A Synthetic War-Game Environment to Assess Emerging and Disruptive Maritime Technologies in NATO Exercises

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ABSTRACT

NATO's Dynamic Messenger operational experimentation exercise, scheduled September 2022 (DYMS-22), investigates the role of maritime unmanned systems (MUS) in operations. To mitigate the limits of an at-sea exercise and further explore the benefits of MUS, a synthetic environment based on the use of Modelling and Simulation (M&S) supports immersive war-game events. This approach continues the team's long-term research aim; supporting decision making by blending human, technology and data.

The synthetic environment consists of three main elements: A NATO Architectural Framework (NAF) dashboard, a comprehensive federation of maritime simulators and an interactive suite of data analysis tools. Together, they allow players to test emerging technologies and extend exercise vignettes in a safe-to-fail environment.

During war-games, the web-based NAF Dashboard facilitates the player's debate and selection of MUS technologies and vignette extensions. Using the federation of maritime simulators, the players visualize the selected vignettes while generating a representative dataset to populate the DYMS-22 key performance indicators (KPIs). Utilising the data analysis tools, the players investigate the effect of their selections on the KPIs in detail.

Interactions with the modular, adaptable and immersive synthetic environment allows DYMS-22 participants to identify the limitations and strengths of MUS technologies in a series of iterating war-game rounds.

1.0 SETTING THE STAGE

NATO's Dynamic Messenger (DYMS) 22 is a Joint Force Development Operational Experiment Exercise [1] in which NATO operational communities are working together with partners from industry and academia to promote the operational integration of Maritime Unmanned Systems (MUS) into NATO operations through extensive experimentation [2]. Within DYMS-22, live, multi-domain exercises will run from 23rd to 30th September in the Portuguese North Atlantic exercise areas close to the Troia peninsula. One syndicate within DYMS-22 focusses on experimentation with innovative MUS technologies in Naval Mine Warfare (NMW) missions. The NWM syndicate will execute a range of mine-countermeasure (MCM) missions, exploring the strengths and weaknesses of both full autonomous mission execution as well as investigating routes to achieve the integration of autonomous and legacy systems with manned-unmanned teaming techniques.

Integrated into the NMW syndicate's daily activities, a separate Evaluation, Analysis and Assessment (EAA) syndicate aims to capture data from each of the DYMS operational teams, allowing an assessment of the effectiveness of each MUS technology area to be estimated and reported. The EAA syndicate capture data from each of the operational teams via the collection of daily, structured and paper-based Quick Look Reports that prompt operators to provide a concise set of quantitative and qualitative data points.

During the planning stages of DYMS-22, both the EAA and NMW syndicates noted a series of shortcomings with the use of daily Quick Look Reports. These shortcomings tended to stem from the competing priorities of each syndicate team; analysts in the EAA syndicate want to collect large quantities of data so that they can draw accurate and comprehensive conclusions while operators in the NWM syndicate want to minimise reporting overheads and focus on executing their missions. In addition to having to find a compromise to these competing interests, a concern was voiced by both syndicates that the compromise data collection process may constrain the analysis to focus on current ways of working and not support the identification of innovative new ways of employing disruptive and emerging MUS technologies to maximise their impact in operations.

Key to enabling the effective employment of these emerging and disruptive MUS in future operations is the ability to reinvent NATO's planning and decision-making architectures so that they can rapidly evolve, develop and keep pace with the rapid technological advances in robotics, artificial intelligence (AI), big data and other MUS enablers. Wargaming has been an established component of military planning, decision-making and operations for some time and provide a route to identify innovative ways of employing these new technologies [3]. As wargames continue to develop, NATO has begun to identify best practices in how to support, augment and enhance wargames with computer-based simulation environments [4].

Set against this wider trend, NATO's Innovation Hub is supporting the analysis of new and emerging technologies in a series of gamified Disruptive Technology Experiment (DTEX) events [5]. The latest DTEX in this successful series of gamified events is investigating the future role of disruptive autonomous systems technologies in maritime Naval Mine Warfare (NMW) operations as part of DYMS-22.

