ENABLING DISRUPTIVE TECHNOLOGIES THROUGH OPEN STANDARDS

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ABSTRACT

Technology is rapidly changing and innovating, with new products, frameworks and methodologies being developed for ever evolving markets.

In order for defence to effectively leverage advancements, modelling and simulation solutions must be built with extensibility in mind. As the future operating environment evolves, simulation systems will need to become richer throughout their lifespan by integrating advanced and disruptive technologies as they become available.

This paper will present research on how the evolution of today's simulation interoperability standards are going to support the introduction of future technologies. We also explore how open interoperability standards development and adherence needs to be pushed further in order to maximise both the potential and return on investment of current and next generation simulation solutions - with the aim of creating a market of truly re-usable and effective simulation components.

We conclude that the route to achieving high impact simulation solutions for the increasing number of defence use cases in complex domains, at a realistic cost, is through developing richer open data models, better standards and collaboration through advanced systems of federated simulation components.

INTRODUCTION

Technology in today's world is continuously and rapidly changing with innovative new products, frameworks and methodologies being developed for ever evolving markets. Whereas in the past, defence based simulations were developing cutting edge technology to meet their needs, which may then make their way into the consumer market, the reverse is now often true. Now, high end technology proliferates our daily lives and budgets in orders of magnitude higher than what is available in public spending are used to create the latest games, streaming services, wearables and mobile technologies for a large consumer market; technologies that defence are now eager to utilise within their simulation solutions.

In order for defence to effectively leverage such advancements, modelling and simulation solutions must be built with extensibility in mind. Modern defence operations are expanding from the traditional air, land, and maritime domains into new domains like cyber and space. Going forwards, modern frameworks must simulate the fast-moving, complex and highly detailed operational environment, replicating the intricate cross-domain interactions and effects to ensure interoperable, co-operative training and mission rehearsal. Simulation systems will need to become richer throughout their lifespan by integrating advanced and disruptive technologies from wider markets as they become available.

Simulations are abstractions of the real world. No single simulation provider will be able to sustainably address all modelling and simulation needs. A trend found in technology is that devices evolve over time to become more decoupled and distributed, with clear, well defined interfaces between them. For example, a PC in the past was sold as single device by a single manufacturer, can now easily be purchased as a collection of interoperable components on a standard backbone (the motherboard, PCI-E, Ethernet etc), providing the consumer with near endless options to choose and combine devices to meet their needs. The same can now be said for the software running on these devices, with software architectures gradually being broken down into smaller, more manageable components or micro services. This then leads us to having a complex environment of many devices running many applications with a need to interconnect. If we assume this trend is to continue, future systems and their components will become more diverse and involve suppliers who are specialists in specific areas, and these applications will continue to have a need to exchange data, which will require common data models to describe what's being transferred.

To tackle these challenges, international open simulation standards have been created and agreed upon to allow simulation components from different vendors to interoperate together and simulate the bigger picture. More and more we see "Standards Profiles" being introduced within defence departments to mandate the use of standards for simulation systems. The profiles are intended, in the short term, to aid the development of simulation systems and in the long term to promote greater re-use of simulation components. However, the current standards only provide a limited level of interoperability, and further investment and development is required in them to ensure we don't risk re-inventing the wheel, as is often unfortunately too common in technology.

This paper will summarise where simulation standards are today, how they are evolving, the outcomes of several research projects on the subject of how standards are evolving to meet tomorrow's technological needs, and finally how simulation standards will need to continue to develop to ensure cohesive and effective interoperability for our simulations going forward.

While defence training and simulation have been making great strides to providing open standards based eco-systems for their simulation requirements, new technology from other domains are on the horizon and face many of the same challenges that defence has faced over the past few decades:

Scalable Platforms

A number of novel frameworks offering scalable constructive simulations are emerging. For example, solutions for simulating large urban scenarios with millions of entities are available in the market. These are often concentrated around scalability of constructive simulations using components from a single vendor or very limited number of vendors. They work well in the cloud given significant bandwidth, extensive computing resources and scalable clients, but the cost of running such simulations could be high.

However, modern live, virtual, and constructive (LVC) simulations will often also involve:

- integrating and exchanging data from heterogeneous systems involving a variety of data formats such as simulation data, audio, video, datalinks, and so on.
- distribution across multiple computer nodes over local and wide area networks (including cloud environments) using fixed or mobile infrastructures.
- exchanging across different security domains where cross domain interactions are necessary.
- synchronised recording and playback of all data streams for efficient and effective data exploitation, review and analysis.

