Taking Simulation Interoperability Standards to the Next Level with Digital Twins

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ABSTRACT

Digital Twins – connected digital representations of physical systems - are rapidly emerging as tools to enhance the capabilities of the Defence Enterprise, for through-life platform development and support, for concept development and experimentation, and for operational activities within the contemporary complex, multi-domain, and multi-national environment.

To fully realise the potential of Digital Twins in the NATO environment where allies work together there is a need to ensure interoperability of models, of simulation environments as well as ensuring consistent and coherent analysis of the data ingested and generated by Digital Twins. Historically, issues have been solved in the military domain with simulation interoperability standards, principally used for training applications.

However, there is now an urgent need to do more to ensure that digital representations of complex systems with accompanying security and Intellectual Property issues can be shared; and build on existing work in Modelling and Simulation as a Service (MSaaS) paradigms and standards that have been developed within the manufacturing and built environment domains.

The paper describes some issues in making progress on this topic, along with the plans and early activities of a new Research Task Group MSG-205 comprising a number of NATO nations and bodies working together to solve them.

1 INTRODUCTION

The term 'Digital Twin' is becoming embedded into our culture, not just in technical system engineering terminology but even mentioned in main stream media **Figure 1** [1]

Figure 1 - Media portrayal of Digital Twin

But what is a Digital Twin? There are even more definitions of a Digital Twin than there are management consultancy firms trying to tell you about them. And indeed it is easy to confuse the use of modelling and simulation (M&S) with that of a Digital Twin. In that respect, due to the long history of use of M&S within military training and education, Digital Twin technology looks very similar to the things we have been doing for a long time. For manufacturing processes and built infrastructure, the concepts and practice of using Digital Twins are now well established but are now becoming much more interesting to the defence and aerospace community.

Within the NATO context, with more than 30 countries being involved in partnership for mutual defence, the shorter the definition the better, and a current authoritative but short definition developed over several years is this one. [2]

'*A Digital Twin is a virtual representation of a connected physical asset'*

Figure 2 gives a pictorial idea of this, there is a real physical asset, in this case a helicopter, along with a virtual representation or twin which exists as a model of the systems within the helicopter. The virtual twin and the physical twin exchange data at intervals allowing useful decisions to be made.

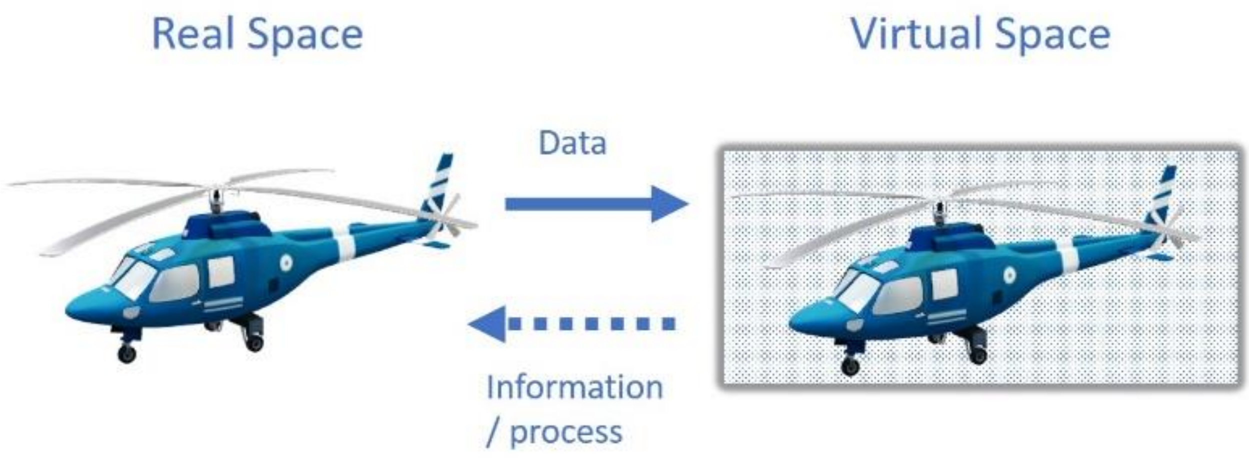

Figure 2 – Digital Twin concept

Many people would also argue that a Digital Twin can also represent a real world process or capability rather than just a physical asset. And the BBC article [1] mentions the concept of making a Digital Twin of a person, something that is obviously of interest in the military training and education community as we seek to better ensure our forces are prepared for every eventuality.

