Simulation model abstraction issues for Digital Twins; Separated at Birth?

Simon Skinner BSc (Hons). CEng. FIET
Thales Training & Simulation
Crawley, W. Sussex, UK
Simon.skinner@uk.thalesgroup.com

ABSTRACT

Digital Twins are seen as a potential solution for many difficult problems in developing military platforms; by keeping a physical asset and a simulated virtual twin in constant communication with each other, they offer the potential to improve operational performance and reduce the cost of development, test and evaluation, production, maintenance, training and support of complicated 'systems of systems'. They have the added benefit of providing flexibility in today's rapidly evolving threat environment.

In the development of Digital Twins, the requirement to have validated and verified models of components that accurately reflect real world physical assets and processes, as well as the aggregated systems containing them is key to their use. Despite massive advancements in compute power, it nevertheless is not possible to represent everything at the highest level of fidelity for many applications, and the alternative of having different unrelated models poses significant problems as well.

This separation of models 'at birth', poses a threat to the implementation of viable, interconnected Digital Twins, due to cost and configuration issues, particularly in the military context. The sharing of computer models, simulations and physical platforms with Allies and with Multi-Domain Integration across Land, Air, Sea and Space is increasingly important to sustain a global force able to flexibly adapt to changing situations.

In the context of a collaborative research task undertaken by the NATO Modelling and Simulation Group, this paper analyses the lessons of the past as they apply to model abstraction, with an analysis of potential solutions, including the use of Artificial Intelligence techniques and service delivery models. This work will enhance the development of interconnected, interoperable and useful Digital Twins for the military end user.

ABOUT THE AUTHOR

Simon Skinner *Simon Skinner has 30 years' experience in the simulation industry in various roles from Hardware and Software Engineering through to Executive Management and is currently the Product Policy Leader for the worldwide Thales Training & Simulation business. Simon is a Chartered Engineer and Fellow of the UK Institution of Engineering Technology. He is appointed by the UK Ministry of Defence as a national member of the NATO modelling and simulation group (NMSG), and is co-chair of the NMSG research task group MSG-205 on Digital Twins.*

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INTRODUCTION

Definition of Digital Twin

The term 'Digital Twin' is becoming embedded into our culture, not just in technical system engineering terminology but even mentioned in main stream media (British Broadcasting Corporation, 2022), where the application of AI technology to a Digital Twin of a human being is popularized.

However, what is a Digital Twin? There are many definitions of a Digital Twin, and it is easy to confuse the use of modelling and simulation (M&S) with that of a Digital Twin. Digital Twin technology, in the view of many commentators, resembles the simulations that M&S practitioners have created for a very long time; however, there are in fact significant differences.

A current authoritative but short definition for Digital Twin developed over several years is this one:

'***A Digital Twin is a virtual representation of a connected physical asset'*** (American Institute of Aeronautics and Astronautics (AIAA), 2020)

The key word 'connected' indicates a regular exchange of data and a feedback loop between the model and physical asset. Figure 1 gives a pictorial representation 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 decision making – this might affect operations like the flight envelope or weapon loads.