The NATO Innovation Hub developed DTEX as a methodology to test and assess new technologies and concepts in gamified settings [5]. In support of this, DTEX assesses the opportunities and challenges associated with emerging and disruptive technologies in a rapid and efficient way through the innovative use of simulation and open innovation. Typical inputs at the start of a DTEX are a problem statement and a set of potential solutions (usually sourced through open innovation techniques such as challenges, hackathons, etc.) The gamified DTEX events typically involve end-users and operators to make sure the ideas are evaluated by those who will actually use the new concepts and technologies in operations. DTEX events also include subject matter experts, students and others with diverse backgrounds to blend different ideas and approaches throughout the series of events. The value of a DTEX is the creation of a ranked list of technology solutions, as well as technology combinations supported by the knowledge of how they solve the problem at hand.

The application of DTEX may allow improvements to the current, paper-based analysis of technologies within operational experiments such as DYMS, reducing the burden on the NMW syndicate, while increasing the value of the inputs to the EAA syndicate while supporting the identification of new and innovative ways of applying MUS technologies in future NATO operations. To test this hypothesis, DTEX will be used in DYMS-22 to support the analysis of the NMW syndicates' activities.

This paper presents an overview of the design, development, test and employment of a Modelling and Simulation based synthetic environment to support the analysis of NMW MUS technologies in DYMS-22. The paper covers all aspects of the work, from the development and use of a standardised synthetic environment development framework to observations and lessons learnt in the use of the synthetic environment in wargames played by the DYMS operational community. The paper's structure is as follows: Section 2.0 identifies and describes the key lines of research activities required to allow augmented wargaming support a NATO exercise. Section 3.0 describes the first of these activities, setting out a reusable reference architecture to support augmented wargaming. Section 4.0 presents the implementation of a target architecture and the activities executed to support DYMS-22. Finally, section 5.0 presents the conclusions and next steps for the DTEX synthetic environment.

2.0 THE CHALLENGES OF AUGMENTING WARGAMES WITH SYNTHETIC ENVIONMENTS

The history of wargames is almost as old as history itself [3]. Typically executed as table-top exercises with paper and card, wargaming in the modern era simulates warfare in order to assess, train and improve military planning and responses [6]. Due to its well-known and accepted benefits, NATO is investigating wargaming as a methodology to encourage alternative thinking for planning and assessment in the use of new and emerging technologies. The potential of wargaming has been well recognized within NATO, allowing the exploration of operational possibilities and discovering unintended consequences in a safe-to-fail environment [3]. In recent years, NATO has been investigating the enhancement of wargaming with computer based simulation aids to support the human analysis of ever-increasing data sets [4] [7]. While this work has led to the identification of best practices in how to wargame with simulation-based capabilities, approaches to how best develop the simulation capabilities to support events have not yet been widely agreed upon [8].

Typical simulation development approaches, such as the Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP) [9], encourage a staged approach to the development of simulation capabilities. Activities within DSEEP start with the identification of end user needs and objectives which are often linked to the need to model, understand and investigate a particular problem, system or specialised area within a structured set of research or engineering business processes [10] [11].

When developing simulation capabilities to support wargames, two development challenges are amplified when compared to traditional applications:

1) **The need for a very wide group of users to interact with the simulation environment;** in a wargame environment, users may span from knowledgeable and specialised subject matter experts to members of the general public. Despite the fact that the simulation environment designers will not know the players before the game starts, all players must all be able to obtain a benefit from interacting with the simulation environment.

2) **The need for the simulation environment to seamlessly integrate with the information flow of the wargame event**; a vital aspect of the wargame event is to encourage the players to understand, discuss and debate the wargame subject matter. The use of a simulation environment must not interfere, disrupt or distract from this core task

Due to the additional emphasis on the human and integration aspects, traditional simulation development frameworks such as DSEEP must be augmented or replaced to support the creation of a wargame synthetic environment [12] [13].

To address these challenges and support the DYMS-22 DTEX event with a series Modelling and Simulation (M&S) enhanced wargame events, the design approach selected is based on the key principles of both standardised industrial development activities [14] and the NATO Architectural Framework (NAF) [15]. The two key activities required to implements this design approach are the development of both a generalised and reusable augmented wargaming reference architecture before then instantiating a DYMS-22 DTEX specific target architecture.

