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OPEN CHALLENGES IN BUILDING COMBAT SIMULATION SYSTEMS TO SUPPORT TEST, ANALYSIS AND TRAINING

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ABSTRACT

High expectations to leverage Modeling and Simulation (M&S) capabilities to support operational testing, systems analysis and user/operator training is motivated by a number of factors. As the complexities of new operations, such as multi-domain operations and operations in highly contested area operations, can no longer be tested and trained in live environments, leveraging M&S capabilities efficiently is paramount. In this paper, we use the differentiation of combat simulation requirements in terms of functional (e.g., model fidelity) and non-functional (e.g., real-time, distributed) characteristics to define a trade space to highlight challenges in relation to simulation purpose. 5th generation weapon systems require lots of data with high fidelity, depending on the purpose of the simulation. As functional and non-functional characteristics are interdependent, the design of supporting simulation systems must be well aligned with the purpose when developed, and is constraining possible purposes to be supported once it is developed.

1 INTRODUCTION

The international military environment continually grows in complexity. The technologies employed by the military's around the globe grow ever more capable and lethal. A challenge facing any military operating in this new environment replete with these new technologies is how to conduct operations. Tactics development are crucial to any military success but tends to lag the implementation of new technology.

Modeling and simulation (M&S) is a powerful albeit somewhat ubiquitous topic and methodology. This is because M&S represents many things depending upon a particular context with which one views M&S. For instance, discussions regarding military M&S might include analytical simulations executed on personal computers, real-time, interactive simulations that include humans-in-the-loop to support training objectives, live systems under test within some physical test range, and interconnections among the above particular cases providing a virtual environment in which simulations, systems and humans interact.

The above instances are by no means exhaustive; models and simulations are involved in all aspects of military operations: system development system analysis, system testing training and exercises and even system demonstrations.

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Despite their widespread use, and the military's increasing reliance on M&S results, there are still many challenges facing M&S. The challenges vary based on the particular context of the M&S. For the purposes of this work we define the following M&S domains, or worlds, to scope our delineation and discussion of the M&S challenges. The domains are constructive or analytical simulation, physical test ranges, virtual simulation and integrated virtual, constructive and live simulation. In the remainder of this paper, these domains are defined and challenges discussed including a set of special challenges emerging from the requirements to support 5th generation weapon systems in test, analysis, and training.

2 LANDSCAPE OF SIMULATION APPLICATION DOMAINS

2.1 The Constructive or Analytical Simulation

Constructive or analytical simulations are what the non-technical person might presume as a computer simulation. These simulations are usually wholly housed in a single system and are used for a variety of purposes. Some of these purposes include:

- characterizing physical performance of a system in some environment;
- assessing operational performance of specific systems within some operational context;
- determining potential outcomes of combat operations over varied periods of time and over varied areas of operations;
- familiarizing forces with areas of operational interest prior to the commencement of any operations (also called mission rehearsal);
- examining configuration changes associated with myriad processes used throughout the military environment.

Clearly there are many uses of constructive simulation. While there is no official taxonomy of constructive simulation uses within the military, an often employed graphic is the model hierarchy such as depicted in Figure 1. The pyramid presents many dimensions of use of constructive simulations. A smattering of example models are included within each of the levels.

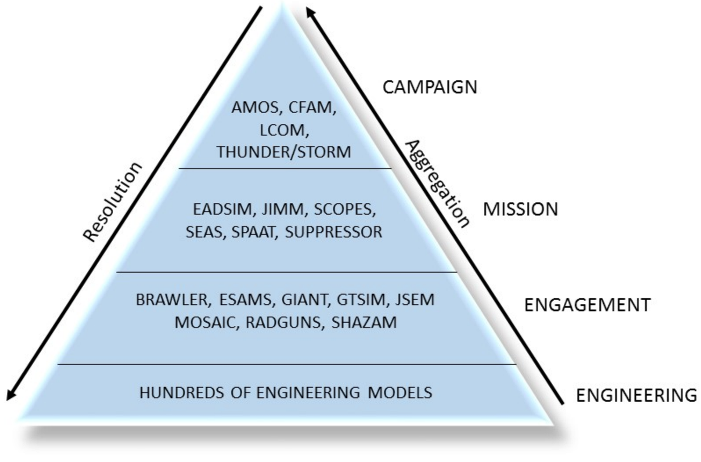

Figure 1: Department of Defense Model Hierarchy with Several US Air Force Exemplar Models for each level (from Hill and Miller (2017)).