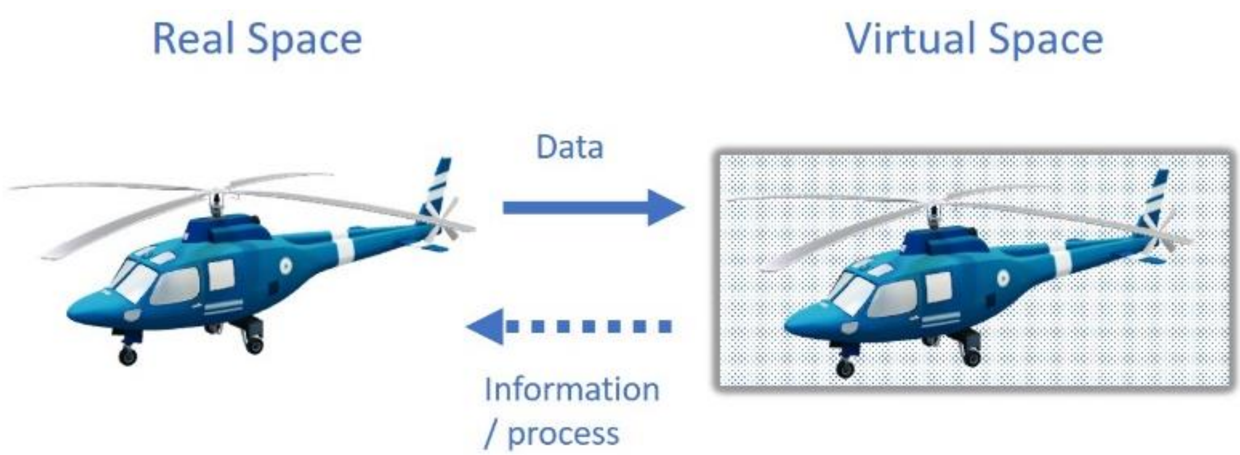

Figure 1 - Digital Twin Concept

Many also argue that a Digital Twin can also represent a real world process or capability rather than just a physical asset. The key point for this paper is that there is an exchange of data between the real world space and the model computational space that leads to the update of the model on a regular basis – i.e. the model has a dynamic state rather than being a static entity that does not change.

Typical Concept of use

Typical use cases for Digital Twins in the military environment center on platform design and implementation, where a platform might be a ship, airplane, ground or space vehicle. Digital Twins offer the opportunity to improve the operational performance of platforms, speed their design, reduce the cost of maintenance and more easily certify their operation as well as provide earlier opportunities for effective training of human operators.

During the lifetime of a platform generated using digital engineering techniques, there is a need for consistent data to be generated and used – the so-called *Digital Thread* running from design to disposal. (Figure 2) The refinement of the initial model through the concept and assessment phase ensures the physical platform is closer to operational needs, with the data gathered in early trials and demonstration reducing the costs of manufacture and support.

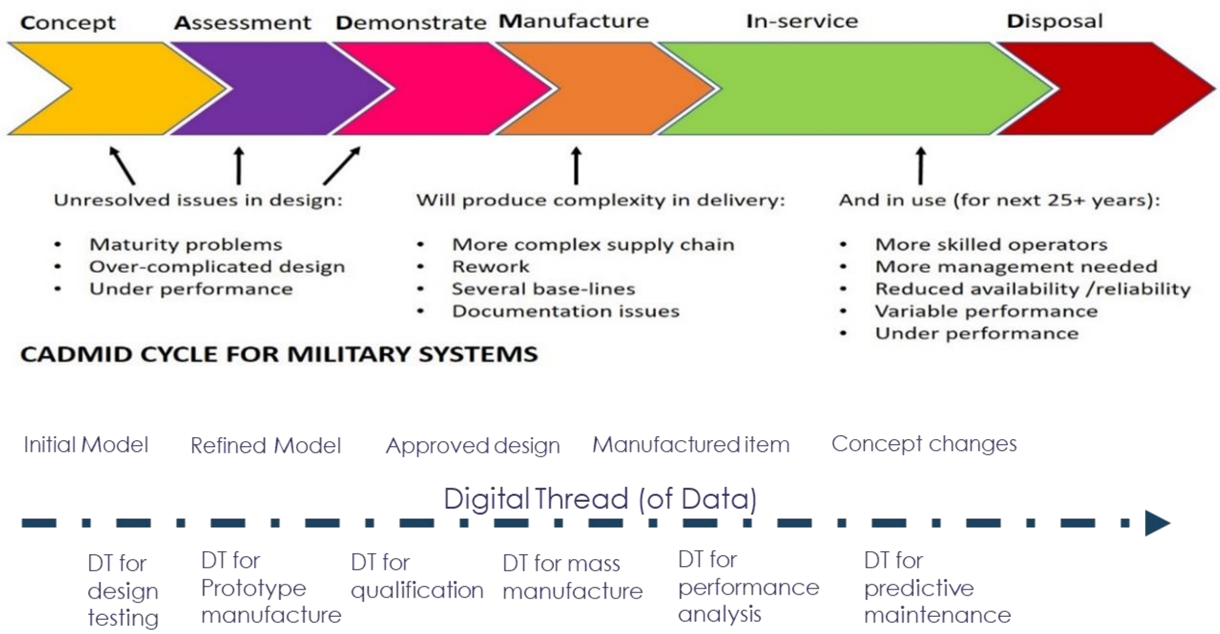

Figure 2 - Military Systems CADMID lifecycle model (UK Ministry of Defence, 2023) and associated Digital Thread

