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A HISTORY OF UNITED STATES MILITARY SIMULATION

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ABSTRACT

The history of simulation and combat modeling associated with the military, and with military actions, is as old as the human race. Since humans began competing for resources, those involved have used simulation techniques of some form to better understand conflict and increase their chances of procuring favorable outcomes in those conflicts. This paper provides a historical perspective on the use of simulation in defense particularly in United States military planning, analyses, and training. This perspective starts by describing the simple table-top, thought exercises and proceeds through the development of ever more sophisticated methods to arrive at the modern United States military simulation environment, which involves everything from laptop applications, through large-scale simulation models, to the advanced distributed simulation architectures currently in use for demonstrations, training, and analytical purposes.

1 INTRODUCTION

> *A model is a simplified representation of the entity it imitates or simulates.* (Battilega and Grange 1984)

Combat is among the most complex of human endeavors. Combat is fraught with uncertainties, something often referred to as the *fog of war*. Trying to plan and understand combat requires the use of models, or abstractions, of the battle or military campaign. These models can be extremely powerful allowing leaders and planners to consider a range of strategies and potential outcomes.

Department of Defense (DoD) modeling falls into the following functional areas:

- analysis;
- training; and
- acquisition.

Modeling however is too broad a term. In fact, the DoD prefers to group the variety of modeling techniques under a common label, modeling and simulation (M&S). Military M&S techniques actually involve statistical, probabilistic, optimization, decision theoretic, and simulation modeling. Our focus in this paper is military simulation modeling, which can also have a wide interpretation. Figure 1 is a wonderful graphic depicting the incredible range of events that are considered in the realm of United States Military Simulation. Our discussion will touch on each of the categories depicted in Figure 1. Each of the above three functional areas have simulation focii as well.

Analytical simulations, those not involving human interaction, are employed to gain insight to help leadership answer specific questions. For instance, one question faced in the 1990s was whether the F-22

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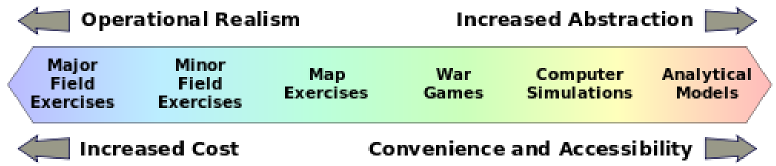

Figure 1: Graphic depicting the spectrum of military simulations based on Modeling and Simulation of Land Combat by J. G. Taylor, graphic available from Wikipedia (2017).

fighter aircraft system would be significantly more effective in air-to-air combat than current systems when facing current, and future opponent systems. Naturally, the question was asked before the system was even built, but an approximate, reasonably certain answer was required. Subsequent simulation analyses created accurate representations of the F-22 in anticipated operation, to include specifically modeling its planned variety of combat capabilities. Similarly accurate representations were created of adversary aircraft. These aircraft were then placed in a wide variety of simulated combat scenarios and results compiled to help Air Force leadership answer the effectiveness question.

Training simulations are used to improve individual or unit capabilities. This training includes very specific training for very specific situations that might arise. For instance, we could load a particular location into the simulation environment and then have a pilot do a virtual fly through of that location. Such a "mission rehearsal" use of simulation helps reduce the uncertainty in a mission faced by a pilot. Inducing potential deviations from a planned scenario helps improve the pilot's capability to react appropriately should any such deviation from planned events become a reality.

Training simulations can be extremely large and not be exclusively contained in the computer. Large-scale exercises, such as Key Resolve or Foal Eagle held in South Korea, Keen Edge held with Japanese forces, or Cobra Gold involving Asian allies and held in Thailand (to name just a couple), incorporate actual forces and systems interacting with computer simulations in a Live, Virtual, and Constructive (LVC) simulation-supported training/exercise construct. These efforts involve thousands of individuals, across multiple military services, generally involving multiple countries, and myriad weapon system representations.

Simulations for acquisition are those used to support the weapon systems development and procurement process, known as the DoD Acquisition Process. Quite often there is a blurring of the demarcation between analytical and acquisition models. For instance, we have used a model called the Logistics Composite Model (LCOM) to model base-level repair processes to determine whether an acquisition program is planning to provide sufficient spares and sufficient maintenance personnel expertise. A life cycle maintenance plan may call for some number of specifically skilled maintenance personnel assigned to a maintenance unit. A maintenance scenario, complete with system failure models and parts supply models, help ascertain if the manning plans are sufficient for the anticipated maintenance demand.

More generally, military simulation analyses support endeavors in (Battilega and Grange 1984)

- battle planning;
- wartime operations;
- procurement;
- force sizing;
- human resource planning;
- logistics and deployment planning; and
- national policy analysis.

Each of the above are generally explained in Battilega and Grange (1984). As mentioned, in the DoD, M&S is a fairly ambiguous term. The specific focus of this paper is on the general history of military simulation modeling.

Quite a few years ago, the DoD defined simulation as:

> *A method of implementing a model over time. Also a technique for testing, analysis, or training in which real-world and conceptual systems are reproduced by a model.* Battilega and Grange (1984)

Fortunately, this remains pretty much the accepted definition.

Note, however, that the above definition does not mention computer technology as a required component to the model. Quite often, however, this is exactly the association formed when referring to a simulation; a computer model mimicking some system or process over time. While computer technology has no doubt provided an impetus for the *explosion* in the use of computer simulation, the history of military simulation predates the use of the computer.

One may argue that the human decision-making process is the oldest simulation system. Recognition-Primed Decision Making (RPD)(Ross et al. 2004) is a theory that posits we play out, or wargame out, scenarios thus simulating them into some expected future state as a methodology for choosing some best alternative. If we accept this theory, which we do for this paper, then humans have been simulating probably since human cognitive processes began. Further, humans have been in conflict with one another for as long as we have been competing with others for resources. The leadership of the factions within these conflicts have long struggled with how best to defend their resources and defeat their attackers.

The human-based, simulation-focused decision process is found in any military or conflict situation. Leaders construct some strategy by which they intend to defeat, or at least hold off, their opponent. Various force deployments are considered and outcomes of those deployments are conjectured, or wargamed out as it is often referred to. That deployment deemed most favorable is selected. Final outcomes are then realized when that selected strategy is pitted against the opponent's similarly derived strategy. What history reveals is the evolution of how the human decision maker is supported in their simulation analyses and how increasingly complex an environment is envisioned during the military planning process.

> "*No Battle Plan Survives Contact with the Enemy*" – Helmuth von Moltke

There are a variety of ways to organize any discussion on the history of military simulation. One reasonable way to provide a history of military simulation is to discuss that history in terms of three overlapping epochs:

- human-thought-based and adjudicated games;
- mathematically-based, computer-based implementations of those games; and
- training-based simulations.

These epochs align with the specific sections of the paper.

This paper is organized as follows. In Section 2 we establish the centuries-old tradition of military simulation with a focus of what we term, human thought-based games. In Section 3 we relate the introduction of mathematical thought into yet another natural process of human interest, military conflict. In Section 4 we note the introduction of the computer as a motivating force behind the explosion in military computer simulation, a theme we continue in Section 5 when discussing a small sample of modern analytical simulations. In Section 6 we describe the rise of distributed simulation and the incredible role it has played shaping current training, demonstration and even to a limited extent, analysis, particularly as this evolved into the LVC constructs we discuss in Section 7. Section 8 focuses on contributions from the military track of the Winter Simulation Conference. Since this history is necessarily too short, and somewhat biased by our own experiences, we recount some of the aspects we failed to cover in Section 9 and wrap up our historical perspective in Section 10.

2 HUMAN-THOUGHT-BASED WARGAMES

The history of simulation in the military is incredibly long (Aebersold 2016) and over time has assumed key roles in a wide variety of application areas (Hill et al. 2001).