We note that within the military domain, the term 'model' is often understood to mean a 'simulation application' that executes 'models' with an understood degree or level of abstraction (i.e., detail, resolution, fidelity, etc.). The pyramid provides a useful graphical organization of the relationships between these levels; it also serves as a guide for how lower level performance measures or results influence (i.e., roll up) and be used as inputs to higher level (i.e., more abstract) models and simulation products. These abstractions map to different conceptual views (i.e., perspectives) about different real world concerns (e.g., the lethality of a particular missile, as opposed to say, the effectiveness of a military campaign within a specific theater).

The right side of the figure depicts the general use categories for these types of simulations. Engineering uses are best thought of as design efforts for a system. Engagement uses would include efforts focused on ship-to-ship, aircraft-to-aircraft, even squad-to-squad combat encounters. The Mission level uses include multiple systems pitted against each other over a fairly short duration, such as hours to a few days. Finally a Campaign 'level' simulation use might examine a full military force going up against another military force over some prolonged period of time.

The pyramid structure also carries two implications of simulation use. First, on the left side indicates the level of resolution, or detail, contained in the simulation; the resolution decreases as the scope of the simulation use (time and range of systems or forces) increase. A similar concept is the use of aggregation in the simulation. A detailed simulation such as in engineering might conduct lots of calculations to seemingly minor aspects. For instance, a detailed simulation of air flow over a wing is extremely important in engineering level use. In a campaign level use, the air flow is insignificant when considering a scenario involving hundreds of aircraft, thus one does not model it in as much detail. The pyramid indicates the use of aggregation increases as the simulation use goes up the pyramid structure.

These levels of resolution and aggregation also tie to where in an organization such a simulation is used. Offices higher in an organization tend to be more concerned with broader issues while organizations lower in the organization tend to be concerned about finer grained, more detailed representations. The higher organizational entities would be concerned with campaign-level performance of a force, the lower organization entities might be more concerned with the daily performance of systems and personnel.

There are other dimensions of constructive simulation use; they can be static or dynamic, in other words capture the passage of time or focused on a specific instance of it. Constructive simulations can be used to represent both continuous or discrete aspects. This differentiation pertains to how the passage of time is handled within the simulation. Arguably, in this domain, an efficient approach to modeling systems is to define them in terms of states and state transitions that might occur due to particular events of interest and/or the passage of time.

The constructive simulation can be deterministic or stochastic based on whether the simulation models random events or does not model random events, respectively. There are benefits to using deterministic simulations in the combat simulation world, but generally a combat simulation will model myriad random events. The constructive simulation might also be used for descriptive, predictive or optimal seeking purposes. A descriptive use might involve a graphics-based simulation in which the execution is displayed to provide insight into the particular event simulated. A predictive use would look to support decision making events, such as using the simulations to conduct effectiveness analyses for new (or proposed) weapon systems. Finally, the optimal seeking use would employ supporting methods to drive the simulation to use those input settings that result in the best possible output from the simulation.

2.2 The Virtual Simulation

While constructive simulations are used to model (or represent) an entire system for study and analysis, virtual simulations represent particular aspects of a system for an entirely different purpose; namely, as a supporting apparatus to train, test, or study a real world entity or asset such as a person or piece of hardware.

The inclusion of humans and systems in the simulation environment can fall into one of the three types of simulation. If both the humans and systems are real, then we have the live simulation, if both components are simulated, it is the constructive simulation and if we mix the two we have the virtual simulation environment. Recently the increasing use of gaming in these environments has led to further refinement into a category referred to as "blended".

Unfortunately, the classification of simulations into distinct types is somewhat arbitrary, as it doesn't capture the degree of reality included as part of the system being represented. For this, we refer to simulations that include (as part of the system of interest) a degree of reality as a mixed reality simulation. Figure 2 provides a mapping from the common military terms of 'live', 'virtual', and 'constructive' to a sliding scale that represents this degree of reality included as part of the system of interest.

