Working on the Problem of Digital Twin Interoperability

Simon G. Skinner BSc. (Hons), CEng., FIET
Thales UK
Manor Royal, Crawley, W. Sussex RH10 9HA
UNITED KINGDOM

simon.skinner@uk.thalesgroup.com

Iván Pena Regueiro MEng., UPM
Navantia Spain
Calle Taxonera S/N 15403, Ferrol
SPAIN

ipenar@navantia.es

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.

The paper provides information on the MSG-205 Research task group along with one specific use case generated by the team. We are presenting from within the group to stimulate cross-panel discussion and increase co-operation between NATO Science and Technology Organisation's Applied Vehicle Technologies (AVT) panel and the Modelling and Simulation Group (MSG).

1.0 INTRODUCTION

The term 'Digital Twin' is becoming embedded into our culture, not just in technical system engineering terminology but even mentioned in mainstream 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. 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.

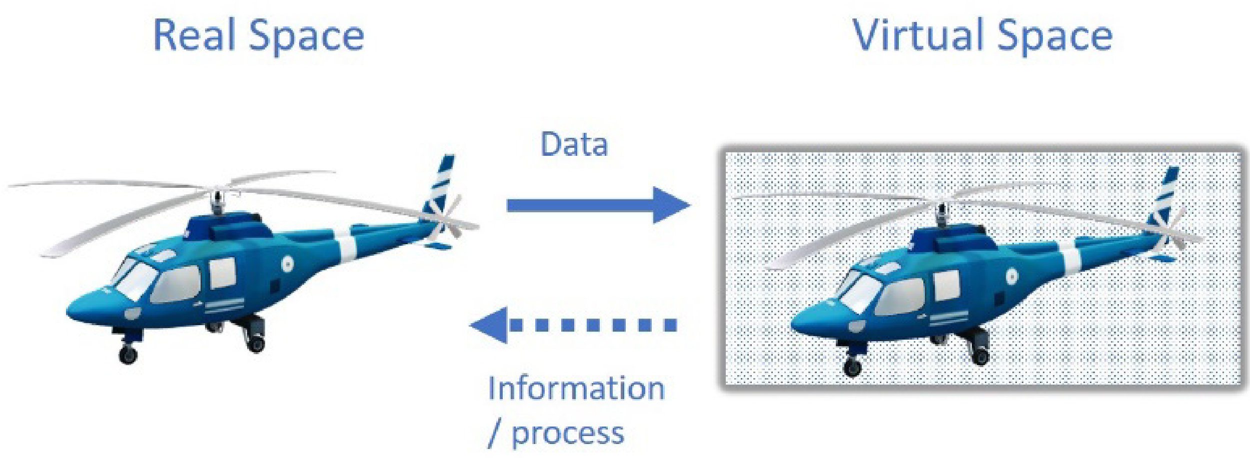

Figure 2: Digital twin concept.

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, and we will deep dive into this area in the Use Case in Chapter 4.

2.0 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. Within the NATO context (and indeed even as nations operate independently), it is 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 3). This applies at early stages of the design concept all the way through test and evaluation to operation in-service and through to disposal.