1.1 Digital Twins are not new

But despite the recent hype, Digital Twins are not new. Apart from their well-publicised use for various NASA space missions over many decades they have also been used in motorsports applications for more than 20 years. The device shown in Figure 3, commissioned by Toyota in 2008, may look like a conventional simulator used to train drivers of rather fast cars, but in fact it is just a tool to help the expert driver to become part of the development environment 'human in the loop'. Accurate simulations of the vehicle derived from real track telemetry data is used with a driver to set up the car parameters for actual racing. The system used a laser scanner to generate a synthetic environment of the race track accurate to a couple of centimetres as well as including the trees and other items that the driver uses to judge position and so allow the 'driver in the loop' to time braking, steering and acceleration manoeuvers accurately as input into the race scenario experimentation design.

Within the trials and test infrastructure simulator runs gather the same data as sensors do during races allowing the vehicle modelling and analysis team to alter various parameters on the vehicle to best effect. The overall concept for this Digital Twin is shown in Figure 2.

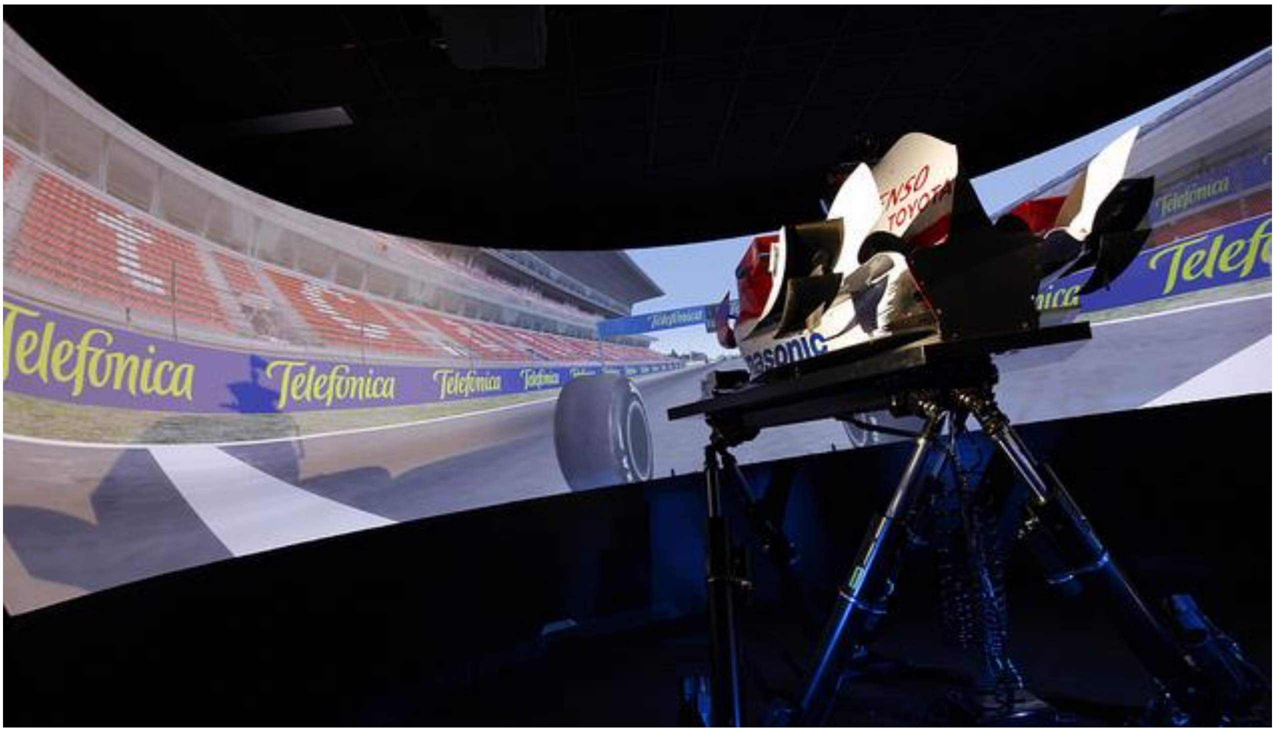

Figure 3 - Toyota Motorsport development simulator

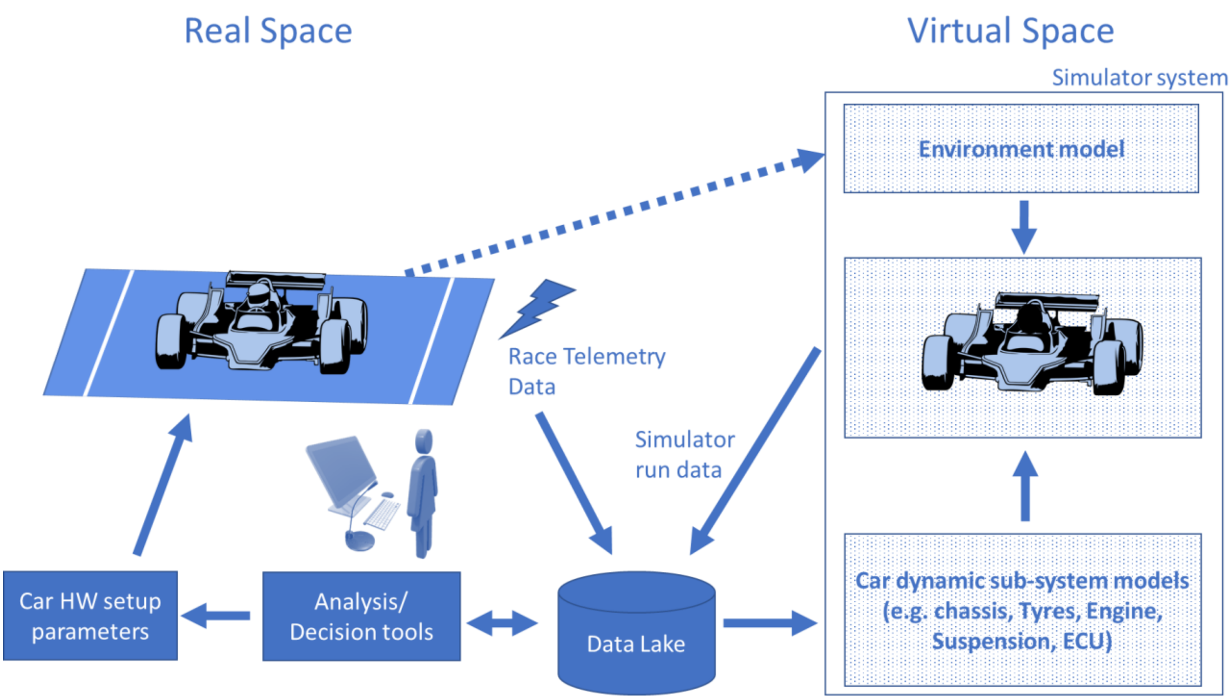

Figure 4 - Motorsport Digital Twin concept of operation

1.2 Potential Digital Twin use cases in the military context

A real benefit of implementing Digital Twins is the use of the data gathered through the life cycle of a particular platform or capability from its initial concept through to its eventual disposal – (Concept, Assessment, Demonstration, Manufacture, In-service, Disposal – CADMID), so that it can be used to reduce design issues, so improving reliability, quality and effectiveness and hence reducing lifetime cost (Figure 4). The repositories of information created and linked across time and lifecycle stage are commonly known as a *'Digital Thread'*. The ability to use a Digital Twin in Model Based System Engineering with the data it produces to design and implement a verifiable, reliable, and resilient platform with less time and rework is a key benefit and value of the approach.