As such, frameworks only focusing on exchange of entity simulation data would be fulfilling a narrow set of requirements of modern simulation based operational and training needs.

Digital Twins

While Digital Twins are clearly in vogue, and to an extent, rediscovering modelling and simulation as a critical capability, they are set to have a profound impact on almost all areas of our life and across industry sectors, not least within defence planning, analysis, education, training and experimentation. Like all other simulations, Digital Twins need not represent everything about the original system. They need to be fit for purpose, and the level of fidelity will vary depending on the primary use cases. As such, digital twins and their ecosystems may vary in scale and complexity with respect to size and scope.

Similar to current simulations, complex and high fidelity Digital Twins will likely have several interoperability and reuse requirements:

- They will often be composed of several components of different specialist developers that require working together; the components likely require reuse in other systems
- The components may have multiple stakeholders and distributed over different computing environments and fixed and mobile networks
- Ability to easily insert new components to allow for technology refresh and insertions and extend the capabilities of Digital Twins over time
- Connecting to the physical system that is being twinned in order to control or optimise the physical asset (also called a digital thread) and / or connecting with other digital twins in a network

It should be possible for heterogeneous models to be linked into a system of systems using standards based frameworks, combining the strengths of each.

Modelling and Simulation as a Service (MSaaS)

A further topic that has garnered significant interest within NATO and wider community is the concept of Modelling and Simulation as a Service (MSaaS) [2] which looks to enable convenient access to M&S products, data and processes to a large number of users as often as possible.

Compared to the current model of modelling and simulation procurement in defence, this approach will truly be disruptive. To enable such a mechanism, standards will be required to ensure interoperability across existing components in an MSaaS, plus enable new components to leverage, enhance and provide choice within an MSaaS ecosystem.

HLA (HIGH LEVEL ARCHITECTURE)

The HLA is a generic and domain independent standard for simulation interoperability. It defines a standardized set of services through a Run Time Infrastructure (RTI), that include information exchange, data distribution management, ownership, synchronization and federation management. One prominent feature of HLA is that it facilitates the development of information models, called Federation Object Models (FOM), for any simulation domain. A FOM describes the shared objects and interactions that are exchanged in a distributed simulation. A FOM can be provided as modules for better separation of concern, and to better support development by different teams. There are standardized FOMs, often known as reference FOMs, that can be extended using project specific FOM modules. Two examples of prominent reference FOMs within defence training and simulation are SISO’s Real-time Platform Reference FOM (RPR FOM) and NATO’s Education and Training Network FOM (NETN-FOM). HLA is mandated in many Standards Profiles for

Modelling and Simulation systems, such as the UK's Defence Modelling and Simulation Coherence (DMaSC) Modelling and Simulation Profile (DMSP) [3] and NATO's Allied Modelling and Simulation Publication (AMSP) 01 [4].

When HLA was created, it was an explicit design decision to specify services in a generic way through an Application Programming Interface (API), leaving room for the evolution of underlying technologies such as run time frameworks (e.g. web-based, cloud-based, platform-based) and networking. The implementation of the Run Time Infrastructure and simulation components are separate to the HLA standard, meaning they can be interchanged as necessary, based on a user's specific requirements (performance, cost, fidelity) or as better RTIs or components become available. Another advantage of this is that the internal RTI protocols can be evolved over time, adding substantial improvements in performance, scalability, and fault tolerance. It has also been possible to optimize RTIs for different environments, such as LAN or WAN.

The approach is in line with an open standards methodology, which can be defined as: parts, modules, objects, products, and systems are based on vendor-independent, non-proprietary, publicly available, and widely accepted standards. Standards allow for a transparent environment where users can intermix hardware, software, and networks of different vintages from different vendors to meet differing needs.

Finally, this decision provides opportunity for further improvements to be made to the standard that meet the needs of future simulation technologies as they become available. The remainder of this paper assumes some basic background knowledge of the IEEE 1516 High Level Architecture standard.

EVOLVING HLA

As introduced at the beginning of this paper, the military domain continually becomes more complex and as a result the training needs continue to evolve, meaning simulation standards will need to evolve and adapt to meet new requirements. In parallel, technology, driven by the needs of other markets and domains, will improve and standards must change in a sustainable way to allow the introduction of these technologies.

HLA has been in use across simulation since the late '90s, but the standard has not remained static with its fourth iteration on the horizon, allowing newer technologies to be integrated into existing simulations.