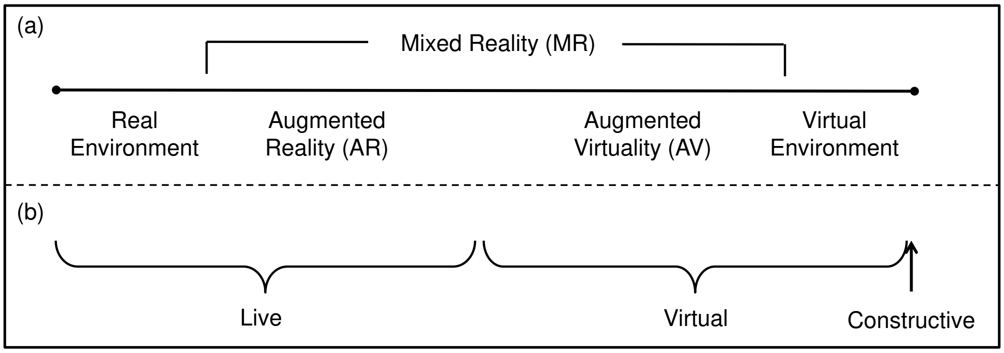

Figure 2: Relationship Between Mixed Reality Scale (a) to Simulation Types (b) (from Hodson and Hill (2014)).

From an implementation point of view, virtual simulations designed to interact with aspects of the real world must also satisfy additional requirements in the form of response time guarantees. In other words, the correctness of the simulation depends on both the outputs generated and the time taken generate them. For example, a response time requirement for a flight simulator to process all pilot stick and throttle inputs and and update graphical displays might be 100ms; longer response times may induce graphical stuttering or user disengagement. Thus, correctness depends on both the updating of the graphical display(s) and the time to do so (the response time).

Because virtual simulations specify non-functional requirements, they are categorized as real-time systems. This implies the software architecture and code associated with both models and simulation execution is different than a (typically) discrete-event-based constructive simulation. Due to the requirement to process inputs and generate outputs in a timely manner, virtual simulations often limit the level of detail and resolution they can support. This is in contrast to constructive simulations where resolution is only limited by available processing power and memory.

2.3 The Live Simulation

Live simulations are at the opposite end of the mixed reality spectrum from constructive simulations. They involve real people operating real equipment and typically take place on training ranges or in the field. A common example of a live simulation is air-to-air combat training. Here, the pilots are real, the aircraft are real, and the maneuvers are real – the only simulated aspect is the kill. This paper is not going to discuss this component in detail.

2.4 The Integrated Live, Virtual, and Constructive Simulation

Existing models, simulations, and live training events are often integrated to meet emerging requirements and improve capabilities. The desire to assemble and reuse simulations for purposes other than those for which they were originally designed is motivated by a number of factors. We articulate a few as follows:

- if various existing assets can be integrated to form a new solution, then, it might be possible to reduce costs in relation to developing a new solution from scratch;
- if unique simulation assets physically located at different geographic locations can be integrated into a new solution, then it's possible both tap those assets for new purposes and even improve them using decentralized processes, if desired; and,
- if particular simulation assets are deemed to be credible, validated or even accredited, then, ideally, they can be integrated with a degree of confidence they will work as expected.

Assembling and constructing simulation solutions using this approach (namely, connecting or interfacing existing or mostly existing assets) is called a Live, Virtual and Constructive (LVC) simulation. It should be noted that an 'LVC simulation' is not a new unique type of simulation with distinctly new properties; rather, it is an implementation method to create different solutions.

The motivating factors highlight significant reasons to understand why the construction of LVC's are of interest; the concept of reusing existing assets and interconnecting their functionality in ways to build new solutions is desirable but also ripe with pitfalls. We illuminate some of the more obvious integration and modeling issues as follows:

- the architecture for a particular 'type' of simulation (i.e., constructive, virtual and live) can be viewed from the perspective of how it interacts with the real-world (if at all). For a constructive simulation, by definition, no real-world interactions occur, so the architecture is often optimized to improve throughput (e.g., process as many 'events' per unit time as possible). For a typical virtual simulation interacting with the real world, the non-functional response time requirements drive its design to optimize timeliness. These are polar opposite objectives and can yield problems with timing and model composability;
- an LVC, by definition interacts with the real world in some way. Because of that interaction, they (akin to virtual simulations) are classified as real-time systems, and must consider response time requirements to support correct operation. Unfortunately, most constructive simulations are designed to optimize execution throughput at the expense of timeliness; this often limits their use as part of a LVC solution;
- simulation assets (especially software-based ones with defined models) are designed for a purpose, with configurable parameters to support a range of closely related purposes. When used as a means to implement a solution for a different purpose, the functionality modeled (detail, resolution, fidelity, etc.) might not align with the conceptual model for the envisioned system;
- leveraging credible, validated or even accredited simulations brings a degree of confidence associated with how that simulation functions and is integrated into new solutions; however, validation will probably have to be revisited due to changes in architecture and purpose. That is, composing a new simulation from validated (sub-)simulations does not imply the composition is valid itself; and,
- interconnecting disparate simulation assets is often accomplished with published protocols and standards. The standards define how each asset should interface and interact with each other, but can't solve all problems. Issues with latency and data consistency often limit the use cases for LVC simulations to training, or other situations in which the simulation is functioning as a stimulus to a system of interest. Using an LVC as a replacement to say, a constructive simulation, will probably present a new set of problems to be considered.

2.5 The Physical Test Range

Physical test ranges predominantly support technical testing of components or full systems - focusing on measures of performance, mainly hardware in the loop (HWIL), evaluating how well the system performs its designed functions - as well as operational testing - focusing on measure of effectiveness, using simulation to provide the synthetic battle sphere, evaluating how well the system contributes to the success of the missions, such as discussed in (Garcia and Tolk 2015). As the complexities of new operations, such as multi-domain operations and operations in highly contested area operations, can no longer be tested and trained in live environments, leveraging M&S capabilities efficiently as an integrated part of physical test ranges is paramount. The Test- and Training Enabling Architecture (TENA) was designed to support this mixed approach (Powell and Noseworthy 2012), but some of the new challenges discussed later in this paper may be stretching the limits of its applicability.

Another lesson learned is that operational tests should evaluate tests against systems that will be in the battle sphere once the system under test is operational. As many of these systems - own and opposing - are under development themselves, only simulation can provide these option, as the discussions in (Stapleton 2017) show. This requires a much closer cooperation of physical test range experts, test simulation experts, and the threat analysis community, starting with good data sharing practice, and hopefully supporting the use of common tools allowing a closer collaboration in the future.

3 CHALLENGES AND RESEARCH TOPICS

The previous section focused on some general aspects of military M&S application domains. Within this section, the focus will shift from these general observations to some specific technical and organizational challenges for the continuous development of combat simulation systems to support test, analysis, and training for 5th generation systems and the increasingly complex battle sphere.

3.1 Definition of 5th Generation Weapon Systems

Although there is no common definition for 5th generation weapon systems, some articles are contributing to a better understanding of the term, such as (Hood 2017). In his article, Hood focuses on the different generations from an aviator's perspective:

- The first generation is represented by aircraft like the US F-86 Sabre and the Soviet MiG-15 Fagot. They are the first jets emerging after the end of WW II.
- The second generation is exemplified by the US F-104 Starfighter and the Soviet MiG-21 Fishbed. Advancement in speed (up to Mach 2), weapons (air-to-air guided missiles), and sensors (enhanced night time and bad weather capabilities) defined this new generation.
- Further improvements resulting in beyond visual range engagements defined the third generation, such as the US F-4 Phantom and the Soviet MiG-23 Flogger.
- Aircrafts like the US F-15 Eagle or the Soviet MiG-29 Fulcrum belong to the fourth generation, that introduced digital datalinks to exchange and share information automatically, and also increased their effectiveness against ground targets with new radars and highly accurate air-to-surface munitions.
- The description of the US F-35 Lightning II by Lockheed Martin can be used as a reference point for 5th generation systems. According to their documentation, very low observable (VLO) stealth capability, next-generation avionics and sensor fusion, and embedded, network-enabled capability are the characteristics that make this multiple role aircraft a 5th generation system. The Russian counterpart is the Sukhoi Su-57, which is also characterized by stealth and advanced avionics.

The significant increase in air-to-air and air-to-ground combat capabilities and avionics make 5th generation fighters a dominant factor in the battle space. Testing, analyzing, and training for this new generation of systems will require not only 5th generation simulation systems, it will also require new scenarios with increased complexity, and may even require a new set of standards and new methods and tools in support of users as well as evaluators and engineers.