DIGITAL TWIN INTEROPERABILITY

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 a 'Systems of Systems' approach within an increasingly interoperable Multi-Domain Integrated concept of operations (UK Ministry of Defence, 2021) - 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. For example, the manufacturer of a missile may use a Digital Twin for its development, as well as the different manufacturer of the aircraft that carries it. The carrying aircraft can affect performance

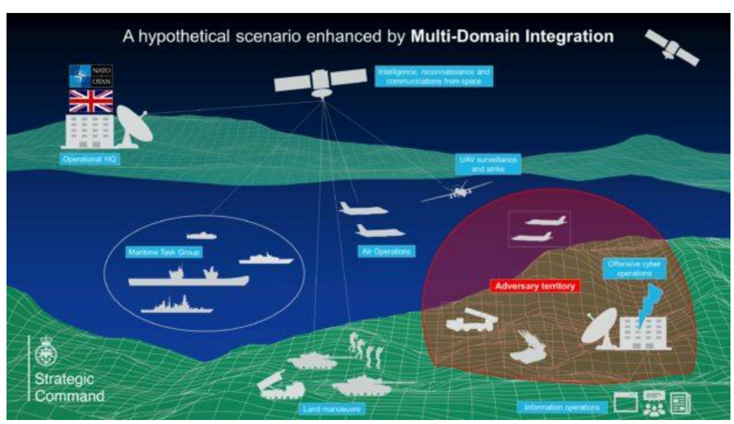

Figure 3 – UK MOD Multi Domain Integration Concept

of the missile 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 require the Digital Twins to be able to communicate with each other in some way and to share data with each other. A patchwork of equipment commonality within NATO and partner countries means that *there is a need to ensure that the Digital Twins, the models and the data they produce and consume are interoperable. Digital Twins will not operate in isolation for many applications.*

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. A number of issues hamper the achievement of interoperability:

Business / Intellectual Property (IP) issues

As Digital Twins contain the essence of the physical asset, the Original Equipment Manufacturer (OEM) generally owns the valuable information and intellectual property associated with that asset. In some cases a military customer or end user 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, and especially if the virtual model is required to execute on computational resources that the supplying OEM does not control. This means that there is a barrier to share information, and the likelihood that proprietary or specific information formats might be used, making sharing more difficult in any case.

Security issues

Ensuring security issues are addressed is of course vital in all military operations, and 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.

Data format issues

A Digital Twin might produce through its lifetime 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 be unstructured and opaque in nature. 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 a multi-domain and multi-national context.

The main topic for this paper is the Abstraction of Digital Twin models, so the related issue of Data exchange formats, categorisation and storage, while important, will not be detailed further.

SIMULATION MODEL CONCEPTS AND ISSUES

Simulation model generation process

Generating models for simulation applications is a mature science with a large variety of tool vendors for many different types of models; common tools in use include MATLAB®, Flexsim amongst many others. (Wikipedia, 2023)

One of the key concepts is that models need to be accurate enough for the purpose they need to perform within a simulation. For example, a model of an aircraft required to ensure that is it structurally correct and have a correct response to simulated airflow requires a much higher level of accuracy and complexity than the 3D visual model that is needed merely for visual representation and recognition.

Simulations often use Computational Fluid Dynamics techniques to test out the highly complex designs developed for aerospace applications. These are very complicated simulations using very precise models, require a vast amount of computational resources to run, and do not generally provide results in real-time (defined here as a fraction of a second). Conversely simulations for training which use an aircraft model (e.g. as a computer generated force) are however required to produce results in 'real-time' both to allow recognition of the aircraft shape and for it to follow a realistic flight path; generally this is achieved by having a different, more approximate, model.

Validation and Verification concerns

Validation and Verification (V&V) of the models used in simulations is of paramount importance. Validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model. Verification is the process of determining that a model implementation accurately represents the developer's conceptual description of the model and its solution. (Los Alamos National Laboratory, 2004)

There is a fundamental need to ensure that *models are as correct as they need to be for the application they are used for* – in order to avoid errors propagating through the lifetime of the platform and its accompanying digital thread.