3.0 ACTIVITY 1 – THE DESIGN OF A REFERENCE ARCHITECTURE TO SUPPORT THE DEVELOPMENT M&S-BASED WARGAMES

To address the current lack of a reusable framework to support the development of wargame simulation environments, the authors of this paper have designed a comprehensive reference framework in recent years of the DTEX project [13]. An overview of the resulting framework, comprised of parallel and incremental gameplay, human and technology development streams, is presented in Figure 1.

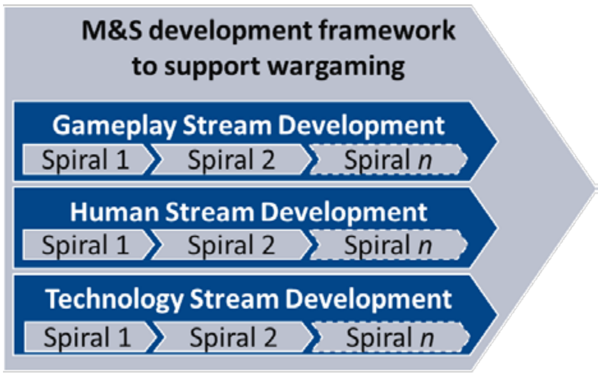

Figure 1 - Overview of the framework to support the development of simulation application to support wargaming

This reference framework provides support to any project that wishes to augment wargaming activities with M&S based support within a synthetic environment. Further detail of each of the main reference architecture elements are described in the remainder of this chapter.

3.1 The Gameplay Stream

Gameplay is a core element in the design of any wargame, creating an environment in which players remain informed, motivated and engaged. Development activities within the gameplay stream relate to supporting and enhancing the wargame's information flow, gamification and user interactions.

The design of the wargame's simulation capabilities information flow forms a foundational starting point for all of the required development activities, typically focussing on three key gameplay stream elements:

1) Presenting background information behind the challenge, setting the scene and allowing players to make choice that they believe will improve the situation.

2) Using simulation to further communicate the impact of the player's choices and generate data based on the new situation.

3) Present information generated by the simulation data to allow players to investigate the effects of their choices, understand their current game score and, ultimately, be better informed in the next iteration of the game and beat their current score.

Understanding these three typical gameplay elements and the information flow among them is a vital area of knowledge that need to be clearly defined in order to support the development of the remaining simulation capability streams.

3.2 The Human Stream

A truly fundamental aspect of any wargame are the players that will contribute to it. The central value of a wargame is in effectively eliciting and capturing knowledge and ideas from a diverse range of player types. Specifically, development activities within the human stream focuses on understanding key stakeholders, attendees and optimising their roles.

The design of information presentation and interaction capabilities within the simulation environment can again be considered in three key elemental areas;

1) What information is to be presented to, and elicited from, the wargame players? This element considers aspects such as, should a facilitator lead the players through the event or should the progression through the wargame be fully player-led.

2) When the information is to be presented and elicited? Wargame events can often present players with large quantities of information, that may not be in the player's normal field of expertise, in a short space of time. Development activities in this area may wish to consider the timing of information delivery and the importance of discussion or reflection time.

3) How the information should be presented to, and elicited from, the players? The background, experience and role that each player is used to may vary greatly throughout a diverse range of players in a single wargame event. Development activities should consider how to maximise the effectiveness of each player interaction with the simulation capability by always presenting information in a format or style that's intuitive to each player group.

Consideration each of these human elements throughout the development of the simulation capability is vital to the engagement, contribution and value of each player in the wargame event.

3.3 The Technology Stream

Whereas a common route in integrating simulation environments into wargames begins with a focus on the technical aspects [16] [17], the proposed framework addresses the technology stream as a final development area that allows the creation of M&S-based software and services to augment, support and facilitate the wargame events. Specific development elements that are typically considered as part of the technology stream include:

1) Standards-based architectures and interfaces allow simulators and other synthetic environment toolsets to be rapidly expanded, reconfigured and reused as lessons from a series of wargame events are observed and learnt.

2) The use of immersive and interactive technologies allow the synthetic environment to support the wargame event to its full potential. These environments may allow players to interact with the wargame elements with a wide range of physical devices, from touch-screen phones and tablets to 3D augmented and virtual reality (AR/VR) systems.