Early uses of simulation focused on what we refer to as thought exercises meant to hone strategic (and tactical) skills in both the preparation and conduct of military operations. Sun Tzu, well-known to anyone with a passing knowledge of the history of military strategic thought, invented Wei Hai involving the use of color-coded stones to represent opposing armies (Aebersold 2016). Smith (2010) acknowledges Japanese references to Wai Hai as far back as 3000BC, and notes the game's lineage to the modern game of GO. Chess also has a military lineage dating back to 500BC India and their CHATURANGA military strategy game (Smith 2010). Leaders of the time viewed these games as useful methods to hone not only their own strategic thinking skills, but those of their subordinates. While the modern versions of these games are no longer officially part of the military planning and training portfolio, their impact in the history of military strategic analysis cannot be ignored. These games evolved to help military members of the time grow as military leaders. Roman commanders employed similar simulations, their particular devices being sand tables in which miniature soldiers were used to represent armies (Aebersold 2016).

History reports the use of table top exercises as early as the Vikings and Celtics. These exercises actually involved varied scenarios, an approach we still employ today in all our military planning. Koenigspiel emerged around 1664 as a board game once again focused on warfare strategy (Smith 2010). Around 1811, Kriegsspeil became the first real thought exercise we might fully view as a simulation. This method involved independent ajudication of player moves and the use of the dice roll to introduce randomness; simulations today will often refer to model random components as the "dice roll" (Loper and Turnitsa 2012).

By 1824 this board-game-based simulation of military plans and operations had become a fairly standard practice. Nothing beats widespread adoption more than success and the tremendous success of the Prussian Army in the early 1800s led to adoptions of military gaming methods by the Austro-Hungarian Empire, the UK, Italy, France and Russia (Loper and Turnitsa 2012).

By the late 1800s and through the pre-WWII years, board-based wargame simulation use in the US grew tremendously. However, as noted by Caffrey (2000), these wargame simulations were not universally accepted, particularly when some injected components were perceived as "out of bounds" for the scenario. A case in point were early efforts prior to WWII to inject air power considerations into primarily ground (i.e., Army) focused studies. Undeterred, Army Air Corps (forerunner of the US Air Force) leaders used these simulations to formulate the air doctrine used in WWII operations. There are many other examples from history where actual plans were "thoroughly wargamed," for instance the Schlieffen Plan of WWI, the 1940 Ardennes offensive, the Operations Barbarossa invasion of Russia in 1941 and the Japenese attack on Pearl Harbor in 1941 (Shrader 2006). Details on the history of wargaming are found in Caffrey (2000) with specific details on their use in Dunnigan (2000).

These "sand tables" as they are called remain in use in a variety of forms. Various objects are used to represent combat forces and these objects are placed and moved around the combat environment depicted. Opposing teams move their forces with outcomes, such as advancement or attrition for either side, independently adjudicated by some agreed to method. Figure 2 provides pictures of these simulation examples, from a depiction of Germany's use, though WWII defense planning in Great Britain, to modern types of sand tables.

By the 1950s, however, organizations such as RAND were evolving these approaches to better represent combat, to incorporate the growing body of work governing the mathematics of combat, and thereby provide a means to analyze combat in the nuclear age.

Figure 2: On left, depiction of German staff engaged in Kriegspiel (PreparedX 2017). In the center, the underground operations room at the Headquarters of RAF Fighter Command during WWII (Lane 2010). On the right Cassidian's Interactive Terrain Sand Table, an interactive terrain sand table that can be used for training purposes and mission planning (Cassidians 2012).

3 MATHEMATICS COMES TO MILITARY MODELS

> *Models and Simulations are representations of reality that allow Airman to better understand and interact with their environment.* Air Force Policy Directive 16-10.

Mathematics has been used to try and understand most natural phenomena (Kline 1985). It follows naturally then that mathematics be used to help understand military action. This use of mathematics as applied to models of combat seems to have started in the late 1700s (Shrader 2006), but was likely limited to adjudication rules supporting the table top wargames.

As discussed in Johnson (1990), Lanchester in 1914 devised a set of differential equations to predict attrition in aimed fire conflicts. One basic example is:

$$\frac{\partial B}{\partial t} = -\rho R \tag{1}$$

$$\frac{\partial R}{\partial t} = -\beta B \tag{2}$$

where B and R are friendly (Blue) and enemy (Red) force levels, respectively, and ρ and β are their respective attrition (or effectiveness) factors. Equations 1 and 2 describe the change in force levels as a function of the size of the opposing force and the effectiveness of that force. While not immediately influential, these equations, and similar equations developed for other aspects of combat, were found fairly effective and easy to calculate. This development provided improved capabilities to adjudicate attrition during the sand table planning efforts. Equations 1-2 were originally developed for air-to-air combat but variations evolved to cover other aspects including ground force combat and naval engagements.

There remains a rich literature on the Lanchester equation-based models. Researchers have used historical data to estimate equation parameters to retroactively describe various combat scenarios. Such systems have been devised for Naval operations and cyber warfare in addition to the originally intended ground and air combat. Some simulation models are built around these equations (Battilega and Grange 1984). These models do not appear as effective at describing more modern forms of combat, such as urban warfare.

The utility of mathematical models for combat analysis grew significantly during WWII efforts. Setbacks against Axis forces, particularly against some of their superior technology, led Allied leaders to engage leading scientists to research problems in their current operations. The models developed by these early Operations Researchers helped improve bombing campaigns, supply operations, anti-submarine warfare, and radar placement, to name just a few (Morse and Kimball 1951). Their models were not particularly complex but were fairly abstract representations of the reality they were examining. Tractability meant less complex models were required. Naturally, improved computing capabilities could change this, and did, allowing rapid computation of the simple, more abstract models and the development of the more comprehensive and complex models needed to gain insight into the increasingly complex, global nature of warfare.

4 COMPUTERS + MATHEMATICS = COMPUTER SIMULATION

> *Simulation and gaming as tools of warfare has a long history* (Smith 2010)

Despite the long history of military simulation, early efforts were always constrained by personnel abilities to comprehend the complexities involved. Tractable planning (and training) required abstracting the scenario into something manageable. Adding mathematics to the human-based simulations improved the accuracy of the abstraction, but did not really address the complexity and tractability. Automated calculators, or if you prefer, computers changed that and really ushered in a more extensive use of military simulation.

> *"..the computer enabled the design and use of much more sophisticated wargames in which a multitude of factors could be considered."* – Shrader (2006)

The ENIAC computer arrival at the University of Pennsylvania in 1943 is usually regarded as the start of the modern computing age (Metropolis 1987); it also played a key role in computer simulation. Researchers involved in nuclear weapons research were trying to solve complex problems in areas such as radiation shielding (Loper and Turnitsa 2012). Famous researchers Stanislaw Ulam and John von Neumann knew sampling theory could be used to solve the problems, but the technique was manually intensive. However, they recognized that the new automatic calculating machine, the ENIAC, could generate samples really fast. They resurrected sampling theory, implemented it on this new computer thereby quickly reviving statistical sampling methods with which they could evaluate complex, otherwise intractable, functions. The method was dubbed "Monte Carlo" in deference to Dr. Ulam's uncle's propensity for gambling (Metropolis 1987). Thus, our earliest computer-based simulations grew out of military-based research. The ENIAC, despite its rudimentary design by modern standards could reduce a 20-hour, human-based calculation to 30 seconds (Shrader 2006). The subsequent results highlighted the tremendous potential of the computer to take over the overwhelming task of performing the calculations associated with the mathematical models of combat used in conjunction with the board games. In fact, the use of computers to augment their wargames was a major part of the work in the Army Operations Research Office through the 1950s (Shrader 2006). Naturally, like all new techniques, it did not take long for the possibilities of computer-based simulation to grow, and fortunately, get realized.