Single Source of Truth

In order to reduce the problems that occur with having a range of models of a system of different fidelities and uses, the concept of a Single Source of Truth is used to meet the model consistency challenge; with all of the different models of a system required for different applications deriving from a single base model. (Zhang, 2023). This derivation of other models – particularly where a simpler model is generated, is termed Model Abstraction.

Model Abstraction

Abstraction is not a new topic within modelling and simulation. Many within the training simulator community will have come across the issue in graphics where a simple representation of a 3D object is shown when the object is far away with a more complex model shown when the 3D object is closer to the viewer (Figure 4). Called 'level of detail' control, it is implemented to ensure 3D rendering systems maintain a real-time performance.

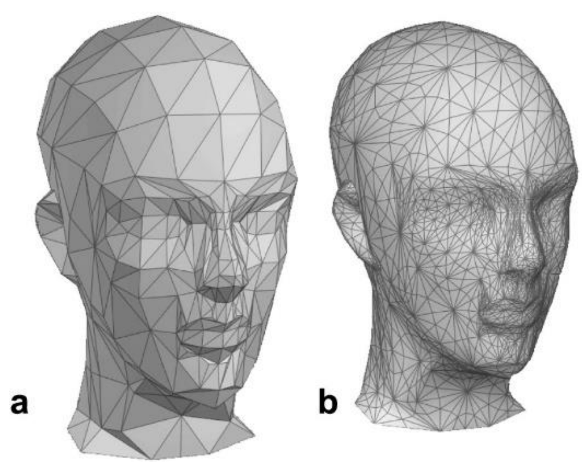

Figure 4 - Abstraction of a 3D graphical model - simple (a) from complex (b)

Various techniques have been promulgated for the last 30 years in the field of modelling and simulation for the abstraction of simple models from more complex ones; for example, a taxonomy was proposed by (Frantz, 1995), a method of suppressing features was proposed by (Russ, 2011) and (Lidberg, 2021) published a survey of simplification methods.

Context of use of abstracted models

Automated or partially automated abstraction has the advantage of speed over manual methods; however, manual methods have continued to be used to ensure that key features are not lost in a particular context. Taking a 3D model for a training simulation as an example; for the purposes of recognition of military vehicles, the position and number of antennae on a vehicle can be key discriminators of the vehicle sub-type, identifying a command and control variant. However, automated polygon reduction tools have often incorrectly removed these antennae, as they are small features that do not affect the apparent shape of the vehicle.

Similarly, for any model, it is necessary to consider the context of use for an abstracted version; the detailed interior structure of an aircraft cabin may not be needed for airflow calculations, but would be needed for modelling evacuation procedures. Thus, manual intervention has proven necessary in many cases.

Abstracted models and data exchange formats

Models might be used in systems other than the one that the original model was generated. In this case, issues with the exchange format in use could mean a reduction of precision, the loss of information or the introduction of errors. Clearly it makes sense to use standardized data exchange formats that preserve as much of the original information as possible.

Security and IP concerns

Simulation models generally will contain design information and intellectual property about the system that is being simulated. As such, the originating organization will seek to maintain control through licensing or another mechanism. This would also apply to abstractions of the model and depending on how it was controlled; the intellectual property ownership chain might get difficult to manage. Restrictions might also apply to the use of the model for other purposes than its original design intent.

Similarly, security concerns around models may affect the way in which abstraction of models is performed, potentially involving the need for manual abstraction to let it be released at a lower classification, along with a lengthy manual accreditation process. Clearly, this is more likely in the context of multi-national operations but it would also apply for military multi-domain operations in a single country where the classification of air assets are generally at a higher level than land based assets.

APPLICATION OF ABSTRACTION TO DIGITAL TWIN MODELS

The issues described above are certainly not unknown to the modelling and simulation community, and some of the ramifications of the problems are often expressed as 'ensuring a fair fight' and 'avoiding negative training'. Over time efforts to produce recommended practices for the development and handling of distributed simulations has resulted in the standardization of the Distributed Simulation Engineering and Execution Process (DSEEP) as an IEEE standard (IEEE, 2022) - Figure 5.