Early HLA federations were usually deployed on a well-controlled Local Area Networks. While some HLA federations were deployed on Wide Area Networks (WAN), however due to unique challenges involved in WAN deployments (bandwidth, latency, reliability, security, etc.), non-standardised vendor specific solutions had to be developed in order to achieve effective operation. Technology, not the least the networking, has also evolved significantly since the last HLA revision in 2010. New programming languages, security architectures (due to ever increasing cyber threats), and the proliferation of cloud based software deployments are also significant. This has resulted in new requirements and new opportunities in the upcoming HLA4 standard, such as: [5] [6] [7]

- An "on-the-wire" Federate Protocol to address the needs of future distributed simulations: such as the requirement to support additional programming languages and environments in federates, improved fault tolerance, the ability to switch between HLA RTI implementations more easily, to better support

HLA deployments in Cloud environments and a point-to-point TCP protocol to work over different network topologies and firewalls

- A mechanism for federate authentication, that will improve the deployment of federations in Zero Trust Network Architectures – an increasingly adopted network security approach in distributed systems

- Improved object model rules to allow more flexible and impactful extension of reference FOMs. Improved FOM merging rules will also make utilising the Data Distribution Management services of HLA easier to incorporate into existing federations – allowing patterns for interest management to be better applied in very high data federations

Alongside the evolution of the HLA standard, it is also critical that richer data models describing the simulated world are developed and standardised. In this area NATO has recently released NETN-FOM 3.0 [8], which further extends SISO's RPR FOM to include new object models for areas like weather, AIS and synthetic environment objects, as well as evolving the objects and interactions available in NETN-FOM 2.0 to meet today's needs. Work on the next revision NETN-FOM 4.0 is already underway, with a release expected in 2024.

Within SISO (Simulation Interoperability Standards Organisation), development of standardised data models is also at the forefront. Further development of the DIS standard has just begun, which will spawn a new revision of the core RPR FOM. Outside of that, recent standards activities have seen a FOMs and data models developed for Space simulation [9], Command and Control Systems [10], Exercise Control of Live Systems [11] and Cyber Warfare [12].

Additionally, as new simulation solutions are brought online that use existing standards, such as the UK RAF's Gladiator capability for team and collective air training, FOM extensions that are developed for their specific requirements (for example Communications and Datalink effects, Cross Domain Security and After Action Review) will be looked at how they can be brought into a standard for use by all.

As the adoption of open standards increases, creating a level playing field and ecosystem for simulation component developers and customers alike, understanding the compliance to a standard and how to integrate components in a cost effective way also becomes more important. To this extent, there are several open standards activities underway looking at how to address these issues, namely SISO's Simulation Interoperability Readiness Levels [13] and NATO's HLA Certification Process [14], which will be discussed further later in the paper.

RECENT RESEARCH AND DEVELOPMENT

The following sections summarise a number of research projects and demonstrations that have looked at how novel and disruptive technologies can be brought into defence simulation in a cost effective way through the use of open standards.

Game Engine Interoperability

The growing popularity of gamification in learning, combined with the power of modern gaming technologies, is set to shape the next generation of simulation based training. Early simulators that used to run in multiple computer cabinets that would fill a server room were then replaced by the COTS PC based systems running bespoke simulation software and high-end image generators driving a variety of visual display systems. Today, game based simulations running on COTS gaming laptops are commonplace in defence training schools. Their use over the internet for home based training is also becoming more common in certain contexts, either through lower-cost hardware deployed to the user or through cloud streaming technologies.

Beyond the very realistic visualization features, game engines today offer many other facilities like advanced physics, artificial intelligence (AI), sound engines, among other modules that can ease the development of simulations for training. Most established game engines have been developed to serve a large community of consumers and developers. A lot of effort is put into developing detailed debugging/profiling tools and other aspects of a game engine to a very good standard. This level of effort is not easily matched by a traditional training and simulation provider.

However, games are generally developed to only work within their own game engine ecosystem. Technologies such as multiplayer frameworks still currently require that all systems use the same game engine – an approach that can pose many issues, not least the risk of vendor lock-in and the prospect of throwing away significant investments already made by the system developers and end customers. Additionally, game developers for the consumer market work with their own requirements and architectures specific to the game they are producing. Most game engines are "closely coupled" and monolithic in their architecture, such that all parts of the game are run together in a single instance. To date, the gaming within entertainment industry has shown no desire to interoperate between games due to consumer market dynamics and they have real incentivisation for creating closed ecosystems through technical and commercial lock-in mechanisms.