Computational combat models, the combat simulations, made sense. Manual calculations and the use of the maps or sand tables were useful but cumbersome and slow. Computer calculations greatly expanded the complexity of scenarios addressed. Computer graphics could be used to easily display the combat environment represented via some grid with additional graphical representations of the planning objects moving around that grid. More importantly, the use of these new computer simulations provided the motivation to develop new algorithms to incorporate other aspects of military operations. These algorithms focused on decreasing the level of abstraction previously required and thus adding more realism to the simulation representations. The previously defined human-based process of military simulation modeling of particular operational scenarios could be replaced by digital representations of more complex scenarios, involving more objects and more aspects. The human analyst could continue to focus on the big picture aspects of the simulation study while the computer handled all the underlying details.

As we have personally experienced, answering some set of questions will often give rise to new questions. Naturally, these questions require deeper study and generally require simulation model changes. This is the beauty of military simulation. When faced with new questions, we can devise new simulation representations necessary to answer the question, build the representations into the simulation, conduct the study and use the results to answer, or provide insight into developing the answer.

Over time, simulations grew more complex but also more comprehensive. These more comprehensive models required more resources, but were intended to provide better answers. The more comprehensive the model the more involved the computer code, which will generally mean more computing resources required. In addition, the more comprehensive the model, the more data necessary to drive that model. Sometimes obtaining the data for some simulation model required the running of other simulation models. For instance, in our campaign-level analyses, we may need loss rate data for adjudicating the air combat components of the campaign-level scenario. These data are obtained by running simulation studies using a model specific to air combat programmed with the air combat scenarios from the campaign analysis. That model of air combat may require probability of kill information for a specific weapon fired against some specific target and this is obtained by running a more detailed model of the specific weapon against that specific target with results compiled tabularly into the air combat model. The more complex the model, the more difficult the model was to understand which could be a problem when simulation results failed to agree with "operational experience." Thus, modelers needed to become more specialized, focused on single models, to bridge the operator-to-analyst knowledge and experience gap.

4.1 An Early Ground Model

Ground models address land-based, force-on-force combat. These models get complex very quickly since they involve many objects, doing lots of different things, moving around a diverse environment, and ultimately, trying to destroy each other. Algorithms are needed to represent target detection and acquisition, object movement, obstacle avoidance, etc. Data are needed to represent many things such as weapon characteristics, terrain, weather, etc. In addition, the tactics and plans created by the actual military planners must be adequately represented in the simulation so that the simulation "behaves correctly."

One such early simulation model, realized in the 1950s, was CARMONETTE. This model grew to be a fairly complex model. The simulation included aspects of infantry, vehicles, artillery, mortar fire and helicopters. As appropriate, these model entities move with their forces to align against the opposing force. They acquire targets in the opposing force, aim and then fire weapons to potentially inflict damage against those opposing forces. Probabilistic elements in these simulations include the time to load and fire weapons, whether or not the target is acquired (so it can be fired upon), and then the probability of kill given the target is hit by the weapon fired (Battilega and Grange 1984).

In practice, the model was not particularly detailed (by modern standards) in its level of modeling yet still required an intensive data preparation effort and an in-depth knowledge of the model logic to conduct studies.

4.2 An Early Air Model

In general, an air engagement is considered easier to model than a ground engagement (Battilega and Grange 1984). The rationale is that the air environment is more homogeneous than the ground terrain with less things getting in the way of object movement. However, as someone who has used these models, this does not mean the models are simple, in fact these models can have the complexity of engineering level models in terms of the physics of flight being modeled.

The AVENGER was an early air-to-air model. The scenario typically considered was the two-aircraft scenario, called a one-versus-one engagement (Shaw 1985). The goal in this simulation was to accurately model the close-in, air-to-air duel based on aircraft maneuvering to fire their cannons or missiles at the opposing aircraft. This meant using the mathematics of flight to capture the accurate dynamics of the aircraft flying in the environment as well as the fly-out of any projectile fired by an aircraft. It meant capturing the tactics employed by the pilots to maneuver the aircraft into a position to fire, capturing the decision process of the pilot to engaging via guns or missiles, and the end-game probabilistic draws to

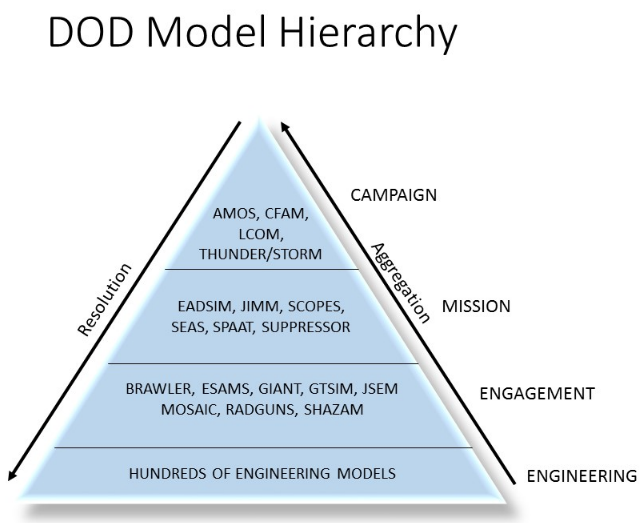

Figure 3: Department of Defense Model Hierarchy with Several Exemplar Models for each level (Adapted from Hill, McIntyre, and Miller (2001)).

determine if a target is hit and then if hit, whether the hit is lethal causing the destruction of the impacted aircraft.

In practice, this model, as with the previously discussed model, required a good deal of data to run and model specific knowledge.

5 MODERN MILITARY ANALYTICAL SIMULATION

The computer has ushered in tremendous change in every field and impacted every aspect of our lives. The military in general has truly been revolutionized with the introduction of computers and computational system technology. When we entered military service, state of the art technology could scan the radio frequency band, data backups were via analog tapes (that had to be changed every couple hours), and computer output was from large impact printers. Now, channel scanning is standard in every car radio, the mention of analog tape induces giggles in our graduate classes, and computer output comes in high resolution graphics sent to color printers or even to high-resolution movies. For military simulation, the computer technology has exponentially increased the quantity and quality of the military simulations, spanning analysis, training, experimentation and weapon systems acquisition.

As a device to get a handle on the complexity of the simulation models, to characterize the wealth of models, and to set the stage for model development and expansion, the DoD in the mid-1990s developed the hierarchy of models concept, such as the one depicted in Figure 3. This hierarchy helps describe the varied uses and levels of modeling detail employed in military constructive simulation models. Constructive analytical models, which has been our primary focus thus far, span the range of analytical applications previously listed. This range covers the earliest phases of requirements determination for new systems, through acquisition of those systems, to include the resource determination of how many to acquire, to the actual testing and evaluation of the system in a fielded environment (Hill, McIntyre, and Miller 2001).