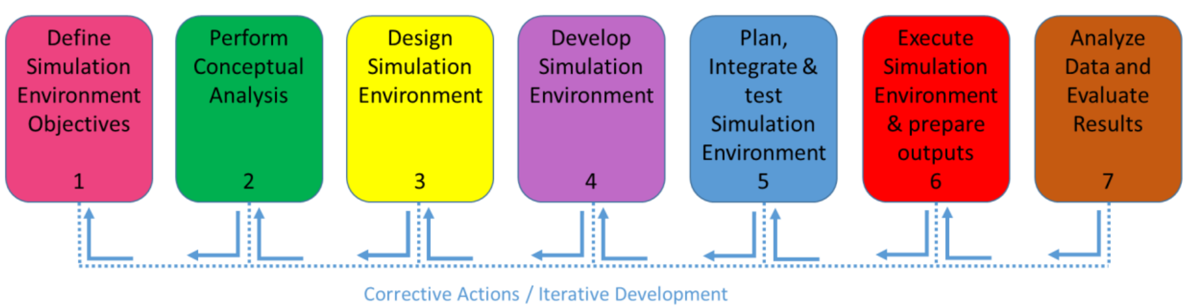

Figure 5 – IEEE 1730 - DSEEP process model

Digital Twins however have certain characteristics that make problems a lot worse for their use in interconnected and interoperable situations:

Digital Twin models are inherently dynamic

Unlike a model that is developed for a particular use case, with design, validation, implementation, verification and application performed once, Digital Twin models will change according to feedback from the associated physical entity, on a regular basis. This dynamic behavior means that manual abstraction and any other manual processes are inherently inefficient, slow and costly.

OEM control of models are necessarily tighter

OEMs are naturally likely to have more control over the 'single source of truth' of models, where the model is regularly updated from data gathered from physical entities. This information might come from prototypes or later in the lifetime from in-the-field usage and maintenance data. Unlike many training simulators, where an emulated lower fidelity model is acceptable for training or where there is a single payment for an OEM data pack, the use of models for concept development and experimentation or decision support will require regular updates with a different licensing and usage model, potentially on a subscription basis.

Models require more computational resource

Using the approach of a Single Source of Truth, models of physical assets are likely to be more complete representations of a physical entity, and so will be more complex and require higher computational and storage resources to achieve a particular update rate. Abstraction of simpler models may be harder and take longer, particularly if manual processing is required.

Model verification and versioning will be more complex

With regular updates to models from data gathered from a physical asset, the issue of ensuring that all abstractions and uses of any model are up to date will be considerably more difficult. Verification of abstractions will be an ongoing process rather than a one-off event, meaning that automated tests will be required for efficient usage.

Therefore, Abstraction will not be a one-time process – but will need to be repeated regularly. There needs to be a solution for abstraction issues when running interoperable Digital Twins.

POTENTIAL SOLUTIONS FOR ABSTRACTION ISSUES

Several alternatives are proposed to solve issues in the abstraction of Digital Twin models:

1) Do nothing – 'separation at birth'

This approach is to accept the inaccuracy that is inherent in all models, and to perform abstraction on a one-off or very irregular basis – or just use an emulation of the model generated independently rather than being abstracted. If the application requirements do not rely on a very accurate model, then updates to the base model may not need reflecting in any abstraction. This approach has the advantage that it will require fewer resources, with the tradeoff being that the results of using an inaccurate model for any application might not be predictable in advance.

2) Use manual abstraction

With this approach, whenever the base model changes, then the abstraction process is undertaken again, with appropriate verification of the result. This might be required in any case, should security issues mean that a manual accreditation is required.

The advantage is that the abstracted model or models match the base model and are verified for the end application, but the disadvantage is obviously that of needing extra resources, along with the time it takes to generate the new abstractions. There is also the question of finding resources for abstraction effort; are they the responsibility of the model producer or consumer?

3) Use conventional automatic abstraction and model verification test suites

Various automatic abstraction and verification test suites and tooling have been developed for engineering applications, and these might be used to produce and test the different models required.