3) The use of distributed and web-based approaches is a key enabler to increase participation reduce planning times for each wargame event. In addition to using these features to improve the quality of the wargame event, agile and distributed wargame events also supports the iterative development of the supporting simulation environment.

By implementing the designs developed to support the gameplay and human streams, the technology stream creates the configuration and debate tools, simulation environments and interactive data presentation toolsets required to validate the designs in each of the framework streams and, ultimately, support each wargame event.

3.4 The importance of incremental development

By design, multiple dependencies exist among each of the framework's three development streams as they progress in unison to augment wargaming with a comprehensive simulation capability. To manage these dependences, it is essential that the project's development activities maintain an agile and incremental approach to development. The incremental development spirals typically begin with minimum viable product (MVP) developments in each of the three framework streams that are trailed and tested in wargame events, allowing framework dependencies to be identified and incorporated into subsequent development spirals.

An additional goal may be to align the incremental development spirals with a longer term or multi-project roadmap of capability development, allowing the resulting simulation-based framework to be incrementally developed and refined over extended periods of time.

4.0 ACTIVITY 2 – THE DESIGN AND INSTANTIATION OF THE DYMS-22 DTEX TARGET ARCHITECTURE

To implement one instance of the reference architecture, a DYMS-22 DTEX target architecture has been designed, implemented and tested. The application of target architecture, throughout a series of DTEX events in support of NATO's DYMS-22 exercise, will be presented and discussed in the remainder of this chapter.

4.1 DTEX in DYMS-22 - Human Stream Activities

To support the post-DYMS NMW analysis activities, the DTEX project began its incremental development activities in the event's planning conferences, beginning in May 2022. A summary of the dates and aims of each of the key DYMS DTEX Human Stream activities is provided in Figure 2.

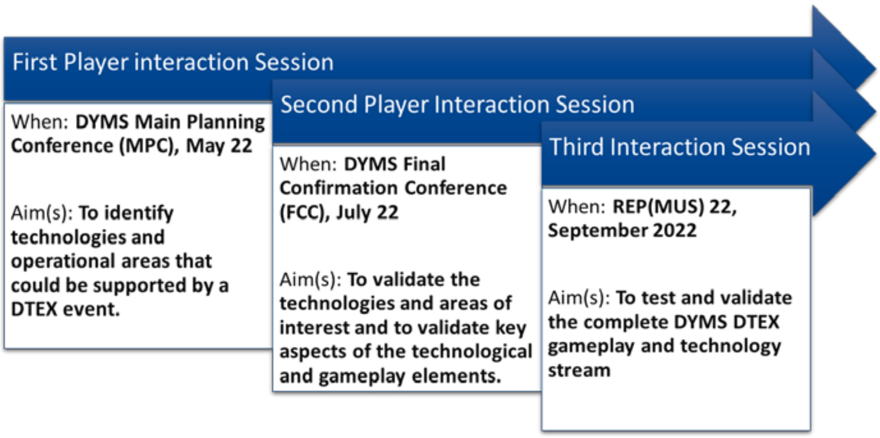

Figure 2 – An overview of key human stream activities in the development of the DYMS DTEX

At the main planning conference in May 2022, human stream development activities began with an interactive workshop with the DYMS NMW syndicate's end user community. With the aim of analysing the experiment's emerging and disruptive MUS technologies, the workshop allowed the DTEX project team to work with the end user community to identify the potential areas of value offered by a wargame event:

> ***DTEX Objective 1)*** Augmenting the DYMS scenarios with additional harsh, hostile and red-force features.
>
> ***DTEX Objective 2)*** Communicating the capabilities and limitations of MUS technologies to non-MCM experts.
>
> ***DTEX Objective 3)*** Identifying how best to use MUS technologies (Inc. understanding their capabilities and limitations).
>
> ***DTEX Objective 4)*** Identifying architectural trade-offs in an environment free from external constrains.

A final value of using the Main Planning Conference workshop to kick off the human stream development activities was the identification of a shared, multi-community method of communicating with end-uses, subject matter experts and other DTEX stakeholder though the use of Key Performance Indicators (KPIs). The use of the existing DYMS KPIs throughout the DTEX project, provides a common, shared frame of reference spanning from the live DYMS trials with operational systems to each of the DTEX development streams and events.