Figure 3 shows the classification of any simulation model according to its level of aggregation and resolution. Aggregation and resolution are inversely proportional to each other. The more aggregate, or abstract, the model the less specific the modeling. The higher the resolution, the more detailed the modeling. The lowest level includes engineering-level models of systems or system components. It is not unusual for such models to address snap-shots in time, or even focus on seconds or minutes of operations. It

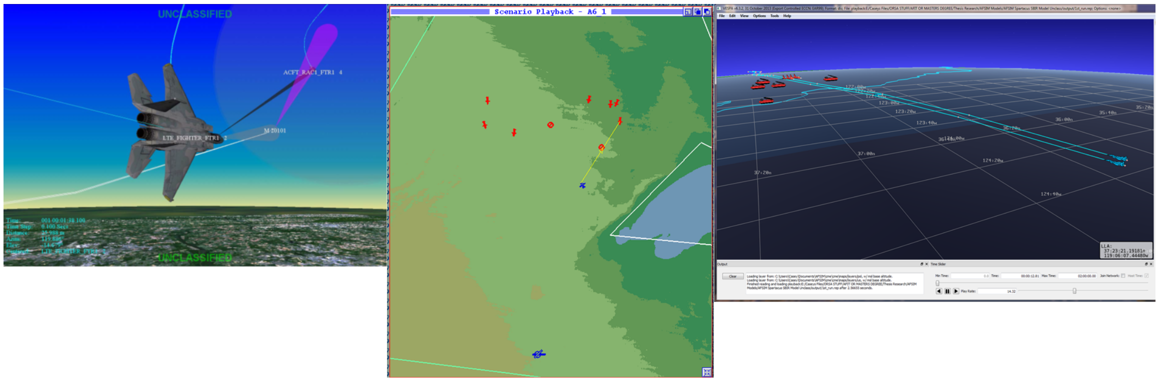

Figure 4: On the left, a screen shot of Brawler (SRS Technologies 2007), in the middle the EADSIM (Azar 2003), and on the right, a screen shot of an AFSIM model (Conners 2015)).

is also fairly common for these simulations to be deterministic simulations (e.g., finite element models, computational fluid dynamics models). Models in higher levels of the hierarchy increase in modeling aggregation and the length of time modeled. Engagement-level models include physics-level modeling as well as some aspect of human involvement. The time span for such models is on the order of minutes to a few hours. Mission level models are more concerned with the interactions among disparate systems, such as one might find in a particular battle. These models can have components of physics-based models but more often will trade-off the modeling fidelity to increase the scope of systems considered. These models will often employ data generated by models found lower in the hierarchy. The time frame for a mission level model is on the order of hours to maybe a few days. Finally, campaign level models are the most aggregate in terms of modeling detail and address the greatest span of time. A campaign model will generally model Army Corps, Air Force Wings or Naval aligned enemy forces. The time span for a campaign level model is on the order of weeks to months and the level of modeling detailed associated with the objects in the simulation is greatly reduced (Hill, McIntyre, and Miller 2001).

To standardize analytical model usage, and reduce new model development for specific purposes, the Air Force created the Air Force Standard Analysis Toolkit (AFSAT). Member models of the toolkit are approved for use in analytical endeavors. We briefly describe three members of the toolkit, each of which are drawn from one of the three upper levels of the model hierarchy in Figure 3 (Hill, McIntyre, and Miller 2001). The Army and Navy have organizations that track their myriad models, but do not appear to have a focused repository such as AFSAT.

Brawler is an engagement-level model used for detailed analysis of air combat in both within and beyond the visual range of the pilot. The Brawler model includes physics-based models of aircraft and missile dynamics, radar, radar behavior to include target acquisition, and radar jamming. Brawler also includes a model of individual pilot behavior, the Brawler Mental Model, used to examine various mission and tactical doctrines particularly in light of emerging and envisioned weapon systems (Hill, McIntyre, and Miller 2001). Very much like earlier air models, Brawler is data-driven. Inputs for a Brawler run involve massive input tables covering everything from aircraft aerodynamics to probability of kill tables. Figure 4 contains a Brawler animation on the left side. Unlike many discrete event simulations, Brawler animations are not necessarily run in real-time with the simulation but are post processed. Defense simulation must retain operational credibility and we use this post processing animation as a playback mechanism to ensure the simulation is generating accurate (and realistic) representations of air combat, as an actual combat pilot would validate it as looking realistic.

The Extended Air Defense Simulation (EADSIM) is a many-on-many simulation of air, missile and space warfare. EADSIM falls within the Mission level of the modeling hierarchy. EADSIM models such things as active air defense systems, air-to-air engagements, bombing attacks, and cruise missile attacks. EADSIM is used by analysts to gain insight into issues such as theater missile defense architectures, battle

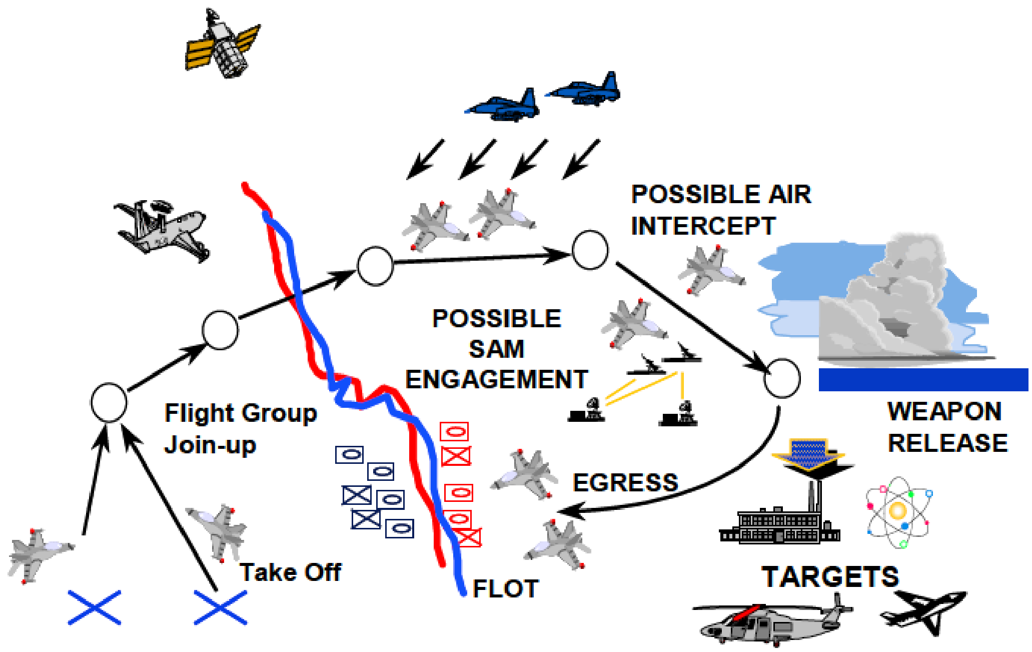

Figure 5: Depiction of the many elements modeled in a typical THUNDER scenario, providing a comprehensive, robust view of what might happen in such a scenario Hill, McIntyre, and Miller (2001)).

management strategies, force structure analyses, and mission planning (Hill, McIntyre, and Miller 2001). The middle of Figure 4 provides a screen shot from an EADSIM run.

THUNDER is a campaign-level model used to model conventional land and air warfare at the campaign level of aggregation and time frame. THUNDER is used to gain insight into such issues as long term expectations of conflicts, course of action assessments, assessments of system contributions to combat capability, and even wargaming. Figure 5 provides a graphic depiction of the many aspects of combat modeled within the Thunder model (Hill, McIntyre, and Miller 2001). The Synthetic Theater Operations Research Model (STORM) has recently been added to the AFSAT as an eventual replacement for THUNDER. A benefit of STORM is its improved representation of Joint Operations, in particular the representation of Naval combat (Seymour 2014).

Over the last few years the Air Force has been investigating a new "framework" rather than a single model to join the existing AFSAT. This framework, the Analytic Framework for Simulation (AFSIM), formerly known as Analytic Framework for Network Enabled Systems (AFNES), is an agent-based simulation framework developed by Boeing and now managed by the Air Force Research Lab (Conners 2015). AFSIM consists of a set of tools in a library used for loading simulation scenarios, populating different objects within the simulation, and then controlling the simulation execution (Zeh and Birkmire 2014). Platforms, sensors, and weapons are examples of distinct objects simulated within AFSIM. Agents in AFSIM typically represent a platform such as a fighter aircraft along with an associated set of sensors and weapon objects. The heart of an agent, such as a fighter aircraft, is the decision making and information flow produced by the processor objects that simulate combat functions from flight, search, and all steps of the kill chain as an example (Conners 2015). In Figure 4, the picture on the right is AFSIM playback from Conners (2015).