The advantage of this approach is that once the automation tools are properly set up, the process is repeatable, does not take an undue amount of time, and reduces the likelihood of errors, producing a higher level of reliability and repeatability.

Disadvantages include the inflexibility of conventional programmatic abstraction, should the base model change substantially, and fall outside the programmed parameters producing an incorrect result, and the cost and setup time required for the automated tools and generation of test suites.

4) Government ownership of models / Model repository with central updates.

Governments in various NATO nations have decided that they wish to own or have effective control over data sources, and derived models and simulations generated and used for military purposes, for distributed training systems and for other M&S purposes and applications. An example of this approach is the Defence Simulation Centre (DSC) in the UK along with the governance provided by the Defence M&S Office (DMSO). The goal of centralization is to provide better ‘value for money across the enterprise’, ‘commonality and re-use of data, models and platforms’ ensuring ‘consistent, enduring, accessible, agile and adaptable modelling and simulation solutions’. (UK Ministry of Defence, 2022)

Updates to approved models can then be made centrally once, then verified and distributed to various different users. This approach has several advantages in terms of consistency and model reuse, but is untested against the frequency of updates that models used in Digital Twins might generate.

5) Automatic abstraction (single source of truth) – Artificial Intelligence (AI) techniques

While not subscribing to the view that AI and Machine Learning (ML) technology can be used for every problem, automatic abstraction of models is one area where there is potential for development using AI technology. Evidence of the use of ML to provide model abstraction comes from CERN where the speed of simulation of the results from particle accelerator collisions requires enormous and ever-growing computational resource, and where ML has provided an abstraction that has speeded up simulations by factors of 20 to 100. (Bandieramonte, 2018)

Generative Adversarial Networks (GAN) have been used for the generation of ‘deep-fake’ content where gaps in information content are filled in using data (Long, 2022), and this technology could be applied within the simulation space to provide a more effective automatic abstraction. Data from verification testing can be provided to the the AI abstraction engine to ensure the abstracted model parameters track the destination use case – especially useful when there are rapid updates of the source model.

6) Modelling and Simulation as a Service / Digital Twin as a Service (DTaaS)

The technical issues about model abstraction are of course not the only concern. The protection of data and intellectual property are also important. Different OEM vendors will use different tools and computational platforms internally, and will have concerns about sharing the details of a model to allow external model abstraction – while this may be possible for a government customer, sharing with a competitor would be more problematic. However if the abstraction is under control of the vendor, they can provide different flavors of models via a common interface.

The Modelling and Simulation as a Service paradigm has been frequently mentioned as a solution to assist in the development of distributed simulations. (NATO Modelling and Simulation Group, 2023), with work being carried out looking at the business challenges as well as the technical aspects (Skinner, Stuart, Ford, & Lloyd, 2018).

Taking this service based approach as a model, the concept of Digital Twins as a Service (DTaaS) offers some promise to help resolve the issues around data and model ownership and control.

Figure 6 shows an example of an implementation for Concept Development and Experimentation (CD&E), where two different Digital Twins from different vendor OEMs are combined for testing and experimentation purposes. In this case, the simulation models exist within the vendors' IT infrastructure and the experimentation co-ordination calls on information needed for the experiment. The vendors maintain control over any model abstraction. They also provide any necessary data gathered from the physical entity prototypes under their control, which may be being updated frequently because of development and testing. The CD&E facility provides the necessary additional components in the aggregated simulation such as test scenarios, terrain and weather models, and other entities to populate the simulation. The CD&E facility maintains control over these aspects.

