, will generally be Service personnel. Some may have Engineering skills but most will not. Their experience may derive from any of the Service skills, navigators, gunners, pilots, logistic experts etc. The skills needed for this stage are communications, with a good level of empathy to bridge the User and Engineering Domains.

Ex-Service personnel, ideally with some Engineering skills or access to them, are one good way to fulfil this role of creating scenarios, establishing required and, importantly (but often overlooked), not-required outcomes. Test Engineers with their customer skills and practical engineering abilities have a role to play to help bridge any gaps to engineering specialists and to play a key role in designing pragmatic scenarios with realistic outcomes. This early-stage communication is a new role for Test Engineers compared to their traditional part much later in the lifecycle process. The techniques used in communication are not only verbal, other techniques, including presentation and prioritisation, are necessary according to the stakeholder groupings and the message to be conveyed.

It will be clear, but for the sake of completeness, the model should be only of the equipment required and be such that it will run in a federation with a synthetic environment and any other existing or prospective models as needed by the scenarios. The functionality of other existing or shared models should not (must not) be incorporated into the Features' Model, otherwise the final deliverable will be bloated with unnecessary duplication. The scenarios may be human scripted or automated. The good/bad outcomes may be auto-checked or by manual checklists.

The Features' Model is akin to simple visual training/gaming software. That gives it the advantage of being understood by its potential users, a very valuable benefit not offered by the traditional document approach.

> A trivial example from the automotive world might be to produce a vehicle to travel from London to Manchester taking no longer than 4 hours in a way that is safe for human occupants. The Features' Model checklists might include: did it find the optimal route from user selected preferences or not (what were the criteria for optimal?)? Did it accelerate and brake with acceptable rates for human occupancy? Did it avoid collisions with all reasonable exception cases presented to it (what were they?)? What was the total journey time (is that acceptable?)?

As will be appreciated from the example that will have presented anomalies, the process is iterative, with: 'Ah, I didn't quite mean that'; 'You've just prompted me to remember something else…'; etc. leading to more Use Cases being added and more conditions being applied. The Features' Model will grow and the scenarios increase in number and complexity.

Although emphasis is on requirements and modelling, there is a need to document how choices and decisions were resolved as well as basic assumptions (what units are used for speed? Why was a rocket engine rejected (if, indeed, it was)?). This is a non-trivial project stage and is likely to be lengthy.

Skills?

The key players of this stage are the User Domain subject matter experts, plus people with gaming skills, as well as communicators with negotiation skills, and Test Engineers to bind the groups together. The deliverables are the validated Features' Model, the scenarios with acceptable/not-acceptable outcomes, plus meta data listing the decisions and assumptions. Although owned by the User Stakeholder, the deliverables are managed by the Test Engineers engaged with the model's development and validation testing as they will provide continuity with other stakeholders through subsequent stages.

Analysis/ Systems Engineering Stage

This stage is launched with the agreed Features' Model being a very solid and executable specification of requirements, plus support data. This is much better than the starting point for many traditional paper-based requirements that were easy to mis-interpret and, very likely, incomplete – at worst inappropriate.

The finalised Features' Model could be used in either of two ways to create a Functional Model that will define the architecture to meet the requirements – leading to bids to implement it:

1. Suppliers will undertake this in a competitive way.
2. Suppliers will be invited to cooperate to produce a Functional Model.

The first option is akin to the current bidding process. However, the current process does not require delivery of a testable Functional Model, nor does it offer an executable Features' Model, and so is open to mis-interpretation often leading to subsequent time consuming and expensive re-negotiation.

Currently, the second option would be seen as optimistic/unrealistic because of IPR and competition issues within industry, but it does offer benefits. The benefits include best-of-breed ideas being incorporated into the design, and the time to explain what is required is reduced to one activity rather than being individual to bidders. The half-way house option is for industry to form into consortia according to the requirements and individual skills. However, the pros and cons of this is outside the scope of this note that is concentrating on mapping existing skills to the new strategic approach.

Whatever the commercial construct, the result is to produce a Functional Model that defines the architecture of the physical entity.

The Functional Model is likely to be a partitioning of the Features' Model to reflect the proposed modular architecture and to facilitate costing. It is a good way for suppliers to gain hands-on familiarity with what is really required and so produce a more informed implementation plan. This is particularly important for larger complex requirements.