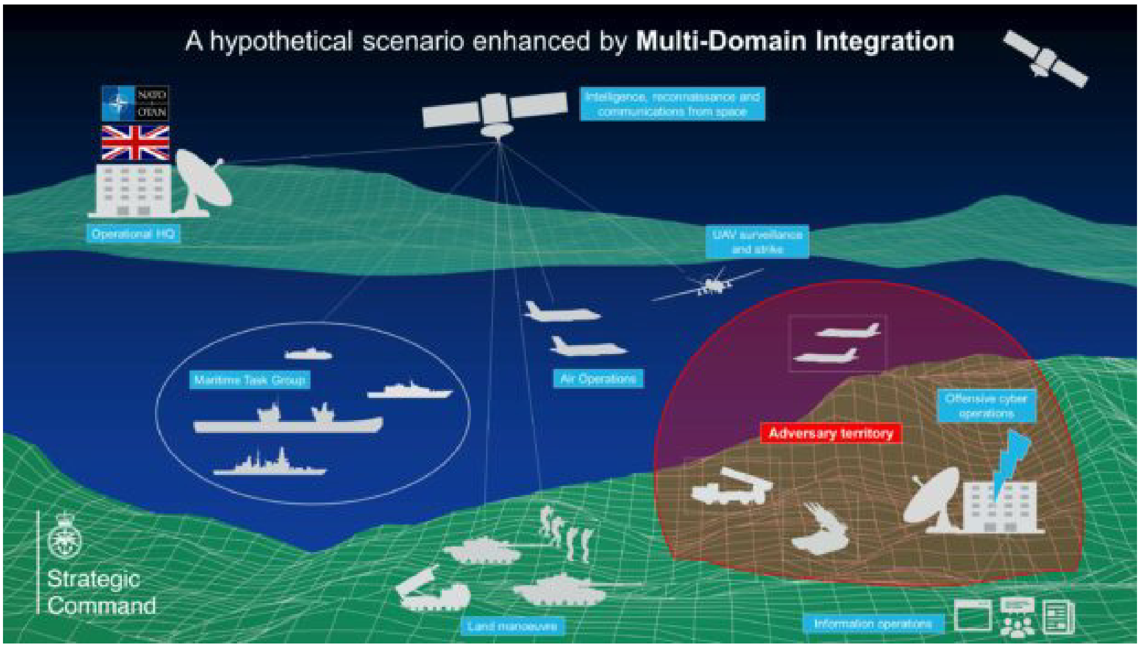

Figure 3: UK MOD view of multi-domain integration.

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 the virtual domain on a synthetic 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 a 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 4.

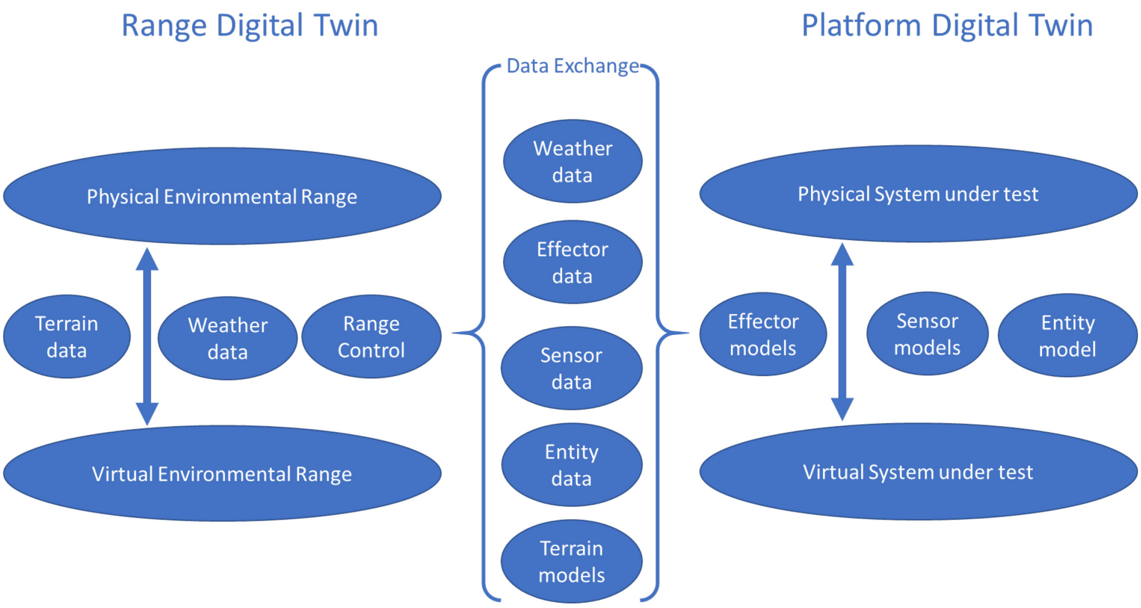

Figure 4: Simplified test range / platform digital twin connectivity.

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). This concept is 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 that 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 and the evolution of the physical counterpart. 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. These prototypes are then evaluated and assessed in both virtual and physical space. Data gathered can be used in monitoring of parameters such as volume quantities of deployed equipment for specific use cases, such as predictive maintenance, assistance to operations and missions, or 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, for instance 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, not feasible with current computing capabilities unless the model is abstracted to something much simpler.

This issue is analogous to the familiar challenge 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 coherencies for all the derivatives.

2.2 Alignment with Existing Research Activities

The problems mentioned here would 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.

3.0 MSG-205 RESEARCH TASK GROUP ACTIVITY

MSG-205, a 3-year Research Task Group (RTG) started in October 2022. Led by the UK and Italy, it has several additional nations joining the effort; Germany, France, Italy, Netherlands, Spain, Turkey, United Kingdom and United States, along with Allied Command Transformation (ACT).

The group are working 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.

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]; and
- Data Distribution Service (DDS) – from the Object Management Group, for data connectivity for Internet of Things (IOT) devices [11].

The team also plans to engage with the Digital Twin Consortium, a special interest group within the Object Management Group (OMG) as part of its activities.

4.0 USE CASE DESCRIPTION – NAVANTIA

Navantia (Spain) are implementing Digital Twins to improve the operation, aid in the maintenance and lifecycle support of frigates and offshore patrol vessels supplied to the Spanish Navy.

The Digital Twin onboard applications focuses on four areas, with the common goal of anticipating to the future, or to what is going to occur in the Physical Twin:

- Maintenance, having all the information available makes this the first step to be integrated in a Digital Twin;
- Training, similarly, having the detailed 3D model as well as how it is supposed to behave, through the functional models, enhances the current training services for the crew;
- And also, where the key potential of Digital Twins is, in Navantia's view, in supporting operations, where competitive advantages arise; and
- And also, due to its dynamic nature, Digital twin shall be updated along the Lifecycle, and therefore it needs to be sustained, in order to keep up with the situation of its physical counterpart.