6 THE RISE OF THE DISTRIBUTED ENVIRONMENT

While computer technology greatly advanced the world of analytic simulation, that pace of change arguably pales in comparison to the tremendous changes in training simulation, and particularly how it provided the basis for the latest buzz in the DoD military simulation world, the LVC simulation environments.

Project Whirlwind followed soon after the ENIAC experience providing video display output to users which provided those air defense analysts a means to train against simulated threats. By 1964 the Base Operations Maintenance Simulator (BOMS) appeared modeling the characteristics of a Strategic Air Command Air Base (Loper and Turnitsa 2012).

By 1961 computer technology moved away from a single player perspective. *Spacewar*, developed at MIT, provided a two-person competitive game. By 1974 these games had evolved to multi-person games. Clearly, these were early forerunners of the plethora of games available on all sorts of home entertainment devices. In fact, Shaban (2013) argues the *Spacewar* development initiated the military-commercial industry collaboration with the military-themed entertainment video games. Nance and Sargent (2002) list such entertainment uses of simulation as an important category when considering the history and evolution of simulation. Some of these games are actually used in military training. We have even used these games as the basis for human-centered research projects. See Loper and Turnitsa (2012) for more examples of their use.

An amazing leap in the technology enabling these multi-user games and systems came with the introduction of Unix in the late 1960s (Loper and Turnitsa 2012). More important to the current discussion was a Defense Advanced Research Projects Agency forerunner program called the Advanced Research Projects Agency Network (ARPANET). Connections between computers prior to this was via hard wire, a direct cable connection between the machines. These hard wire connections generally needed to be among similar computers. The ARPANET introduced the novel idea of packet switching. In packet switching, the messages are decomposed into smaller components, called packets, and these packets are then routed over the network and reassembled at the destination node (computer). This approach increased network efficiency and more importantly provided computer independence. The impact for the simulator community was the potential to interconnect disparate computers, running different simulations. Packet-based communication is still the norm on the modern Internet.

By the 1970s, the military simulation modeling world was really being driven by the engineering and development communities (Miller and Thorpe 1995). Training, that military emphasis driving those really early simulation experiences, was not really a focus. However, the training world took notice and did start using these new engineering and development-driven simulations as individual training devices (Miller and Thorpe 1995). While individual skills development is necessary it is not sufficient for operational success. As Shiflett (2013) notes, skills are required for these individuals as members of teams and working within systems or a system of systems.

A memo by Thorpe in 1978, as recounted in Miller and Thorpe (1995), envisioned the use of connected simulators, manned and operated by humans, for training purposes. In 1984 the SIMulator NETworking (SIMNET) project commenced. The growth in computing capabilities, and their use in networking, provided the basis upon which to realize the SIMNET promise. The initial challenge was to connect 50-100 simulators dispersed over 4 sites. SIMNET ultimately achieved 250 simulators over 9 sites (Miller and Thorpe 1995).

Connecting humans tied to distributed simulators created a novel training environment but limited by the availability of the necessary personnel. A research question was how to replace the human operator with a simulated operator. Such a capability would mean even larger scales of training scenarios. The Semi-Automated Forces (SAF) capability of SIMNET realized this vision (Shiflett 2013). Modern games see these virtual entities in all their first-person shooter games, but for SIMNET and the technology of the time, this was a major advance. Additional details on SIMNET can be found in Miller and Thorpe (1995), Cosby (1995), and Loper and Turnitsa (2012).

The DoD realized the potentials associated with this explosive growth in simulators and the technology surrounding their use. The Defense Modeling and Simulation Office (DMSO) can be viewed in large part as a outgrowth of the SIMNET success. Created in 1991, the DMSO provided executive-level oversight of DOD M&S efforts, led M&S policy development, and was responsible, in large part, for the development of standards for distributed simulation (Shiflett 2013). Such standards would facilitate simulator networking and promote the growth in the technology. Additional details of the DMSO role can be found in Shiflett (2013).

These efforts spilled over into the analytical world of military simulation modeling as well. Programs like EADSIM required data from programs like Brawler to adjudicate any air combat instances. Naturally the question arose "why not just call Brawler." In a modeling demonstration, the employed scenario was an air-to-air instance which would prompt a call via some connection to Brawler. The Brawler would "play" out the air-to-air scenario and send the results back to the EADSIM. While feasible, and demonstrated, the scenarios involved tended to be too simplistic for realistic use. Thus, the use of such distributed analytical environment had to wait.

Another influential training-focused development occurred in the 1990s. The Synthetic Theater of War (STOW) Architecture (STOW-A) conceived what is now referred to as LVC simulation. The STOW-E (Europe) in 1994 was the first actual instance (Systems 1999). Despite limited functionality (Systems 1999), the event led to many future events and generated a multitude of lessons learned subsequently used to advanced the technology. Of note was the STOW use of SAF from the SIMNET as a means to connect the operators in the simulators with the simulated forces within the collective training scenario.

Meanwhile, the training community continued making strides with new protocols and computing architectures. In the early 1990s, the Distributed Interactive Simulation (DIS) architecture appeared. The DIS was specifically developed to support the connection between training simulators (Tolk 2016). In the mid 1990s, the High Level Architecture (HLA) was introduced. A key aspect of HLA is the separation of the communication and simulation components in its attempt to better unify the distributed simulations. Key components of HLA included (1) rules regarding how components worked together, (2) specification regarding what simulations could request (from other simulations), and (3) a structure for information exchange among the simulations (Tolk 2016). HLA had drawbacks including the communication overhead associated with transmitting simulation information to all the participating simulations but the implementations of HLA led to various lessons learned and improvements over time. TENA, the Test and Evaluation Enabling Architecture, arose shortly after the rise of HLA and DIS and focused on improving the distributed training capabilities. All three remain in use. Davis (1995) provides a wonderful discussion of DIS within a context of his own depiction of a history of military simulation.

7 LIVE, VIRTUAL, AND CONSTRUCTIVE SIMULATION

The history of military simulation has a clear focus on human-based planning by military experts, the training of those experts, and the use of simulation models in the analysis of military related operations. Each provides important contributions to military preparedness and planning. This history paper reflects how technology enabled the development and use of increasingly complex analytical simulations to help meet the challenges of an increasingly complex world. To meet modern challenges, the technology grown in the training environment holds the greatest promise for analytical military simulation.

From an analysis and training perspective, joint operations wherein many systems from multiple services interact brings even greater complexity to the military planning and analysis challenge. This complexity must be accommodated given that joint operations are the new norm for military actions. Thus, it is not surprising that the services must test new systems, and improvements to existing systems, as those systems would function in these joint environments. Unfortunately, bringing together all the systems from the various services to some common location for the purposes of some test event is likely cost prohibitive in addition to being logistically impractical.