But, the technology used in gaming has great potential for exploitation in the training and simulation. A NATO Modelling and Simulation Group (NMSG) Exploratory Team [15] conducted a study investigating if and how standards and technologies could be developed to promote modular game architectures for greater exploitation within defence modelling and simulation. The team concluded that:

- commercial gaming technologies, when combined with appropriate use of open standards, can provide increased efficiencies, quality and validity benefits and more flexibility for defence applications

- more flexibility and reusability of game engine components would make systems more valuable and cost-effective

- more flexible standards would be needed to avoid frustrating game technology advancements

On the journey towards exploiting gaming technologies in defence simulation, Pitch Technologies, as a recipient of an Epic Games Mega Grant, created an Unreal Engine plugin that allows developers to connect their Unreal Engine Project to a HLA Federation [16]. This opens up a broad range of possibilities for the simulation developers:

- utilise Unreal as a visualisation engine for entities simulated in an HLA federation

- enable entities simulated within the Unreal Engine Project to interact with entities and other services simulated elsewhere in the HLA federation and vice versa

While the Unreal Engine connection provides a simple solution, the paper explores the technical challenges of completing such a task, such as the use of non-standard programming language and co-ordinate system concepts within Unreal and strict performance requirements. However, this is not a criticism of the Unreal

Engine's approaches, rather it highlights why interoperability between different solutions – that are selected to meet specific requirements – is so important within defence simulation.

In general, gaming technologies have already had a profoundly positive impact within training and simulation. However, unless the engines find greater utilization of open simulation standards, their exploitation within defence training will be limited. A number of game engines already support common standards for visual models, which helps developers re-use the models across technologies developed by different vendors. Technologies supporting common standards for gaming must continue to be evolved and established to allow procurement agencies to convincingly mandate modularization and open standards for even greater exploitation of commercial gaming technologies.

Technologies such as HLA-game connectors will greatly assist game developers as they collaborate with their counterparts in the simulation community. Multiplayer and cross platform capabilities hitherto have only enabled players to play inside one game built by a single vendor and only recently allowed them to choose their hardware platform of choice. However, technologies such as the HLA-game connector could be stepping stones towards going beyond the multiplayer gaming concepts and becoming a player inside any simulation.

Novel Simulation Frameworks with HLA 4

The emphasis of this research was to demonstrate a scalable CGF concept using the upcoming HLA4 features by leveraging cloud technologies. The demonstration [17] comprised of a scalable multi-domain scenario implemented in a hybrid onsite cloud framework, such that a large number of entities are simulated in the cloud. The simulated scenario included friendly, opposing, and neutral/civilian platforms as well as humans. The framework was based on a cloud deployed Pitch HLA RTI using early versions of the HLA4 federate protocol, bringing together several software components to build a scalable federation.

The scalable CGF concept was enabled through both Docker and Portainer. The containers representing components of the scalable CGF (Air, Land and Sea based entity simulations) were distributed across three Ubuntu Virtual Machines (VMs) to manage the load. Two VMs ran Docker Engine and the entity simulation containers, whilst the third ran the pRTI and a single Federate Protocol Server. Each of the entity simulation container instances then updated the Federation through a connection using the Federate Protocol Server.

While the initial research proved that an open standards based scalable architecture was possible using HLA4, it was limited in terms of CGF behaviours. However, using an open standards based approach enabled an architecture that could evolve to use more HLA services to allow the CGF to adopt more advanced behaviours, whilst also efficiently and dynamically making use of available computing power.

Figure 1 shows a container-based scalable architecture, that blends the benefits of elastic cloud computing with the power of the HLA services Data Distribution Management and Ownership Management.