The customer can check that the partitioned Functional Model produces the same outcomes as the Features' Model, or that an acceptable alternative is proposed. Note that 'acceptable' may mean that some features are modified so that cost and/or timescale can be reduced, but the original intent is maintained.

Systems design processes are specific to each company and need not change. Modules need only produce correct functionality (i.e. interfaces and transfer functions) not necessarily the appropriate mathematical-physical representations of the physical entity. To reduce risks, these may be explored but will be introduced during the subsequent stages when the detailed design takes place under contract.

So, what skills are needed at this stage? Does it require those difficult-to-obtain Engineering skills?

This stage is Systems-Engineering intensive but with Features' Model comparison being facilitated by the Test Engineers to verify the proposed design's outcomes against those of the Functional Model for the various scenarios. The Test Engineers are well placed to help resolve any discrepancies and provide any clarification that may be needed.

The modules in the Functional Model become the specifications for detailed implementation. Importantly, the scenario traceability with the Features' Model is maintained. This continuity gives the project great potential to reduce subsequent modifications and re-work during the implementation phase. In turn, that reduces risk and therefore cost and delivery timescale. Like the end of all stages, a comparison of the performance results from running the scenarios on the current model, in this case the Functional Model, with the those produced by the original Features' Model is the way to verify if the deliverable is satisfactory.

There is another important consideration at this stage. During the in-Service stage, Support Engineers and others will require maintenance information: 'is it time for routine maintenance?'; 'Is preventative maintenance required? If so which components, what are they, where are they sourced etc.?'. This is the appropriate stage to introduce these features into the modelling to add value, ideally as part of the functional but alternatively as a parallel model.

There are other complications. It will be appreciated that a huge amount of data continues to be generated and many users require access. A growing level of data access is required for all lifecycle stages, including progress monitoring. Access control to the data repository is required to protect IPR and to avoid data being damaged. Because data needs to be compatible with many existing technical and management tools from multiple suppliers, on-the-fly data conversion features will need to be added to the packages in use.

Data management is an important area to be addressed by joint MOD-Industry representatives to agree what classes of data are required, what meta data are required to describe classes and parameters and what access controls are needed. The Digital Backbone has been identified as the carrier and the Open Innovation Laboratory has been identified as a way to test some of the options of how it will actually work.

Build/Implementation Stage(s)

In these stages the twins are produced, digital models that represents the physical entity being delivered in each iteration. It requires the most Design Engineering effort but also involves the least change from traditional methods. Whatever design tools are currently used can continue to be used. The only condition is that, to avoid mistakes, the data and parameters used by the tools are supplied by a common data repository, ideally delivered by the Digital Backbone.

It should be clear that, during this stage, the modules in the Functional Model have their functions elaborated to match the physical design, whilst retaining the original key-performance factors for each function. Furthermore, the physical entity must communicate with its twin to exchange key data so that, for example, wear and preventative maintenance predictions can be made. In many cases, the twin may also communicate with the physical entity for such purposes as initiating the use of reversionary modes to prevent pending catastrophic failure that the twin is able to predict.

As further equipments are built, it may become necessary to use different components (screws, belts, integrated circuits etc.) and so the deliverable model (twin) is also modified so that it truly represents its physical entity. It is important for the integrity of the implementation to have a truly representative twin delivered with each physical entity. It is also useful to retain Features, Functional and Generic Implementation Twins because they can be re-used, in whole or part, in future designs.

So, what skills are needed at this stage? Does it require those difficult-to-obtain Engineering skills?

Regular test runs (undertaken by test Engineers), using the original scenarios, are needed to verify that the results are consistent with earlier stages. By doing this, any deviation can be identified as soon as possible so that project time and cost can be controlled.

However, these activities require software implementors to work alongside other Engineers who are designing the physical entity's mechanical, electrical, electronic, aeronautical and other features. Design

Engineers provide the main-stream efforts in this stage, supplemented by (many) verification activities undertaken by Test Engineers and supported by on-going meta data management.

Deployment/In-Service Stage

Successful Twin implementation offers two benefits compared to traditional methods:

Improved availability: Predictive maintenance is built-in and so equipments' down-time can be organised to cause minimal disruption and scheduled into suitable timeslots. Parts ordering can be automated and pre-aligned with the maintenance schedule. The twin can be used to train users and maintainers without taking the physical entity out of service

What if?: As an extension to training, it is much simpler to explore if and how an equipment will respond if used for an application that was not foreseen – for example, in response to an unexpected Use Case as typically happens during in-Service life e.g. 'we have a broken tank, will damage occur if we use this personnel carrier to tow it 6KM over this terrain for repair?'. Once the Twin has been used in this 'off-line' mode it can be restored to its previous state prior to the new scenario being run.