The LVC construct creates an integrated computing environment in which live assets (e.g., pilots in aircraft, operators in tanks), virtual assets (e.g., pilots or operators in system simulators), and constructive (or analytical) models interact within the created battle space. All components are distributed and communicating

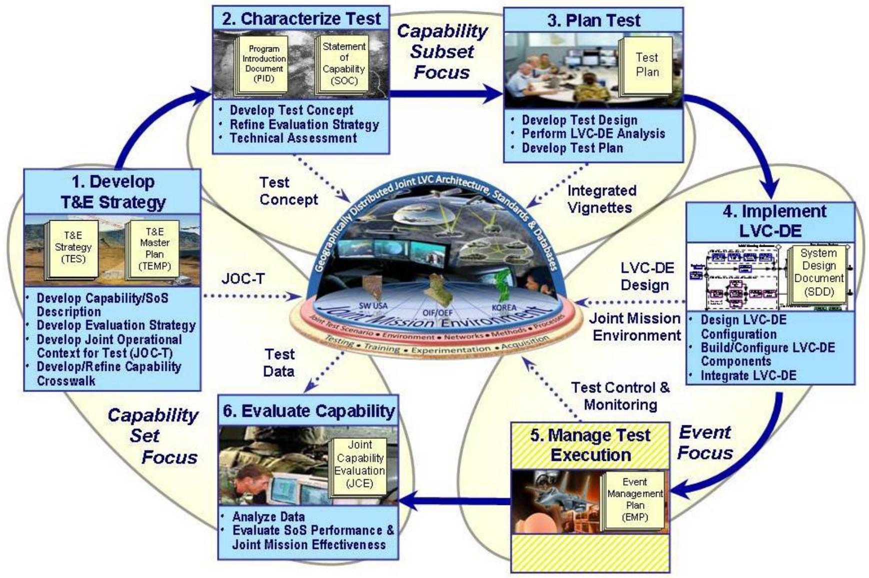

Figure 6: Depiction of the Capability Test Methodology architecture highlighting the comprehensive nature of system-of-systems testing available when that methodology is enabled by an LVC architecture (Haase, Hill, and Hodson 2011).

over network connections (Menke and March 2009). This distribution of assets can be over vast distances. Thus, operators can be at test ranges or operating in their home territory. The operators in simulators remain at their home site, and the constructive models remain installed where ever they happen to be best suited. Gray (2007) notes that this LVC structure provides what is needed to conduct joint, system-of-systems testing. Figure 6 from the discussion in Haase, Hill, and Hodson (2011) depicts an architecture envisioned for LVC in a joint test and evaluation environment. A takeaway for this paper is to note the incredible complexity involved and the comprehensive nature of the scenario depicted, something simply not possible without the evolution of computer-based simulation and distributed technologies.

LVC holds promise for joint testing (Foulkes 2009), experimentation and subsequent analyses. However, there remains challenges to realizing the LVC potential for test (Haase, Hill, and Hodson 2011). These challenges, based on our observations, stem from the source of LVC development. Constructive military simulation models were conceived and built for analytical purposes – to better understand the military implications of the system or process under study. Analytical results require capturing realism in the model while removing sources of noise or error that might otherwise confound the results. Live and virtual military simulation models emanate from the training world. While operational realism is still required in training simulation systems, sources of noise are not as controlled, in fact might even be viewed as part of the training experience. In more than a few LVC situations, the greatest source of noise in the collected results is the human operator. Humans adapt, think, and ignore rules if those actions will help them attain some defined goal or set of goals. Such “free play” behavior would scuttle an analysis effort.

As we have written in Haase, Hill, and Hodson (2011) and Hodson and Hill (2013), LVC holds promise for the analytical needs of test and evaluation. It is currently the only viable option for conducting system-of-systems testing, particularly in a joint warfare environment. However, experimental planning and more importantly execution requires a reigning in of some of the training aspects of LVC to focus on the control of lurking effects that doom analysis. This experimental design for LVC experimentation remains an area of active research.

8 MILITARY PAPERS IN THE WINTER SIMULATION CONFERENCE

There are a number of conference outlets for work on military simulation: Western Decision Sciences Institute, the Annual Conference of the Institute of Industrial and Systems Engineers, the Summer Computer Simulation Conference (SCSC), the Interservice/ Industry Training, Simulation and Education Conference (I/ITSEC), recognized as the world's largest modeling, simulation, and training conference, and the Military Operations Research Society Symposium (MORSS), to name a few. However, none appear to have provided the high quality archival output of the Winter Simulation Conference (WSC).

The military simulation community has a long history with the WSC. The first WSC was chaired by Harold Hixson with a conference keynote by Colonel K. Swanson, both from the Air Force Logistics Command (now Air Force Materiel Command). In fact, the WSC has been chaired by military associated people at least three times with the conference keynote honor going to current or past military members six times, the last being Astronaut Col Nancy J. Currie in 2005. That first conference featured four papers with a military focus capturing themes commonly found among military analysis and future WSC sessions: operational effectiveness of systems, logistics and maintenance functions, and human performance.

Those themes present in that first conference align with common questions that face the military for which simulation has proved adept at supporting: how good are the systems and how can they be improved, how to best train and employ the personnel authorized, and how much and when are resources needed to make the systems and personnel effective. In other words, the military faces questions of operational assessments and resources management. Huffman and Rogin (1967) examined aircraft carrier operations and the maintenance process, the first of many papers focused on logistics support. A number of papers examined the human resource aspects of military operations, how many personnel are needed, what types of personnel skills are needed, and how well does the human interact with the system. For instance, Schuppe (1989) examined pilot workload, while human factors modeling associated with various aspects of the military mission garnered 1-2 sessions per track in the early 2000's, a WSC aspect started when Suhler (1967) focused on human operator interaction with an Army system. There are also myriad papers associated with the use of simulation to examine and potentially improve the capabilities of defense systems, those in operation, those under modification consideration, and some others in development.

The military papers in the WSC have always had a close alignment with hot issues in the military simulation community. Wargaming has always had an important role in the military. The 1981 conference featured a session devoted to wargaming, specifically for the training and readiness of Naval fleet operations and for the advanced education of Air Force leaders in their professional military education school. Distributed simulation is an important technology and WSC papers and sessions supported military adoption. The influence of DIS and ALSP appeared by 1994 with a focus paper on the topic in 1999 (Nance 1999). Interestingly Dominiak and Ireland (1973) discussed a simulation model feeding aircraft tracks to actual radar systems providing an early example of the hardware-in-the-loop technology often viewed as a precursor of modern distributed simulation systems. Similarly, major simulation system developments garnered attention at the WSC; the Joint Theater Level Simulation program was featured in two sessions of papers in 1995 while the incredibly expensive Joint Warfare System was highlighted in its own session in 2001 (see Stone and McIntyre (2001) for instance). Unmanned vehicle research and agent-based modeling applications are hot topics in 2017; these emerged in the military applications track by the early 2000s.

The Dominiak and Ireland (1973) work was not the only instance of new technologies and techniques appearing in military papers. Hixson (1969) discussed a combined discrete event/continuous simulation model. Boehm, Guzy, and Paetzold (1976) discuss a simulation for examining circuit switching, message switching and packet service; at the time, military messaging systems were still based on the message switching paradigm and were just investigating the more modern and efficient packet switching service. Alberts (1985) provided an early history of wargaming and simulation with conjectures of future developments. Clark, Prueitt, and Smith (1984) provide an early use of experimental design to examine military model results while Roberts and Morrissey (1986) details the use of the design of experiments to examine a targeting algorithm.

There have been some influential panels and sessions associated with the military and WSC. In 1990 a session focused on trends for M & S in DoD. Horowitz (1990) discussed the results of an very influential Defense Science Board report of M & S use. Hughes (1990) discussed simulation for test and evaluation, something that continues to be of military interest, while Goodman and Enk (1990) provided some very profound statements regarding future trends for test and evaluation and the computing infrastructure needed. Schuppe (1991) echoed the panel discussion when presenting M & S as a critical defense technology.

Kent et al. (1992) summarized a panel discussion on operational art in military simulation. This panel brought together four of the arguably most influential leaders in military analysis in the post-WWII era, with Lt Gen (retired) Glenn A. Kent arguably the most influential. In 1998, the military panel focused on future trends and challenges facing military simulation. Then in 2004, the military panel brought together the senior analysts from each of the military services and the Office of the Secretary of Defense to discuss senior leadership perspectives on defense M & S.