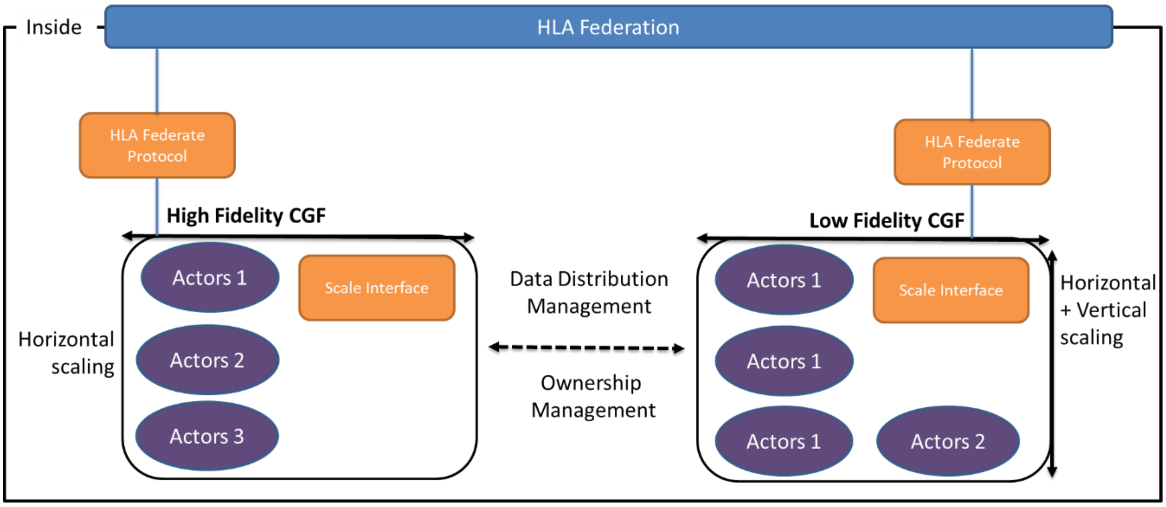

Figure 1 Evolving the an HLA architecture for fidelity and scale using DDM and Ownership Management

This architecture adds the concept of both a High Fidelity and Low Fidelity CGF working in tandem. The High Fidelity CGF would exhibit more advanced behaviours at a higher update rate and would therefore use more CPU and memory than a Low Fidelity CGF.

By using HLA Ownership Management, the CPU and memory usage of the High Fidelity CGF can be reduced by only handling certain elements of an entity's definition (such as its sensor model) while the Low Fidelity CGF continues to model other aspects of the Entity that are less important to a given training objective (such as its flight model).

The load on the High Fidelity CGF can further be reduced by using Data Distribution Management (DDM). The Low Fidelity CGF will be outputting a large amount of data onto the HLA network, not all of this will be relevant to the High Fidelity CGF. We can use DDM to limit amount of data the High Fidelity CGF needs to process by stopping it receiving irrelevant messages to process (such as from outside a specific Geographic Area).

The use of these services results in an architecture that is both scalable in terms of entity counts but also scalable in terms of efficiently modelling entity behaviours.

Standards Certification in Simulation

Due to these demands of modern simulation systems, defining a set of standards is an important first step to allow the components to talk to each other. However, these "standards profiles" often still contain ambiguity, such as the exact standard to use where multiple applicable standards have been included, or how exactly to apply them. What we end up with is a market where simulation systems and components can adhere to standards, but are not always interoperable, meaning the benefits of standardisation are not fully realized. Through research and development activities, both at national and international levels, a number of concepts have been proposed to address some of these challenges, such as the standardized Interoperability Requirements and Capability Badges concept for simulation interoperability [18]. Recently, NATO activities have resulted in the establishment of a certification process for verifying simulation component compliance with the HLA interoperability standard [14], and SISO are nearing the completion of a "Simulation Interoperability Readiness Levels" toolkit [13].

The general approach for Capability Badges is analogous to other interoperability approaches within the technology industry, such as: "HD Ready", "Works with Alexa". Organizations that perform and maintain interoperability certification activities in consumer markets advertise the key benefits of "Capability Badges" as:

- Shows customers that your product will work
- Clear & independent proof of interoperability
- Lowers barriers to market entry by providing access to the vast technology ecosystem
- Confirm product's interoperability via testing from experienced professionals

Capability badges are primarily intended to support system design, test and integration but are also proven to be useful when defining system interoperability requirements and procurement. Capability badges encapsulate a number of clearly defined and measurable interoperability requirements, defined by interoperability experts, that aim to provide a clear definition of the aspect they represent. For some nations, it is reusing these interoperability requirements during their system requirement definition that is proving most useful currently.

One of the main objectives of NATO's MSG-163 was to develop the NATO HLA Certification Service. The service is a solution that NATO identified to overcome the challenges faced when establishing a reliable and trusted federations of distributed interoperable simulations. It is a process built around the Capability Badge and Interoperability Requirement concepts, aims to provide a mechanism of certification for simulation components around key capabilities that are often taken for granted during development: e.g. HLA and FOM compliance. Alongside the process NATO Integration, Verification and Certification Tool (IVCT) has been developed to aid automated testing of federates in the certification process. It is proposed that further development of the tool and interoperability requirements will continue in MSG-191.