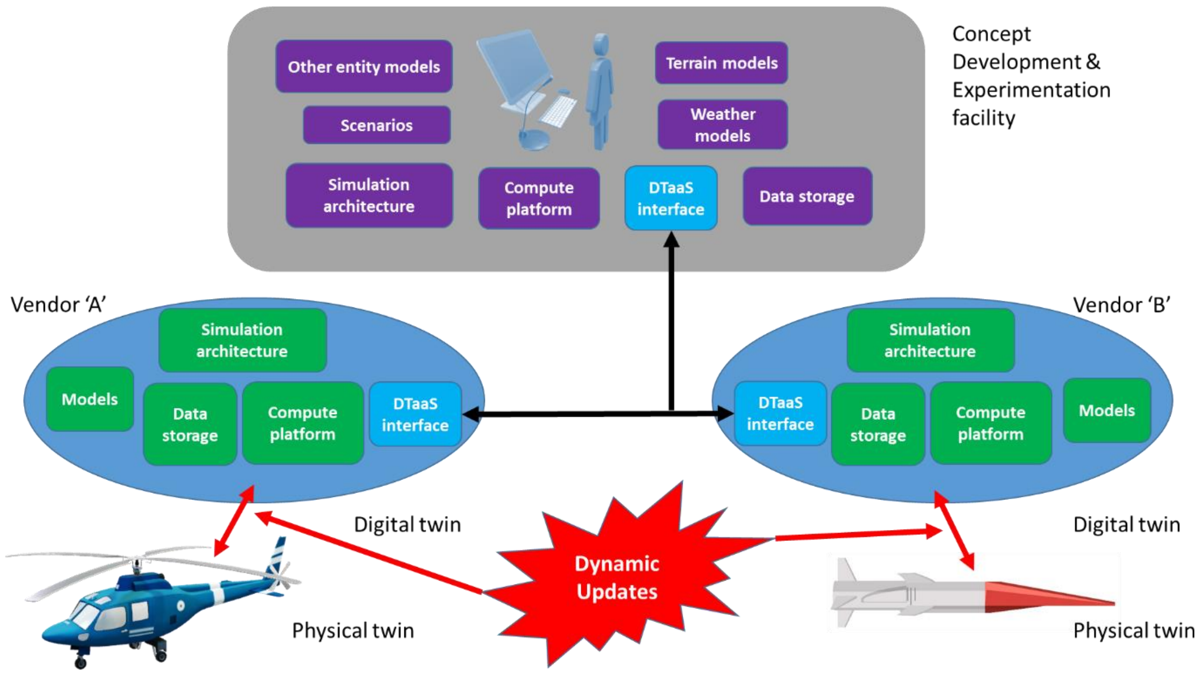

Figure 6 - DTaaS implementation for Concept Development and Experimentation (CD&E)

Summary of Potential Solutions

A combination of these techniques may be employed to solve the abstraction issues, and it will depend on application which will be the most effective. However to maintain the benefit of Digital Twins in an interoperable environment it is likely that the technical maturity of automatic model abstraction and the implementation of DTaaS will need to be increased over time.

NATO Research Task Group activity

Started in late 2022, a NATO Modelling and Simulation Group (NMSG) research team from 9 nations and organizations entitled **'Allied Interoperability and Standardization Initiatives for Digital Twins'** has been working on a variety of topics including:

- Defining what a Digital Twin is for NATO activities
- Examining the problems and issues in interoperability

- Assessing the various existing simulation standards for constructing and operating Digital Twins and gaps
- Develop solutions for gaps using NATO and commercially available products and services
- Develop experimental potential solutions and a multi-national technical concept demonstrator;
- Generating a set of guidelines / best practices for Digital Twin implementation

The aim of the group is to make progress on the difficult problems surrounding the implementation of interoperable Digital Twins and address issues raised in model abstraction, as well as other problems preventing uptake within the Alliance and within individual NATO nations.

CONCLUSIONS

The need for, and process of, model abstraction is well understood in the modelling and simulation community, along with the need to ensure V&V of the base and abstracted models for accurate simulations. Manual and automatic techniques for abstraction have been often employed to achieve this goal.

The advent of Digital Twins means that the base simulation models are not generated just once purely for training or analysis purposes, as has previously been the case, but are both **dynamic** and **much more complex** as they are being used for the development and test of complex physical systems. This means the need for abstraction is greater; and that abstraction, as well as V&V must be performed on a more regular basis.

In addition, as most physical military platforms are developed by industry, the concerns about the ownership of data and simulation models used for development by OEMs becomes more pressing, as do issues around security of the models given the potential for their use by adversaries.

Manual abstraction will become increasingly more expensive and slow as the degree of abstraction gets greater, leading to the potential divergence of models used in different applications, and the potential proliferation of uncontrolled and inaccurate models. This will restrict the applicability of Digital Twin technology, especially where the models and simulations created by Digital Twins are interconnected.