The aggregation of data from a family of twins (often called 'the fleet') can also be used to benefit the fleet. A fleet modification may be required if unexpected failures have occurred in several members of the fleet.

So, what skills are needed at this stage? Does it require those difficult-to-obtain Engineering skills?

Running these predictive tests is an extension of those of the Test Engineers described above. It is likely that they will be performed by Test Engineers who are in the Services. Hand-over issues need to be addressed. Importantly, information fed back to the data-base can be used to inform future designs and updates.

Summary, Conclusions and Next Stages

The Defence Digital Transformation, like any other transformation, presents challenges and opportunities. The opportunities are powerful and discussed in many places. The challenges are many but discussed in fewer places. The challenges are not mutually independent, here we have tried to explore the interactions between process and the skills required to implement them.

In the current MOD procurement process[ix], the modelling stage would be undertaken by dstl/DE&S. The bidding prime contractors' Systems Engineers and Test Engineers would not be involved until the requirements' specification was completed, an exception being possible mini-studies.

There are significant benefits in changing the process so that industry, particularly the prime contractors, are exposed to the requirements as early as is practical. Not least to create a better understanding what is required (and not required), and its practicality (or not), rather than having suppliers start from the currently experienced large volumes of paper specifications for bidding purposes.

There is potential to minimise the overall timescale by merging the modelling stage with bidders hands-on running of the Features' Model. Taking it further, it would be possible to re-structure the procurement process so that preferred bidders play a greater part in Features/Functional Modelling. Current practice of letting independent study contracts and consolidating outcomes – can be a lengthy process that introduces contractual issues with a plethora of inconsistent management and contractual frameworks to control the various contracts.

Given this perspective, here we have tried to consider the skills issues by comparing the 'new' demands with current practice, to try to promote thinking about how best existing skills can be utilised.

In practical terms, as described in this Note, ex-Service personnel and Test Engineers have a lot to offer in bridging technical and communication aspects of the lifecycle stages and so catalysing the convergence of understanding between stakeholder groups.

The key next-step is to define clearly, by engaging with all stakeholders, how the strategy will be implemented and the responsibilities of each stakeholder group at each stage. This is likely to lead to changes being required and people-skills present a key challenge area as addressed by this Note and the referenced works – see Appendix A. Lessons can be learned from others, particularly the built environment, automotive and rail sectors.

Finally, and to re-iterate the objective, this Note will have been successful if it promotes thinking, and responses, about the skills needed for the implementation of Digital Twin techniques. All contributions welcomed!

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Appendix A Others' Work in this Area

- *Benefits Manager*
- *Ontologist*
- *Data Regulator*
- *Data Consumer*
- *Data Leader*
- *Data Producer*
- *Data Steward*
- *User Researcher*
- *Data Governance Specialist*

Organisations with interest in the use of DTs have produced bodies of work related to the topics addressed here. Notable amongst these are the following:

The UK's Digital Twin Hub - Skills and Competency Framework

A research project undertaken by a group of DT Hub members produced a Skills and Competency Framework[x]. More information is available as indicated in the reference but it may only be accessible to members of the DT Hub**.**

The document includes a skills gap as well as skills and competencies required for each role. There are cross-references to the level of skills for each role.

National

- *Benefits Manager*
- *Cyber Security Specialist*
- *Data Regulator*
- *Industry Leader*
- *NDT Architect*
- *Ontologist*
- *Policy Maker*
- *Sector Regulator*

Organisational

- *Cyber Security Specialist*
- *Data Architect*
- *Data Consumer*
- *Data Custodian*
- *Data Producer*
- *Data Steward*
- *Data Leader*
- *Process Modeller*

The UK's Digital Twin Hub - Developing a Capability Enhancement Programme

In support of the above, the DT Hub also produced a document to assist in Developing a DT Capability Enhancement Programme[xi] in accordance with the Information Management Framework[xii] (IMF) and the National Digital Twin[xiii] (NDT).

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[xi] 'Developing a Capability Enhancement Programme', April 2021, https://digitaltwinhub.co.uk/files/file/78-capability-enhancement-programme/?do=download&csrfKey=b9c2daca40d3ea96e759c1d0dde7c049.

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