3.2 Technical Challenges

The focus of our paper is divided into technical challenges that concern the amount of data that is connected with the simulation of and for 5th generation systems and the need for improved standards supporting these activities. These are surely neither complete nor exclusive and will require more discussions and additional ideas in the future.

Our focus touches two main categories: the data challenges for new combat simulation systems, and the potential need for new infrastructures, which also implies the need for new standards, best practices, etc. Our current standardized simulation interoperability solutions are conceptually rooted in 20 year old technology, and there may be the need for new ideas to be incorporated.

3.2.1 Data Challenges

Improved avionics, increased on-board sensors, and the full integration of the flying platforms into the command and control capabilities as sources as well as targets is one of the main characteristics of 5th generation systems.

These implies that the amount of data needed to stimulate sensors, avionics, and network-enabled components surpasses current data requirements by far. How much data will be needed, and in which form it will be used to support operational testing and training, is yet to be fully understood, but comparing the sensor and avionics equipment of 4th and 5th generation systems clearly motivates that we are looking at a number that is at least an order of magnitude bigger than what we support with current simulation systems. The increased used of video and free messages for reports and information exchange is part of this challenge as well.

In addition, the data may need to be channeled through several independent routes to receiving entities that require different scope, resolution, and structure, a polymorphic variety that needs to be conceptually aligned. To put it simple: the same data representing phenomena in the environment must trigger various sensors that all provide different facets of such observations, so they will all use different data types to do so. Sensor fusion algorithms are used to merge different sources into a common situational awareness; these new challenge requires to do the opposite, namely to provide a magnitude of viewpoints to the sensors. As the test and training applications for sure will be interested in testing the fusion algorithms used by the system under test, the data must be realistically changed. Maybe entropy-based algorithms can support addressing this challenge, inverting the ideas presented in (Friend and Bauer Jr 2010).

In order to deliver these multiple and slightly distorted views of data to the simulated systems, we may need multiple data routing options on which aligned versions of the data are used to stimulate the sensors of the operational flight platforms, kind of having multiple RTI/Data channels that all provide inputs derived from the synthetic environment. What the systems are doing operationally will influence what data will be needed as well as what data is obtainable by the simulated system. These will require a very tight coupling of operational and technical experts to ensure that the simulated system receives all the data required, but not data unavailable under the currently simulated operational constraints.

The huge amount of data may result furthermore in time issues. In particular for distributed experiments, the pure latency time may result in constraints that oppose real-time testing and training (Millar et al. 2016). This implies that instead of the currently implemented central server solutions or even cloud computing approaches, these future application may require edge computing (Varghese et al. 2016), including services such as these following examples:

- Very smart data management may reduce the data actually needed to be exchange, hence reducing the bandwidth needed.
- Instead of providing data and computing in the cloud, synchronized algorithms may have to be provided at the edge in multiple instances. This is like the next generation of dead reckoning algorithm ”on steroids,” as we are envisioning full replicated and synchronized models to communicate to

the edge of the cloud, or whatever the infrastructure utilized for the next generation of combat simulation systems may look like.

The data challenges discussed in this section are only a small subset, but they already point to various weaknesses in current international standards that have to be addressed by future infrastructures, as discussed in the following section.

3.2.2 Improved Use of Standards

The overall problems when building combat simulation systems to support test, analysis, and training for future weapon systems will be challenges of transferring explicit knowledge, information, and data in the supported large and heterogeneous organizations (Tolk and Aaron 2010). To ensure this will be the case, computer engineering methods and solutions will be necessary, but the will not be sufficient. The overall conceptual alignment not only within the simulation systems, but also between the various phases will be required to ensure that the correct problem is investigated and solved, and solutions will be unambiguously documented and communicated. Current solutions are usually focused in supporting a particular phase. If model-based systems engineering approaches will be used, the knowledge gained can be easier transfered between the different phases, starting with a common set of metrics and success criteria, and allowing to feed back scenarios from real-world operations for training, testing, or analysis purposes from early procurement phases on. Each phase can continue to have its phase-specific viewpoints, but the underlying model ensures consistency when knowledge is captured, documented, and communicated. Furthermore, model-driven approaches may even support the development of supporting systems, including simulations thereof.