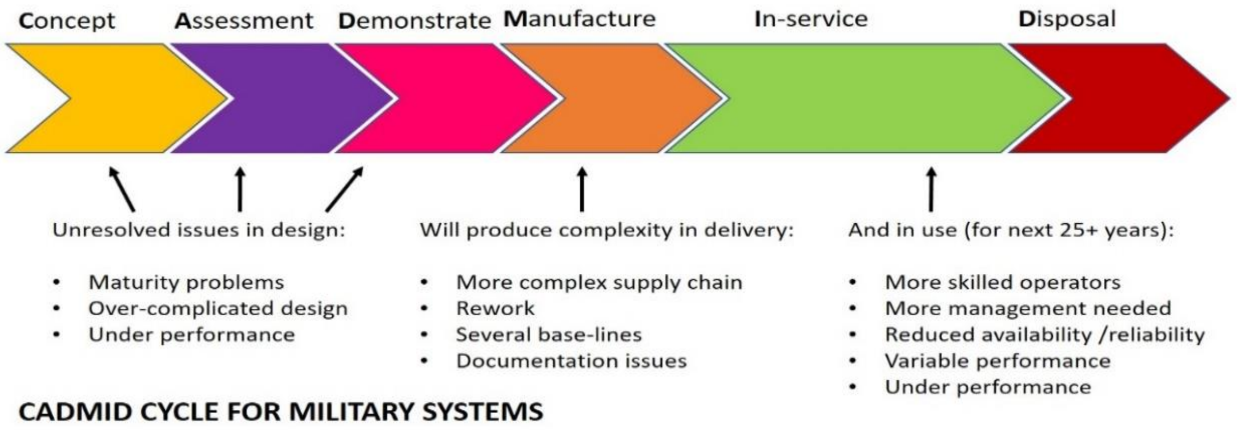

Figure 5 - CADMID life-cycle structure and issues

During development of a new platform, live test ranges are often used for evaluation and test. To reduce cost and environmental damage, a Digital Twin of the platform can be used in combination with a Digital Twin of the test range and associated environment to perform virtual test and evaluation – see Figure 6.

The output of these Digital Twins operating together will be a vast quantity of data of various types and uses – sometimes referred to as a '*Data Lake'*. The data accumulates through the life of the system and can be used to improve the live system design and implementation – the Physical Twin, and the accuracy and usefulness of the virtual simulated system – the Virtual Twin.

Depending on the context some data may be stored in different places due to security policies and may be accessible via cloud storage systems for other projects and uses.

Some data may be useful, other data might be generated because of a failed test which results in a virtual redesign and is seen as less valuable. However even this data might contain patterns which could indicate trends over time. This approach to storing and managing information is sometimes referred to as *'Big Data'*.

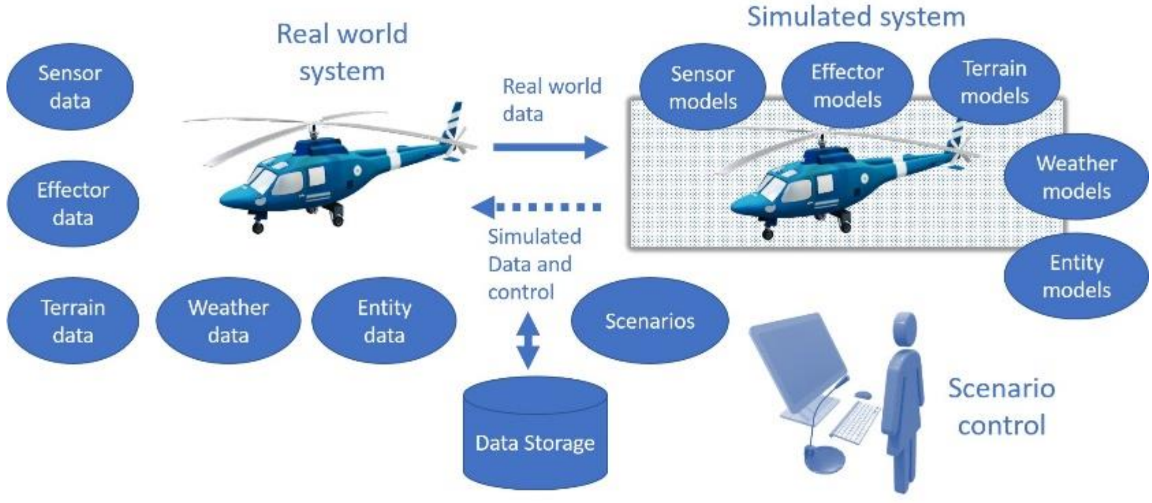

Figure 6 - Platform test range environmental Digital Twin

2 DIGITAL TWINS NEED TO BE INTEROPERABLE

While many of the case studies that can be seen through a quick search on the internet on Digital Twins provide an excellent range of use cases; from the example above, within the NATO context (and indeed even as nations operate independently), it’s important to restate that individual platforms such as ships, aircraft and armoured fighting vehicles and their separately procured sub-systems like missiles and radars do not operate on their own. They act in combination with each other as part of systems of systems approach within an increasingly interoperable Multi-Domain Integrated concept of operations [3] (Figure 7). This applies at early stages of the design concept all the way through test and evaluation to operation in-service and through to disposal.