Prior to the Final Confirmation Conference in July 2022, the objectives and opportunities identified in the first workshop were clarified and implemented into a series of tangible minimum viable products (MVPs). These MVPs allowed the NWM syndicate members to play through and discuss the concepts recorded by the project team in the first meeting, providing guidance, feedback and clarification where required. The workshop also allowed the architects of the synthetic environment to demonstrate, interact with and explain the core simulators within the synthetic environment's federation. This activity formed a key element of the synthetic environments verification, validation and accreditation (VV&A) activities.

Finally, the multi-national Robotic Experimentation and Prototyping for maritime unmanned systems, REP(MUS) exercise in the days before the start of DYMS provides a final opportunity for NWM syndicate members to test, discuss and validate all aspects of the DYMS-22 DTEX before the project moves into the post DYMS analysis phase.

4.2 DTEX in DYMS-22 - Gameplay Stream Activities

The observations from and interactions with the NMW syndicate in the human stream formed the foundation of all gameplay stream activities. One major observation from the first workshop was the focus that the NMW syndicate placed on operational key performance indicators (KPIs) as a route to understand and articulate the benefits of the DYMS experimentation technologies. The importance of utilising this common set of KPIs to link both the real-world operations and those conducted in an M&S based synthetic environment was the key factor that led to the tailoring of previous DTEX events to lead to the design of the gameplay flow depicted in Figure 3.

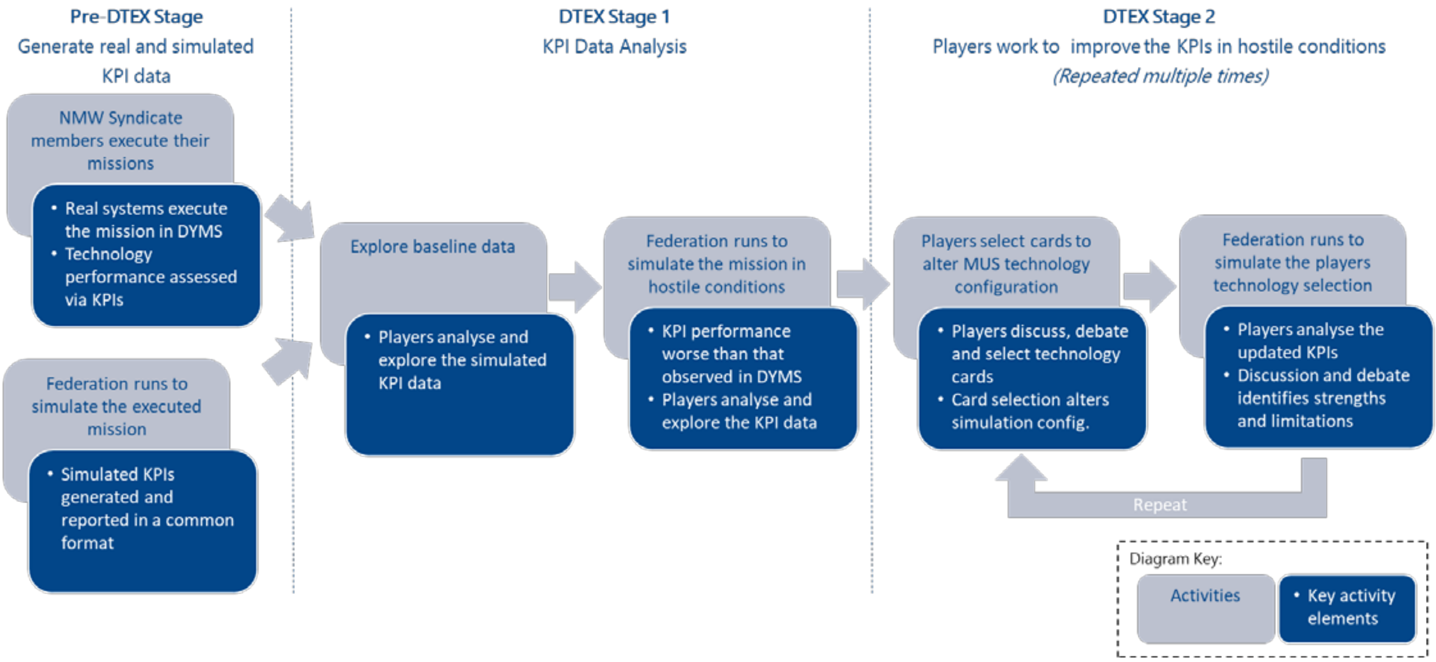

Figure 3 – High-level summary of the DYMS DTEX gameplay design.