To support such a vision, better HWIL integration approaches will be needed allowing concept to prototype to component testing with the same framework. In several other domains, these ideas are already implemented and applied, such as described in (Wetter 2011) for architectural projects. Other examples are automobile design, smart cities, and more. Current standards may not be sufficient to support the full spectrum, but lessons learned from building such prototypes show the value of these approaches (Valverde and Sun 2017).

Overall, the better support of open architecture and maybe even open source solutions should be a pillar of the simulation standards of the next generation. Other domains, such as the Smart Grid (Strasser et al. 2011), show that such approaches are not only feasible, but also lead to high reuse and repeatable results, including transfer from virtual to operational environments and vice versa. The cyber physical system domain is another example of interest, although they currently focus on standard solutions outside of the simulation domain (Tolk et al. 2018). The more open standards, open architecture, and open source solutions are integrated with future simulation standards, the easier will be the transfer of knowledge to provide best support for testing, analyzing, and training. These new solutions should also include the use of visual effects as used in movie productions, realistic representations of virtual partners in virtual and augmented realities, as known from the game industry, and all other possibilities that will help to make the next generation of combat simulation systems better.

3.3 Organizational Challenges

It is well understood in the engineering management world that in order to be successful with new methods and tools, you do not only need the necessary IT infrastructure, you also need an educated workforce that knows how to put the tools to best use, and you also need a supportive management. That is true for the next generation of combat simulation systems as well. We will in particular need knowledgeable personnel in all background requirements, such as modeling, statistics, software engineering, and systems engineering, as well as less traditional requirements such as knowledge management, distributed systems, and more.

Modern warfare is characterized by a multitude of nonlinear relations and interconnections of a multitude of heterogeneous components and systems, resulting in a highly complicated, potentially complex environments. Such complexity requires a new set of methods from the domain of complex systems engineering (S. Sheard and S. Cook and E. Honour and D. Hybertson and J. Krupa and J. McEver and D. McKinney and P. Ondrus and A. Ryan and R. Scheurer and J. Singer and J. Sparber and B. White 2015) that allow better recognition, understanding, and management of complex systems properties – in particular, emergence. This will require a new understanding within organizations regarding exactly what their task is, as the role will change from being the ”watchmaker” in complicated systems to becoming a ”gardener” in complex systems, moving from engineering of solutions to the governance of constraints.

Overall, more organizational alignment will be needed, as without a common framework allowing for easy assembly, each organization will bring its own assumptions, paradigms and toolkits to the table, leading to an increased interoperability issue set with higher complexity than we experienced in the past. Despite some shortcomings, a model-based systems engineering approach is currently the best solution to cope with these issues. A side challenge is that some organizations may simulate for the simulation's sake, without clear guidelines. This needs to be addressed.

The last topic to be addressed in this section is multi-level security. Some foundational work regarding special requirements for simulation challenges has been published more than a decade ago (Danner, Muckenhirn, Valle, McElveen, Bragdon-Handfield, and Colegrove 2002; Danner, Valle, and Sparta 2005), but no real break-throughs have been published since. Some good guards have been applied, and the Operation Blended Warrior demonstrated at the recent Interservice/Industry Training, Simulation and Education Conference showcased some advanced solutions, but the main challenges still remain: how to avoid observers and analysts deriving classified information from the execution of simulation experiments? How to reach the overall objective – that operators do what they must in an unrestricted, but not necessarily technically deep environment while analysts get access to the data they need to accomplish their approved activities, but not more than what is required – is still topic of ongoing research.

3.4 Combat Simulation Challenges

Combat simulation has always faced challenges. In the light of 5th generation system requirements, We discuss some of these persistent challenges followed by a discussion of some of the pressing modern challenges.

3.4.1 The Standard Challenges

While there may be longer lists of standard challenges facing combat simulation, we limit this discussion to three we believe are the most prevalent.

One of the key ongoing challenges is how to sufficiently represent systems in the simulation. This relates to the aggregation-fidelity trade alluded to within the modeling pyramid. Simulations require enough detail in any system representation to properly answer the question driving the study, and the use of the simulation. A simulation used to assess aircraft maneuverability needs detailed aerodynamics. This level of detailed modeling is computationally expensive. Representing that same aircraft in an air-to-air combat simulation requires only an aggregate representation of maneuverability. This aggregate representation reduces the computational burden associated with the aircraft movements, allowing more aspects of the scenario to be considered in the simulation.