Additionally, another key differentiator with other systems, is the fact that the DT may be connected with ashore. This allows to exploit its functionalities from these premises, and even having specific applications geared towards being used from land.

One specific example of a use case in supporting operations, is the crew fatigue detection. Fatigue is defined by the International Maritime Organization as 'A state of physical and/or mental impairment resulting from factors such as inadequate sleep, extended wakefulness, work/rest requirements out of sync with circadian rhythms and physical, mental or emotional exertion that can impair alertness and the ability to safely operate a ship or perform safety-related duties' [12].

Therefore, the ultimate objective of this use case to improve the quality of life for the crew onboard. This is achieved by gathering data from traditional systems onboard, in this case developed by Navantia, but also from those owned by the Navy, and by introducing the use of wearables. This is complemented with the self-reporting of individual or collective status, and alongside with the health data monitoring, allows for notifications when thresholds are exceeded.

Figure 5: Navantia's vision of digital twin.

This use case is supported by developing specific functional models to simulate and predict the mental and physical fatigue, and hence why this is a use case labelled as Digital Twin. The Digital Twin is not only a series of separate use cases, but they are interrelated, and synergies arise. In this particular case the conclusions from the crew fatigue detection may be used for the enlistment assessment for a specific mission.

As usually recommended in the Digital Twin development [13], an agile approach has been followed for this use case. An experiment was conducted in an existing ship from the Spanish Navy, with 45 crew members with different duties participating for 2 months. In the following figure there are snapshots from the first App iteration, where the crew was required to provide the self-reporting (left side) and the guidelines for the crew to consult and review in case of doubt (right side).

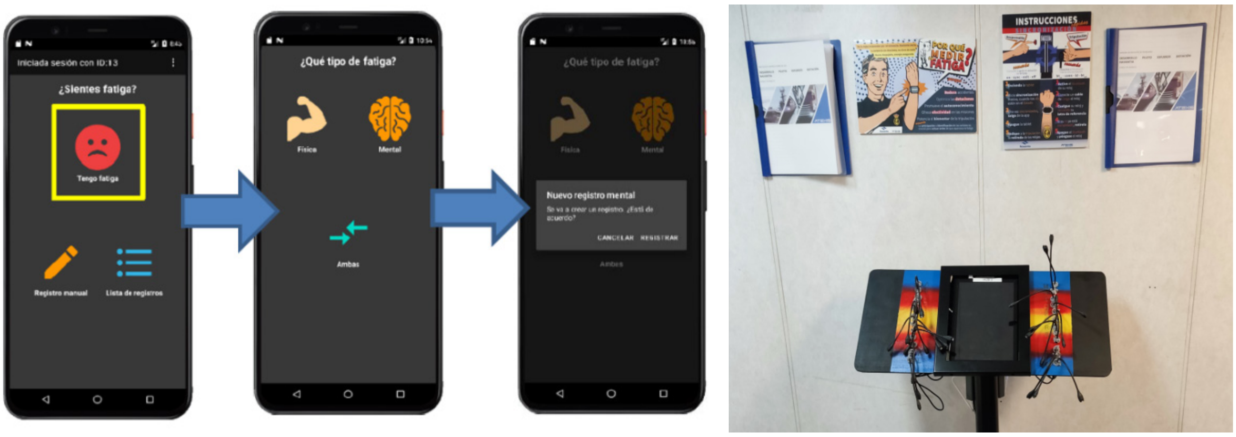

Figure 6: HMI for an Minimum Viable Product (MVP) developed for this experiment and synchronization hub and guidelines for the crew.

Needless to say, HMI for the end product and data gathering is significantly different and based on the latest technologies, but the focus in this experiment was on developing a functional model, as well as obtaining lessons learned and insights from the stakeholders. Significant improvements and refinements have been implemented in the end product/Digital Twin use case. Some of these findings were:

- Identification of the most relevant parameters to be inputted in the functional models;
- Evaluation and identification of the most promising algorithms to use for training the model;
- Decision to have separate models for predicting physical and mental fatigue;
- Move from qualitative to quantitative self-reporting;
- Include non-intrusive reminders for the self-reporting as well as corroboration when the prediction detects an event; and
- Importance on dealing with GDPR aspects from the early stages.

This experiment has enabled this use case to be in the forefront of the development phase for the Spanish Frigate Digital Twin Program, and to showcase the possibilities the DT brings to the Navies. In particular this use case will promote self-awareness, increasing and visualizing the quality of life onboard and allowing for a decrease in incidents.

5.0 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 are updated, that are unsuited for rapid and flexible adaptation. 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. The group can, however, 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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