This paper has proposed several different methods to address the issues; and while no single method is perfect; the dynamic requirements of Digital Twins imply the need for more automatic model abstraction. The implementation of DTaaS will potentially help solve the IP and security issues.

Future activity

This paper has identified several issues that need addressing around the topic of model abstraction to assist in the interoperability of Digital Twins. The NMSG research task group on Digital Twins will be looking at several of these, in particular:

- Implementing Digital Twins as a Service (based on the MSaaS model)
- Reuse of existing standards or influencing the development of new standards for the exchange of simulation models
- Investigation of AI enhanced Automated Abstraction and Validation and Verification tools

Experimentation relating to this research and the results of the group activity is planned to be carried out in combination with the NATO Allied Command Transformation authority over the next two years.

REFERENCES

American Institute of Aeronautics and Astronautics (AIAA). (2020). *Digital Twin Definition & Value.* Retrieved from aiaa.org: https://www.aiaa.org/docs/default-source/uploadedfiles/issues-and-advocacy/policy-papers/digital-twin-institute-position-paper-(december-2020).pdf

Bandieramonte, M. (2018). Fast Simulation with Machine Learning. *23rd Geant4 Collaboration Meeting.* Lund, SWE.

British Broadcasting Corporation. (2022, 06 13). *Why you may have a thinking digital twin within a decade*. Retrieved 08 22, 2022, from https://www.bbc.co.uk/news/business-61742884

Frantz, F. K. (1995). A Taxonomy of Model Absrtraction Techniques. *Proceedings of the 1995 Winter Simulation Conference*, (pp. 1413-1420).

IEEE. (2022). IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP). *IEEE 1730-2022*. IEEE Standards Association.

Lidberg, S. F. (2021). *Model Simplification Methods for Coded Discrete-Event Simulation Models : A Systematic Review and Experimental Study.* Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:his:diva-20625

Long, G. (2022). Building a World With Deepfake Content – Who Needs Real Data? *Interservice / Industry Training, Simulation and Education Conference* (p. Paper 22190). Orlando, FL, USA: NTSA.

Los Alamos National Laboratory. (2004). *Concepts of Model Verification and Validation LA_14167_MS.* National Nuclear Safety Administration / Southwest Research Institute.

NATO Modelling and Simulation Group. (2023, 06 15). *NATO M&S as a Service*. Retrieved from Allied Framework for Modelling and Simulation as a Service (MSaaS): https://nmsg.sto.nato.int/themes/msaas

Russ, B. D. (2011). Suppressing Features to Generate Simplified Models for Finite Element Analysis. *Proceedings of the ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 2: 31st Computers and Information in Engineering Conference, Parts A and B.* (pp. 115-125). Washington DC, USA: ASME.

Skinner, S., Stuart, L., Ford, K., & Lloyd, J. (2018). 'Mind the Gap' Avoiding pitfalls in taking the MSaaS concept from research into everyday use. *NATO Modelling and Simulation Group Symposium MSG-159* (pp. MSG-159-15). Ottawa, Canada: NATO.

UK Ministry of Defence. (2021, 10 21). *Strategic Command Blog*. Retrieved from UK Government: https://stratcommand.blog.gov.uk/2021/10/11/multi-domain-integration-demystified/

UK Ministry of Defence. (2022, 12 15). *Defence modelling and simulation coherence*. Retrieved from UK government: https://www.gov.uk/government/collections/defence-modelling-and-simulation-coherence

UK Ministry of Defence. (2023, 06 13). *ASEMS*. Retrieved from https://www.asems.mod.uk/guidance/manual/acquisition-lifecycle

Wikipedia. (2023, 06 13). *List of computer simulation software*. Retrieved from https://en.wikipedia.org/wiki/List_of_computer_simulation_software

Zhang, Y. C. (2023). An Ontology Based Single Source of Truth (SSOT) Construction Approach for Aircraft Modeling and Simulation. *The Proceedings of the 2021 Asia-Pacific International Symposium on Aerospace Technology (APISAT 2021), Volume 1* (pp. 81-87). Singapore.: APISAT 2021. Lecture Notes in Electrical Engineering, vol 912. Springer, .