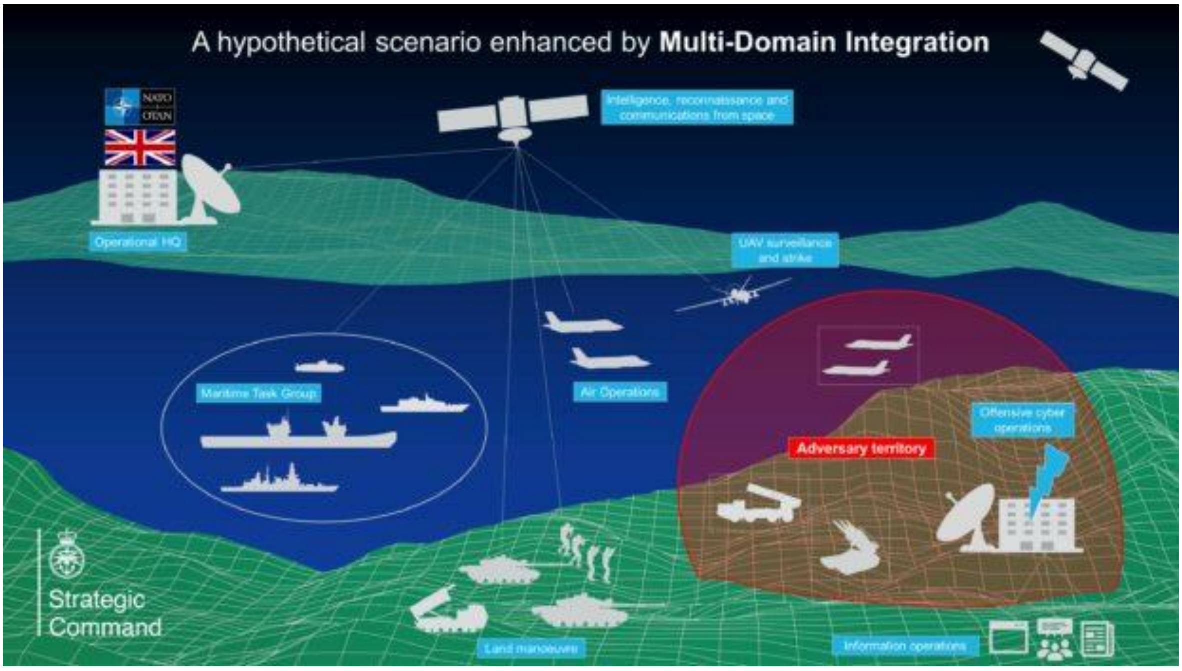

Figure 7 - UK MOD view of Multi-Domain Integration

For example the manufacturer of the missile may have a Digital Twin as well as the manufacturer of the aircraft that carries it. The performance of the missile may be affected by the carrying aircraft and vice versa. Testing the combined system in a virtual domain on a virtual range against simulated opponents rather than in a live environment would have significant cost and other operational benefits in development. This would need the Digital Twins to communicate with each other, so instead of the view of an integrated system already shown in Figure 6, an actual digital test range activity where different systems could be tested would consist of multiple connected Digital Twins (A range digital twin and platform digital twin) which would be exchanging data with each other. A simplified view of this is shown in Figure 8.