In the first stage of the DTEX event, the KPI data generated from both the execution of the mission with real systems and data generated from a parallel simulation run. Comparing the KPIs from each provides an important moment in the VV&A of the synthetic environment, in particular in the first wargames, while providing the NMW syndicate members with a known reference point as they enter into the DTEX event and its synthetic environment. To maximise the effectiveness of this stage, the presentation of the simulated data is very closely aligned to the views and methodologies that the end-user communities use to assess their live trial performance[1]. Further, the availability of simulated data allows players to further investigate technology interactions during the mission by using views and data sets that cannot be obtained in real-world operation. The presence of this data is likely to prompt discussion about the MUS technologies under analysis, providing the first area of value from the DTEX event.

Once the players have analysed the performance of the technologies in a simulated replica of the executed mission, the synthetic environment is able to advance the debate in a way not possible with existing DYMS technologies. Specifically, the performance of the systems in harsh and hostile conditions can be simulated and the estimated effects of these conditions on the KPIs can be presented. These conditions, ranging from poor weather and adverse seafloor coverings to the presence of civilian hazards, such as fishing nets, cause a degradation to simulated KPIs, again prompting debate among the players that is a valuable output to the DTEX stakeholders.

Once the impact of the degraded KPIs has been communicated, Stage 2 of the DTEX event challenges players to improve the KPI metrics in hostile conditions, in effect challenging them with a 'score to beat'. At this stage, the player is provided with a series configuration options that will allow them to select from all of the available DYMS NWM technologies to build their own mission architecture. The selection of technologies is limited by applying a cost to each of the cards and limited the budget available to the player. This forced limitation provides a motivation to the players to efficiently select only the technologies combinations that they think will best improve their KPI scoring. If desired, the presence of a timer may be

[1] The Federation is compliant with the Common Architectural Tasking Layer (CATL), the exercise`s shared data model for command and control.

used to limit the time available to the player to select technologies, providing additional motivation to concisely debate and analyse the available technologies.

Once the player has selected their mission architecture, as simulation is run to generate updated KPI metrics, indicating the performance of the player's inputs. The player is encouraged to repeat this stage multiple times, building up knowledge of the MUS technologies, debating them with facilitators and teammates while experimenting with ways to better apply and combine technologies to improve their score in a gamified setting. To further motivate the players, their scores are compared not only with the KPIs obtained n more benign conditions but also with scores of previous players, providing a strong motivation to select technologies to the best of their ability.

The selected technologies, along with the qualitative rationale behind their selection is recorded to provide the main output of the DTEX event.

4.3 DTEX in DYMS-22 – TEchnology Stream Activities

The design themes identified in both the human and gameplay stream activities drives the development of the technology development stream. Reflecting the design of the wargame, the technology architecture consists of the three main elements detailed in Figure 4.

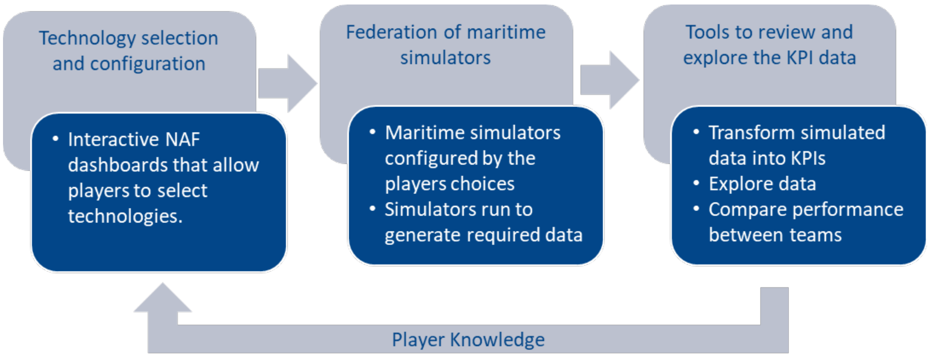

Figure 4 – Architectural elements of the technology stream.