Military related papers have been in every WSC held with those early papers found in Aerospace or Government-focused sessions. Military sessions appeared in the 1977 conference growing to two sessions in 1983 with a peak in participation in 1988 with 12 papers. By 1993, the Military Applications track was established with nine sessions. The 1994 conference featured a distinguished panel in the first session to "kick off" the track and in 1995, the Military Track started featuring a dedicated keynote speaker. In 2007, interest in the track started to drop, a trend further exacerbated by defense travel restrictions in 2012. In 2014, the track was merged with the Homeland Security track to become the Military, Homeland Security & Emergency Response track. The track continues to retain its keynote presentation as a main feature of the WSC conference and continues to contribute to the growing history of military simulation.

9 WHAT WE MISSED

This history of United States military simulation is necessarily incomplete. It is difficult to fully summarize a field that has the long and rich history of military simulation. There are too many aspects to cover in one conference paper so we have to scope the breadth and even the depth of the history that we do relate.

Military simulation is not restricted to just the United States DoD. There are similar endeavors within the United States Department of Energy and the Department for Homeland Security, to name just two. The military departments of all non-US countries are similarly involved in the simulation of their systems and their plans. However, we needed to focus our attention on just the US military.

There was no way to provide a comprehensive review of all the models within each of the levels of Figure 3. With over 3300 registered simulation models (Yu 2017) in the US Military alone, we would simply never finish. For instance, the lowest level of Figure 3 depicts engineering models. Important entries in this level are the many models used to assess system survivability and system lethality, which are used to generate probabilities of survival and probabilities of kill, which in turn are critical aspects of most engagement models. These models are continually evolving to consider new systems and technologies.

We also chose to not even try to compile a chronology of the technological advances in the evolution of these models. As previously mentioned, answers to some set of questions raise new questions prompting model updates. These updates often present new challenges that are addressed by advances in technology. Full histories on some of these areas, such as that by Shiflett (2013) and Cosby (1995) for training environments are necessarily focused on that single modeling domain.

There is a whole history on just wargaming aspects of military simulation. Wargames are still played by the military, most being quite involved affairs even having elements of live training and constructive simulation adjudication. The DoD is particularly involved in the Field Exercises portion of Figure 1, and incorporating the virtual and constructive models into these live components. There is a rich history on board-based wargaming including a thriving commercial market for recreational board games and computer-based games. There is even a wargaming certificate offered by the Military Operations Research Society and has been quick successful. See Caffrey (2000) for a very nice summary of this area. An excellent discussion of the use of wargames through military history through computer-supported wargames can be found in (Shrader 2006, 111–119) as well as the book by Dunnigan (2000),

We only briefly touch on the training aspects of military simulation and even then, the components we address are later in the process with the rise of the distributed simulation environment. There are nice works on the history of military training simulation. For instance, the book chapter by Loper and Turnitsa (2012) is a very nice read. Page (2000) provides a brief history of flight simulation presented at the Royal Aeronautical Society conference in 1979 commemorating 50 years of flight simulation. There is much less on the combat models likely due to model sensitivities in their use. The text by Battilega and Grange (1984), though somewhat dated, still does a nice job of describing the areas of military modeling and some of the earlier models. Their general comments on modeling still apply.

There is a rich literature on the study of military conflict. Computer technology has given rise to a line of research re-examining historical examples. Many of these recent efforts involve the use of agent-based models, for instance those in Champagne and Hill (2009) or Hill, Carl, and Champagne (2006) and other examples found in the Military or Agent-Based modeling tracks of the WSC. Some of these historical examples serve as backdrops for commercial games. A final area we did not cover is the rise of the commercial gaming industry and how parallel to that rise is the increase use of these commercial-types of games as a training platform and in some cases a research platform.

10 FINAL COMMENTS AND FUTURE DIRECTIONS

The DoD employs a lot of models, many of them non-simulation. As of this writing, the DoD uses over 800 models and 3300 simulations (Yu 2017). The use of simulation has always been part of military planning. Computer simulation is now a crucial part of the military planning, analysis, and training infrastructure. Simulations are used for engineering studies, weapon system analyses, force structuring, and operational planning. We employ training simulators for initial through advanced skills training, even for purposes of specific mission rehearsal. We distribute and interconnect simulations with actual systems and human operators to create large, distributed, interacting systems for concept and capability demonstration, for training, and, over time, for analytical purposes as well as for test and evaluation.

Despite the wide-spread use, simulation remains a growth industry. Large scale distributed LVC environments will be used to test joint systems via distributed simulation. The time and resources required to realize these LVC instances must be reduced so work continues on building scalable distributed computing architectures. As we strive to model combat in environments not usually associated with United States military action, such as urban warfare, we will look more to visualization of analytic models and even the incorporation of human operators into the analytical model process to strive for the realism needed to make the output results useful. Agent-based models are now being used to model everything from maintenance processes on the flight-line or on-board a Naval vessel to examining personnel retention. Finally, embedded simulations are likely the big growth area as these find implementation in various autonomous systems and systems designed to provide assistance to human operators.

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DISCLAIMER

The views expressed in this article are those of the authors and do not reflect the official policy or position of the US Air Force, Department of Defense or US Government.

REFERENCES

Aebersold, M. 2016. "The History of Simulation and its Impact on the Future". *AACN Advanced Critical Care* 27 (1): 56–61.

Alberts, H. C. 1985. "Gaming and Simulation: The Next 25 Years". In *Proceedings of the 1985 Winter Simulation Conference*, edited by D. Guntz, G. Blais, and S. Solomon, 102 – 110. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Azar, M. C. 2003. "Assessing the Threat of High Energy Lasers in Combat Simulations". Master's thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH, USA.

Battilega, J. A., and J. K. Grange. 1984. *The Military Applications of Modeling*. Wright-Patterson AFB, OH: Air Force Institute of Technology.

Boehm, P. P., J. J. Guzy, and R. K. Paetzold. 1976. "A Communications System Simulation for a Network Displaying Circuit-Switching, Message Switching and Packet Service". In *Proceedings of the 1976 Winter Simulation Conference*, edited by H. J. Highland, T. J. Schriber, and R. G. Sargent, 167 – 172. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Caffrey, M. 2000. "History of Wargames: Toward a History Based Doctrine of Wargaming". www.strategypage.com. Accessed 16 August 2016.

Cassidians 2012. "Cassidians Virtual Rock Drill". http://www.miltechmag.com/2012/12/iitsec-2012-cassidians-interactive.html.

Champagne, L. E., and R. R. Hill. 2009. "A Simulation Validation Method Based on Bootstrapping Applied to an Agent-based Model of the Bay of Biscay Historical Scenario". *Journal of Defense Modeling and Simulation* 6 (1): 201–212.

Clark, T. D., G. C. Prueitt, and R. L. Smith. 1984. "A Policy Analysis for Logistical Support of Multiple U.S. Amry Contingency Requirements". In *Proceedings of the 1984 Winter Simulation Conference*, edited by S. Sheppard, U. Pooch, and D. Pegden, 723 – 726. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Conners, C. 2015. "Agent Based Modeling Methodology for Analyzing Weapon Systems". Master's thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH, USA.

Cosby, L. 1995. "SIMNET: An insiders perspective, IDA Document D-1661". *Institute for Defense Analyses, Defense Technical Information Center, Washington, DC*.

Davis, P. K. 1995. "Distributed Interactive Simulation in the Evolution of DoD Warfare Modeling and Simulation". *Proceedings of the IEEE* 83 (8): 1138–1155.

Dominiak, K. E., and R. J. Ireland. 1973. "Simulation of a Multiple Element Test Environment". In *Proceedings of the 1973 Winter Simulation Conference*, edited by J. Sussman and A. C. Hoggatt, 387 – 394. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Dunnigan, J. 2000. *Wargames Handbook, Third Edition: How to Play and Design Commercial and Professional Wargames*. Lincoln, NE: iUniverse.com, Inc.

Foulkes, J. B. 2009. "Realizing Jointness Through Early Testing of Systems in a Distributed Live-Virtual-Constructive Environment". *ITEA Journal* 30 (1): 191–192.