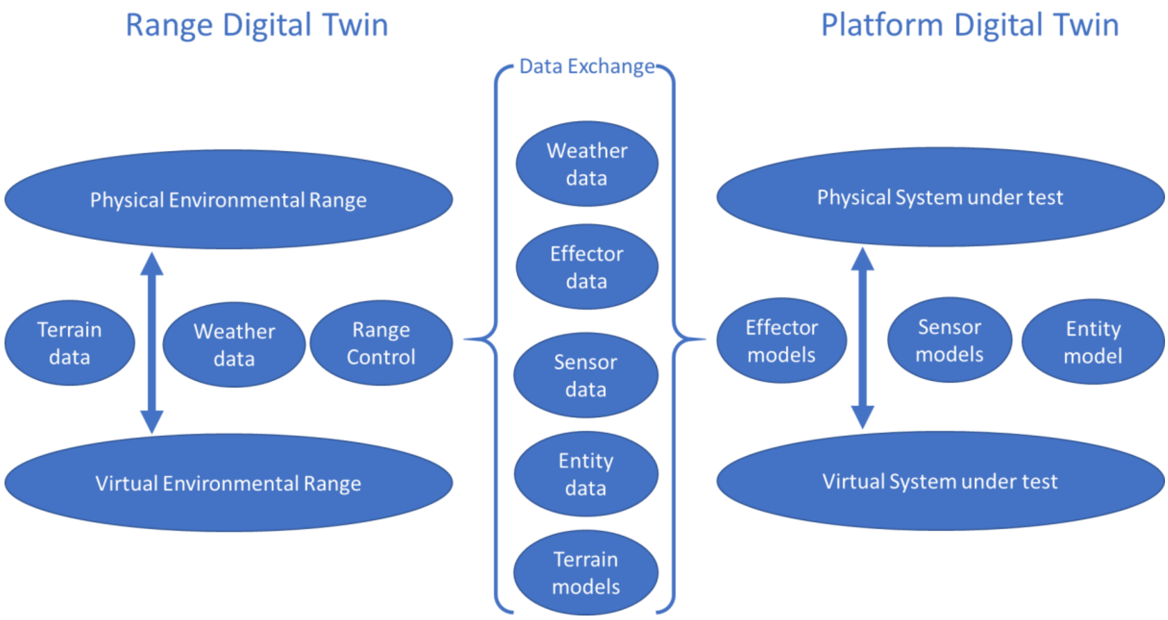

Figure 8 – Simplified Test Range / Platform Digital Twin connectivity

In addition being able to communicate the sensor data generated by the live systems when they are tested in the real world back into the Digital Twins is just as important.

A patchwork of equipment commonality within NATO and partner countries means that there will be a need to ensure that the Digital Twins and the data they produce and consume are interoperable.

The need for interoperability does not just exist in the military domain; there will also be a need to connect military systems to Digital Twins operating within critical national infrastructure (for example power and transportation) as well as more local contexts such as ‘Smart Cities’ and similar initiatives.

2.1 Issues which prevent Digital Twins being interoperable

2.1.1 Intellectual property and ownership

As Digital Twins contain the essence of the physical asset, they contain valuable information and intellectual property which is generally owned by the Original Equipment Manufacturer (OEM). In some cases the military customer might have some rights to the data or the design but often this access is limited, particularly if the item is commercially available in quantity.

While OEMs are generally more likely to share data with customers they are less likely to share with other OEMs particularly if they are competitors, especially if the virtual model is being supplied on computational resources that the supplying OEM does not control. This means that there is a barrier to share information and also the likelihood that proprietary or specific information formats might be used making sharing more difficult in any case.

One potential solution is to offer Digital Twins as a Service (you might call this DTaaS) – analogous to Modelling and Simulation as a Service (MSaaS), where the originating OEM provides access to the virtual model and data on a service basis using its own computational resources and data repositories via some sort of application interface or service which is paid for.

2.1.2 Dynamic nature of Digital Twins

Digital Twins are inherently dynamic. As the physical and virtual twins exchange data, the Digital Twin will change over time, depending on requirements. While the Digital Thread of data persists, the function of the Digital Twin may change entirely with the application moving from a purely virtual model used for conceptual phase testing operational models and activities, through to the development of a true Digital Twin with physical prototypes which are then evaluated and assessed in both virtual and physical space and onward into monitoring of parameters from volume quantities of deployed equipment for predictive maintenance and performance analysis.

This means that the underlying structure of a Digital Twin will change over time and thus issues like version control, performance verification and release status will need to be carefully managed when a Digital Twin is used.

2.1.3 Data standards and interoperability

A Digital Twin might through its lifetime produce a vast quantity of data including from sensors while in-service, from analysis and from evaluation and test. The data may be in many different formats and may also be unstructured and opaque in nature. While a coherent analysis of the data is important for decision making there is also a need to find formats for sharing valuable data and the accompanying metadata within the NATO context, in order to provide mutual reassurance and assistance for allies, particularly where there are common platforms in use.