The first of these blocks should allow players to understand the flow of the wargame, navigate to the relevant elements and, vitally, make changes to the DYMS MUS technology architectures. To enable this, a web-based architecture has been implemented to allow players to explore the problem space in their own time and without the presence of a facilitator. Once the players are orientated within the synthetic environment, they are prompted to select technology chances using interactive, movable cards in a tablet interface. An example of this card-selection capability is provided in Figure 5.

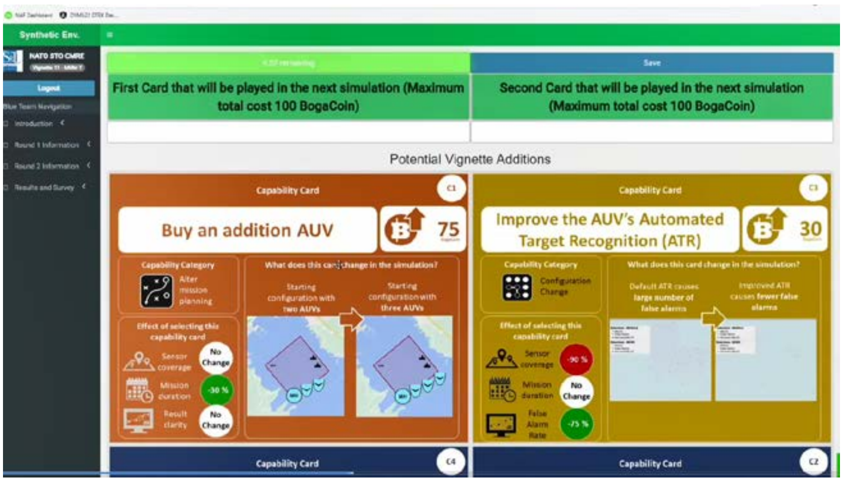

Figure 5 - An MVP screenshot of the card-based interactive technology selection toolset

To improve the interaction with a wide range of users, the user interface was designed in line with guidance contained in NATO's Architectural Framework (NAF) specifications [15]. Within these NAF specifications, varying viewpoints have been developed in order to communicate effectively with stakeholders ranging from high-ranking senior officers, to technical partners and project delivery specialists. Tailored viewpoints are provided to each community group depending upon information obtained from their route into the toolset at login.

Once the players have understood the problem space and selected cards to make their first architectural modifications, a federated simulation capability, based on High Level Architecture (HLA) standard [18], is run to execute the mission with the new configuration in the versatile federation of maritime simulators [19] [20] to generate a selection-specific data set. A screenshot of the 2D and 3D viewers during the mission execution is shown in Figure 6.

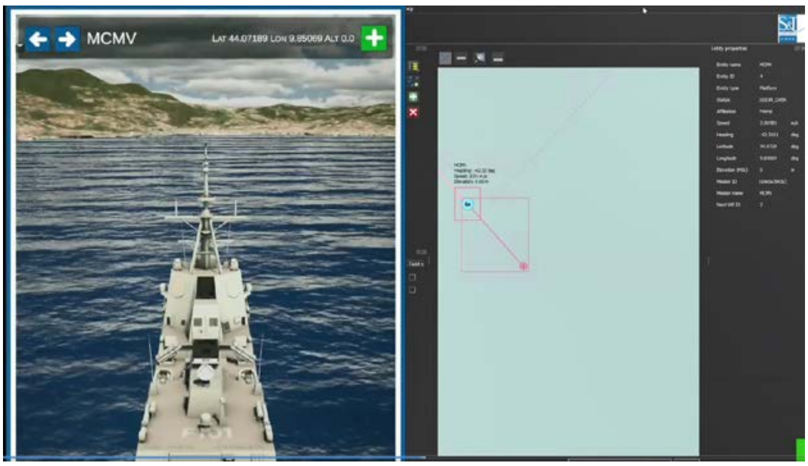

Figure 6 - A screenshot showing the tools available to the wargame player during the execution of the mission with their bespoke MUS technology selection.