Alongside the NATO work, SISO has been developing Simulation Interoperability Readiness Levels (SIRL): a methodology to objectively measure interoperability between two simulations using engineering artefacts [13]. These metrics would contribute to easing the integration of a distributed simulation and can make the integration more mechanical and less prone to error-based discovery. In general, it builds upon existing standard processes (Distributed Simulation Engineering and Execution Process (DSEEP) and artefacts (Federation Engineering Agreements Template (FEAT)) to identify and reduce integration issues as early as possible into the development process.

One observation is that Interoperability Requirements and Capability Badges would be a prime input into the SIRL process, as they would provide clear evidence of whether a simulation component is meeting the engineering evidence criteria for a particular level - and could drive the creation of further criteria.

Certification for interoperability is not a concept unique to modelling and simulation. There are many examples of the process applied across the technology sector, addressing interoperability at different levels. It has been proven in other industries that the certification approach reduces barriers to achieving interoperability between systems. Indeed, some of the largest companies in the world are coming together to address some of these interoperability issues [1]. The launch of the Metaverse Standards Forum (MSF) and the Matter initiative that look to standardise smart homes and Internet of Things (IoT) platforms are recent examples of diverse industry players coming together to tackle macro-level problems like interoperability. Both initiatives are clear that open standards and industry consensus are essential to achieving their goals.

We can reasonably expect that MSF and Matter will focus on mass consumer markets (at least initially). For smart home technology developers, Matter provides a unifying open standard that allows developers to introduce proven technologies; interconnecting IoT devices built to the same standard, reliably and securely. Offering standards-based products increases consumer adoption overall, as use of one standards-based product helps push demand for other products based on those standards.

While great steps to increase simulation interoperability have been made in the last two decades by using established open standards, higher level interoperability is not always achieved and often still involves high costs and risks during integration. As explored in the research, simulation component certification will have a big impact in improving interoperability between and within training systems, reducing risks and providing highly advanced cost effective solutions to customers. Additionally, establishment of such certification frameworks would enable better convergence of emerging technologies for M&S use in future.

CONCLUSIONS

It is clear that technology will continue to evolve and it will almost certainly improve the way we build and use solutions for defence training and simulation. However, in order to do this in a cost effective and sustainable way, the solution architectures we build them upon must be carefully thought about.

The introduction to this paper proposed that defence is now following the consumer market in terms of technology, however there is an argument to say that defence is actually leading the way again in one aspect: constructing large scale distributed system of systems, comprised of specialised components provided by different manufacturers that will continue to use different technologies. These components would rely on system architectures offering robust and enduring information exchange and interoperability mechanisms that we cater for a broad range of defence M&S use cases.

However, corporations often tend to develop closely coupled proprietary solutions, a tendency that is not unique to defence industry. At first thought, a proprietary solution may seem to offer short term incentives – it may seem quicker and easier to develop and initially appears to cost less, but the real world is full of case studies revealing the opposite to be generally true. Loosely coupled architectures based on open standards yields rewards of longer term maintainability, flexibility and extensibility along with reduction of full life-cycle costs.

It has been shown in wider industry that the use of standards and certification of compliance to them means that consumers can choose applications from a wide range of suppliers and not worry about compatibility issues. Alternative proprietary approaches, no matter how large the offering organisation, generally only reach a subset of the market resulting in limitations of features plus higher costs for consumers.

However, developing standards is not something that can happen for free. In order to achieve meaningful standards applicable to as many requirements as possible, defence industry must take heed of lessons from other industries and come together to invest in them. An argument often used against using some standards is that they are slow to develop or evolve, and therefore restrict innovation, yet most simulation standards development groups within NATO, SISO and others are inadequately resourced. Therefore, in order to maximise the benefits of using open standards, defence organisations and industry must encourage and invest in open standards development wherever possible, or risk creating another iteration of the wheel and adding to the list of new standards needlessly looking to compete with existing ones.

HLA as a standard was built with open principles at its core. One can replace a simulation component or the entire run time infrastructure as they see fit with minimal integration effort, at least in theory – vastly reducing the risk of vendor lock in or ending up with something unsuitable for the requirements. By truly embracing open standards, defence will have the freedom to focus on building innovative new technologies and find wider reach for their products in international markets, instead of creating and solving new interoperability issues. Recent developments in the consumer markets, such as the Metaverse and IoT make one thing clear – Open standards form the path of future defence M&S ecosystem.

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