Mechanisms to pool shared data, to allow it to be searched and accessed from repositories need to be developed to make the best use of Digital Twins in the allied context.

2.1.4 Security standards

Ensuring security issues are addressed is of course vital in all military operations and in the NATO context there is interest from adversaries in understanding operational concepts, platform performance and likely tactics. Maintaining the integrity in operation and security of the models in the virtual Twin is important, as well as ensuring the safety of the valuable data gathered in operation of the physical Twin. Different nations have different requirements and standards, and will only share data to a certain level of classification and within NATO there is a need to navigate these issues in order to maintain security but also to achieve useful results from shared data and models.

2.1.5 Fidelity and abstraction issues

Different fidelities of models will be needed for different applications. It might be necessary for multi-hour runs for the virtual model of an aircraft on high performance computing (HPC) clusters to evaluate its performance against wind tunnel data from a physical prototype or to evaluate its radar cross section.

Using the same aircraft model for deployment for operational evaluation in a multi-domain distributed environment may require multiple updates per second, obviously impossible unless the model is abstracted to something much simpler.

This issue is analogous to the familiar issue in using Levels of Detail in visualisation systems to ensure the image generator is not overloaded – and suffers from the same issues; ensuring the abstraction represents the model accurately enough to be useful, while requiring fewer computational resources. In addition it is important that models are consistent with a single source to ensure coherency for all the derivatives.

2.2 Alignment with existing research activities

The problems mentioned here will be familiar to some readers as they have much in common with issues in the planning and operation of distributed training exercises using simulators both internally in nations, and also in the allied context in NATO. Current and previous research task groups have examined the issues and are finding solutions to some of them.

For example Modelling and Simulation as a Service (Research Task group MSG-195, formerly MSG-164) is investigating technologies to allow models to be shared through catalogues and repositories and also to be able to access the information generated by models running on an 'on-demand' basis using remote services.

Within the NATO Science and Technology Organisation (STO) the Applied Vehicle Technology (AVT) panel is also working on Digital Twins in group AVT-369 'Digital Twin Technology Development and Application for Tri-Service Platforms and Systems'

The use of Artificial Intelligence and Machine Learning potentially might supply some answers to the issues around data analysis and model abstraction, permitting more automation and less manual intervention on traditionally highly manual and specialised activities. These topics are being discussed in various groups and specialist teams.

3 EXPLORATORY TEAM ACTIVITY

In December 2021, Exploratory Team 053 was set up to by NMSG examine the issues around the use of Digital Twins in the NATO context.

The team consisted of 9 NATO nations: Germany, Czech Republic, Norway, Italy, Netherlands, Spain, Turkey, United Kingdom and United States, along with partners Ukraine and Australia and NATO bodies Allied Command Transformation (ACT) and NATO Industrial Advisory Group (NIAG).

The team conducted 9 meetings between December 2021 and March 2022, with 32 members taking part to develop a Technical Activity Proposal (TAP) for a full research task group (RTG)

There were several presentations from nations about the work being conducted by them in the area of Digital Twins including diverse topics such as Digital Twins in the built environment and application for naval ship design and construction.

The group considered the following 4 key questions:

1. What is the definition of a Digital Twin that will be used in this group and others within and outside NMSG?

2. How can we effectively exchange information (such as mathematical models, simulations, equipment and environmental data) between Digital Twins operating in different nations?

3. How can we ensure coherency in analysis, storage and discovery of the large quantities of data ingested and generated by operating Digital Twins in the NATO context?

4. How can we ensure the security of information exchange and operation of a Digital Twin against adversarial penetration and attack against the distributed networks and diverse computing and

storage resources that host it?

The first question is crucial as defining what a Digital Twin is (and is not) is important to gain a common understanding across the Alliance.

The next two questions are most relevant to the discussion in this paper. The last question is more general around the area of security; which is common to other areas of Information Technology in the military context, although there are of course special considerations when connecting virtual systems, simulations and models to physical military assets.

3.1 Interoperability through Standards

The NATO approach to Interoperability is to encourage the development, promotion and use of standards across the Alliance.

The aim of using standards is to enhance the ability of NATO nations to work together seamlessly and rapidly in all aspects of military operations and planning.