Due to the fact that the federation is implemented using the highly expandable and configurable HLA standard, previous simulator elements could be efficiently reused to support the DYMS missions and areas of interest required to address DTEX objectives 1, 3 and 4. The data created by the federation of simulators was logged and saved for further processing.

The simulation data generated by the player's execution of the mission with their bespoke MUS technology configuration was processed and presented in the final gameplay development area, a KPI and data visualizer, with a typical view shown in Figure 7.

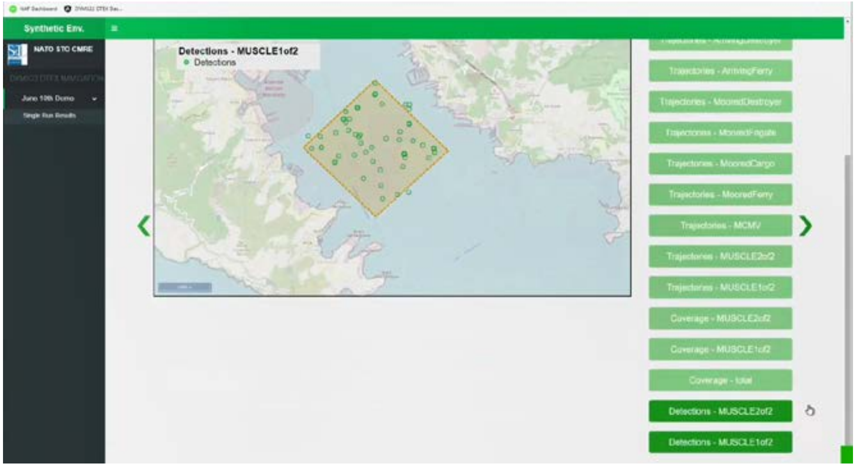

Figure 7 - A screenshot showing a map-based analysis of MUS system performance in the data visualizer toolset.

Like the NAF-based configuration tools that allowed the player to explore and configure the mission's MUS technologies, the Data Visualizer toolset is implemented within in a distributed, web-based architecture.

This combined suite of web-based, distributed and interactive toolsets has allowed all of the elements discussed within the human and gameplay streams to be implemented. Testing of each of the functional blocks has been carried following the reference architecture's recommendation to utilise incremental and iterative development activities. Within this approach, each of the elements have been tested in dedicated sessions with both NMW syndicate members as well as non-military end users through a series of dedicated online test and demonstration sessions.

5.0 CONCLUSIONS AND FUTURE ACTIVITIES

This paper presents the innovative work carried out as part of the DTEX project to augment wargaming events with M&S capabilities to support NATO in the analysis of emerging and disruptive technologies at its first joint force development operational experiment exercise.

This work first designed a reusable and versatile reference framework that builds upon standardised approaches for M&S development activities while addressing the unique aspects required when developing a synthetic environment to augment wargames. An instantiation of the reference architecture is described, highlighting key outcomes in the route to augmenting wargaming with M&S in the DYMS-22 DTEX event and addressing each of the four identified DTEX objectives:

1) Augmenting the DYMS scenarios with additional harsh, hostile and red-force features has been made possible through the development and test of a comprehensive federation of maritime simulators.

2) Communicating the capabilities and limitations of MUS technologies to non-MCM experts has been

achieved through the development of integrated and intuitive data analysis and data exploitation toolsets that build upon standardised NAF approaches.

3) Identifying how best to use MUS technologies has been made possible by empowering and motivating NMW syndicate members, as well as other stakeholders of interest, to configure, trial and experiment with technologies free to the constraints of real-world operations

4) This work ensures that the data captured throughout a series DYMS-22 DTEX events will identify architectural trade-offs in an environment free from external constraint.

Building upon this solid foundation, future activities are likely to focus on three key areas. The first area aims on increasing the availability of the synthetic environment to distributed groups (*more players*). A second line of effort will focus on maximising the modularity of the synthetic environment to reduce configuration times (*more events*). Finally, new methods to capture player contributions will be trialled through the inclusion of techniques such as the Bag of Lemons [21] and structured debating aids [22] (*increasing the value of outputs*).

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