Goodman, D. R., and R. G. Enk. 1990. "Future Real-Time Testing and Evaluation Computing Environments". In *Proceedings of the 1990 Winter Simulation Conference*, edited by O. Balci, R. P. Sadowski, and R. E. Nance, 237 – 242. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Gray, F. 2007. "Experimental Designs for Development Tests in Distributed Joint Environments". In *Proceedings of the 2007 Air Force T& Days*.

Haase, C. L., R. R. Hill, and D. Hodson. 2011. "Using Statistical Experimental Design to Realize LVC Potential in T&E". *ITEA Journal* 32 (3): 288–298.

Hill, R. R., R. G. Carl, and L. E. Champagne. 2006. "Using Agent-based Simulation to Empirically Examine Search Theory using a Historical Case Study". *Journal of Simulation* 1 (1): 29–38.

Hill, R. R., G. A. McIntyre, and J. O. Miller. 2001. "Applications of Discrete Event Simulation Modeling to Military Problems". In *Proceedings of the Winter Simulation Conference*, edited by B. A. Peters, J. S.

Smith, D. J. Medeiros, and M. W. Rohrer, 780–788. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Hixson, H. G. 1969. “Equipment Maintenance Studies using a Combination of Discrete Event and Continuous System Simulation”. In *Proceedings of the 1969 Winter Simulation Conference*, edited by A. OcKene and P. J. Kiviat, 76 – 85. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Hodson, D. D., and R. R. Hill. 2013. “The Art and Science of Live, Virtual, and Constructive Simulation for Test and Evaluation”. *Journal of Defense Modeling and Simulation* 41 (1): 6–19.

Horowitz, B. M. 1990. “Defense Science Board Recommendations: An Examination of Defense Policy on the use of Modeling and Simulation”. In *Proceedings of the 1990 Winter Simulation Conference*, edited by O. Balci, R. P. Sadowski, and R. E. Nance, 224 –230. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Huffman, H. and Rogin, L. 1967. “Performance Prediction and Verification of a Military System”. Presented at the 1967 Winter Simulation Conference.

Hughes, R. G. 1990. “Simulation for Design, Test and Evaluation, and Training: Reconciling the Differences”. In *Proceedings of the 1990 Winter Simulation Conference*, edited by O. Balci, R. P. Sadowski, and R. E. Nance, 231 –236. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Ronald L. Johnson 1990. “Lanchester’s Square Law in Theory and Practice”. School of Advanced Military Studies, Ft. Leavenworth, Kansas. Accessed 16 March 2017.

Kent, G. A., W. L. Goodson, B. C. Hosmer, C. J. Thomas, and P. F. Auclair. 1992. “Operational Art in Military Simulation (Panel)”. In *Proceedings of the 1992 Winter Simulation Conference*, edited by J. J. Swain, D. Goldsman, R. C. Crain, and J. R. Wilson, 1104 – 1111. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Kline, M. 1985. *Mathematics and the Search for Knowledge*. New York, New York: Oxford University Press.

Lane, D. C. 2010. “High Leverage Interventions: Three Cases of Defensive Action and their Lessons for OR/MS Today”. *Operations Research* 58 (6): 1535 – 1547.

Loper, M. L., and C. Turnitsa. 2012. “History of Combat Modeling and Distributed Simulation”. In *Engineering Principles of Combat Modeling and Distributed Simulation*, edited by A. Tolk, 331–355. New York: John Wiley & Sons Inc.

Menke, T., and W. W. March. 2009. “Simulation and Analysis Facility”. *ITEA Journal* 30 (4): 469–472.

Metropolis, N. 1987. “The Beginning of the Monte Carlo Method”. *Los Alamos Science*:125 – 130.

Miller, D. C., and J. A. Thorpe. 1995. “SIMNET: The Advent of Simulator Networking”. *Proceedings of the IEEE* 83 (8): 1114–1123.

Morse, P. M., and G. E. Kimball. 1951. *Methods of Operations Research*. Alexandria, VA: Military Operations Research Society.

Nance, R. E. 1999. “Distributed Simulation with Federated Models: Expectations, Realizations and Limitations”. In *Proceedings of the 1999 Winter Simulation Conference*, edited by P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 1026 – 1031. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Nance, R. E., and R. G. Sargent. 2002. “Perspectives on the Evolution of Simulation”. *Operations Research* 50 (1): 161 –172.

Page, R. L. 2000. “Brief history of flight simulation”. *SimTecT 2000 Proceedings*:11–17.

PreparedX 2017. “PreparedX”. http://www.preparedex.com/war-gaming-part-1-the-history/.

Roberts, B. H., and D. W. Morrissey. 1986. “The Use of Statistical Experimental Design Techniques for the Systematic Improvement of an Automated, Heuristic Targeting Algorithm”. In *Proceedings of the 1986 Winter Simulation Conference*, edited by J. Wilson, J. Henriksen, and S. Roberts, 802 – 807. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Ross, K. G., G. A. Klein, P. Thunholm, J. F. Schmitt, and H. C. Baxter. 2004. "The Recognition-Primed Decision Model". *Military Review* 84 (5): 6–10.

Schuppe, T. F. 1989. "A Comparison of Serial and Parallel Processing Simulation Models of Pilot Workload". In *Proceedings of the 1989 Winter Simulation Conference*, edited by E. A. MacNair, K. J. Musselman, and P. H. (eds.), 1003 – 1009. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Schuppe, T. F. 1991. "Modeling and Simulation: A Department of Defense Critical Technology". In *Proceedings of the 1991 Winter Simulation Conference*, edited by B. L. Nelson, W. D. Kelton, , and G. M. Clark, 519 – 525. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Seymour, C. N. 2014. "Capturing the Full Potential of the Synthetic Theater Operations Research Model (STORM)". Master's thesis, Naval Postgraduate School, Monterey, CA, USA.

Shaban, H. October 2013. *The Atlantic Monthly*.

Shaw, R. L. 1985. *Fighter Combat: Tactics and Maneuvering*. Annapolis, MD: Naval Institute Press.

Shiflett, J. E. 2013. "Observations on the Development and Implementation of Distributed Simulation". In *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2010*, Paper No. 1F1301.

Shrader, C. R. 2006. *History of Operations Research in the United States Army, Volume I: 1942 - 1962*. Washington, DC: Office of the Deputy under Secretary of the Army for Operations Research.

Smith, R. 2010. "The Long History of Gaming in Military Training". *Simulation and Gaming* 41 (1): 6 – 19.

SRS Technologies 2007. "Brawler V7.0 Release Notes". SRS Technologies, Arlington VA.

Stone, G. F., and G. A. McIntyre. 2001. "The Joint Warfare System (JWARS): A Modeling and Analysis Tool for the Defense Department". In *Proceedings of the 2001 Winter Simulation Conference*, edited by B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, 691 – 696. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Suhler, W. C. 1967. "A GPSS/360 Network Flow Simulation". Presented at the 1967 Winter Simulation Conference.

Systems, L. M. I. 1999. "Synthetic Theater of War - Architecture (STOW-A) 1.6 S/W Baseline Upgrade, Lessons Learned Report". Technical report, Lockheed Martin Information Systems, Orlando FL.

Tolk, A. 2016. "Tutorial on the Engineering Principles of Combat Modeling and Distributed Simulation". In *Proceedings of the Winter Simulation Conference*, edited by T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Hushka, and S. E. Chick, 780–788. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Wikipedia 2017. "Military Simulation". https://en.wikipedia.org/wiki/Military_simulation.

Yu, L. 2017. "M&S Catalog". http://www.msco.mil. Personal Communication, April 2017.

Zeh, J. and Birkmire, B. 2014. "Advanced Framework for Simulation, Integration and Modeling (AFSIM) Version 1.8 Overview".

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