The NATO modelling and simulation group (NMSG) has worked extensively with the Simulation Interoperability Standards Organisation (SISO) for many years under a Memorandum of Understanding, co-operating on development of simulation standards that may have application within Digital Twins such as:

- Distributed Interactive Simulation (DIS) IEEE-1278.1-2012; [4]
- Higher Level Architecture (HLA) - IEEE-1516-2010; [5]
- Command and Control Systems Simulation System Interoperation (C2SIM) – SISO-STD-019-2020; [6]

And including some standards in development such as:

- Discovery Metadata Specification for M&S Resources (DMS-MSR); [7]
- WebLVC protocol. [8]

In considering the use of Digital Twins in the NATO context it is important to ensure that all relevant standards which promote interoperability are considered and reused where possible rather than generating new standards which partially or completely duplicate existing work and do not provide any extra benefit. Traditionally the NMSG has looked at the use case of modelling and simulation for training as a primary focus of its work. The horizons of the group have been expanded by this exploratory team activity to consider much wider use of modelling and simulation including Digital Twins.

This work will require a wider focus of work including engagement with other standardisation bodies that have activities relevant to Digital Twins that have promulgated standards for the exchange of data and models for manufacturing, internet sensors and the built environment, some examples being:

- ISO IEC 10303 -242/2020 – provides interchange standards (e.g. STEP) for Computer Aided Design, Engineering and Manufacturing; [9]
- ISO IEC 12006-2 and -3 – Standardisation of the organisation of information for construction works; [10]
- Data Distribution Service (DDS) – from the Object Management Group, for data connectivity for Internet of Things (IOT) devices. [11]

4 MSG-205 RESEARCH TASK GROUP ACTIVITY

At the time of writing this paper, MSG-205, a 3 year Research Task Group (RTG) has been approved, but has not yet started. Led by the UK and Italy, it has several additional nations joining the effort.

Subject to agreement on the Programme of Work the group will work on a variety of topics including:

1. Defining what a Digital Twin is for NATO activities providing terminology into the NATO terminology database; ideally reusing an existing definition rather than creating something new;

2. Examining the problems and issues in interoperability terms of using Digital Twins in the NATO context identifying technological and standardisation gaps;

3. Assessing the various existing simulation standards for constructing and operating Digital Twins, examine if existing standards from a variety of standardization organisations can fill these gaps and if not what developments (technology, standards) might be needed;

4. Assessing existing government, NATO and commercially available products and services for Digital Twins to help develop solutions for the gaps;

5. Based on these investigations, develop experimental potential solutions and a multi-national technical concept demonstrator;

6. Assessing current NATO regulations that may affect Digital Twins, generating a set of guidelines / best practices for implementing a Digital Twin in the NATO context: and work with NATO bodies, standards and other organizations to refine and promulgate the guidelines / best practices;

7. Working with appropriate NATO stakeholders and end-users, produce a final report describing the work of the team, achievements and set of recommendations.

5 CONCLUSIONS

The need for modelling and simulation for applications other than training is becoming more relevant with the increasing requirement for a simulation based approach to concept development, design, development, manufacture, test and evaluation and in-service support for military platforms.

Digital Twins form part of the infrastructure and capability of this new approach, allowing the real world asset, system or process to be effectively modelling throughout its lifetime. Digital Twins can create value in terms of better and more reliable platforms, reduced environmental impact through-life and more effective application in the Multi-Domain Integration operating space.

However for maximum benefit for the NATO alliance, interoperability of data and models used in Digital Twins is crucial if they are to be connected together in a ‘systems of systems’ approach. If this is not achieved, then the benefits will be limited to small isolated systems with traditional issues around connectivity and reuse.

The issues do not just involve purely technical interoperability concerns; it is important to note that business practices and processes also need to be reviewed to ensure that existing procedures for creating distributed simulations in the Alliance context that are unsuited for rapid and flexible adaptation are updated. In addition enabling capabilities such as network infrastructure and computational resources need to be addressed.

The experts within Research Task Group 205 have a challenging task to find solutions to the issues raised in this paper, however the group can rely on the efforts of previous NATO task groups and international standards bodies which have developed robust standards for M&S based training systems as well as working with other groups that are committed to developing standards.

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