Data is a huge aspect of a combat simulation. Data is used to define the specific capabilities of all the systems modeled within the simulation scenario under study. Crucial aspects of a combat simulation include things like radar signatures for the aircraft; any targets and weapons; weapon capabilities such as flight speed, maneuverability and end-game probability of kill; operational tactics employed by components in the simulation, particularly as those tactics adapt to opponent tactics; and communication networks. Bad data employed in the simulation will produce incorrect results. Accurate, valid data is needed to obtain meaningful results. As discussed before, ensuring that these data are not only obtainable, but also conceptually aligned, is particularly hard, but necessary.

Combat simulations require context – what operational scenario is considered in the study. Classification issues aside, defining the scenario that might be faced in some future conflict will never be accomplished with absolute correctness. Thus, analysts must define scenarios of sufficient fidelity so that results obtained instill confidence in the insights gained. An ongoing challenge is how to define and employ realistic simulation scenarios particularly when the questions being asked of the analyst are constantly changing.

3.4.2 The Newer Challenges

There are also many challenges to the combat simulation domain that might be considered new. For this work we consider just three that we find particularly vexing.

Combat is an inherently human endeavor. Modern technology may often remove the humans from direct contact, but these systems are still operated by humans. Combat simulations do an aggregate job in the modeling of humans. Engagement-level simulations capture the tactics employed by the operator, but these are as specifically programmed. Mission-level simulations capture command and control functions, but again only at an aggregate level. As more combat operations end up in urban settings, or in conflict with terrorist organizations hiding among the populace, or in humanitarian operations with aggressive components, the combat simulations used to prepare our forces and shape the decisions of our leaders must capture the true human element. The challenge in capturing that element lies in attaining the proper balance between model fidelity and model run time. As associated challenge is how to appropriately incorporate the human-in-the-loop as an avenue to represent human decision making. While the involved human may add decision making realism, that same human decision making component may introduce extra variability into the simulation output potentially obscuring results.

Combat simulation output is meant to provide insight to the decision making process. The utility and acceptance of that insight is predicated on whether the simulation is deemed acceptable for use, also known as model validation. Unfortunately, no simulation can be fully validated since any model is a simplification and abstraction of reality. However, a simulation can be deemed valid-enough to provide the intended insight to answer the driving analysis questions. The challenge then is how to define "valid enough" and developing the validation methodologies to make that decision. Valid enough is admittedly quite ambiguous. However, there are surely enough cases of model validation and metrics to derive a simulation's validation status. The decision analytic domain has very applicable methods with which to derive value models for unique decision situations. A useful challenge is how to develop such a value model for a combat-simulation-based decision situation and from the value measures within the value model, derive a rating for the validity of a particular combat simulation for a particular analytical endeavor, which includes unambiguously capturing the validity context to ensure proper reuse and composition.

The final new combat simulation challenge is how to fully promote the concept that models and simulations provide insight, not answers. Decision makers provide answers ideally based on quality insight provided by the combat analyst using the combat simulation. The challenge boils down to developing an assessment mechanism with which to define how good the simulation results are and how good the resulting insights are for the decision maker. This is true for operational tests requirements for 5th systems as well.

4 SUMMARY AND DISCUSSION

These research challenges discussed in this paper are not limited to the military domain, but many have been identified as critical M&S capabilities in other domains as well, such as in (Tolk and Rainey 2015; Fujimoto 2016; Diallo, Mittal, and Tolk 2018). An underlying hypothesis of this paper is that our battle space may have evolved from a complicated system into a complex system that no longer can be evaluated using the so far successful principle of reductionism. Systems have to be tested, analyzed, and trained in the enterprise context, which may require a new well-orchestrated tool set and even more increased collaboration.

In the NATO Net Enabled Capability Command and Control Maturity Model (N2C2M2) the author provide a vision to evolve from system- and organization centric structures to self-organizing, highly agile and resilience net-centric structures (Alberts et al. 2010). The simulation community does not only need to follow this recommendations, it should lead the way to support testing, analysis, and training in such complex environment in all domains and categories discussed in this paper.

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