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An Introduction to Wargaming and Modeling and Simulation

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Introduction

Nations have long utilized simulations of combat to help understand how to better man, train, equip, and employ forces in preparation for future combat operations. These force generation, force structure, and force design decisions are often informed by simulating combat against potential adversaries in projected future scenarios, and then analyzing the simulation results to determine the necessary future investments to ensure the force is prepared to meet these potential adversaries. This book will discuss the current practitioner use of both wargames that investigate the human decision-making processes and computer simulations that investigate the quantifiable aspects of combat. Our goal is to provide the reader a better understanding of how each tool brings unique qualities and attributes to bear on the assessment of the phenomenology of combat that allows our senior leaders to make better informed decisions.

Terminology

There are many different types of combat simulations that exist today, and in order to have a fruitful discussion we will need to adopt a standard lexicon. The first step in developing this lexicon is to define the terms "model," "simulation," and "wargaming." A model is "a physical, mathematical, or otherwise logical

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representation of a system, entity, phenomenon, or process."[1] A simulation is "a method for implementing a model over time."[2] A wargame is "a representation of conflict or competition in which people make decisions and respond to the consequences of those decisions."[3] Often in today's Department of Defense (DoD), the term "simulation" implies that all the models that comprise the simulation are instantiated in executable computer code, and because of that, most wargames are not thought of or referred to as "simulations." From this point forward, when we use the term "simulation" it will refer exclusively to computer-hosted closed-loop combat simulations, and thus will not include wargames.

Combat simulations are categorized by the amount of human interaction required, the use of probabilistic processes and the level of war they represent. Combat simulations that require periodic human decisions are called "Human-in-the-Loop" or *H-I-T-L simulations*, and these are often used as computer-hosted wargames, with human commanders or command and staff teams making the necessary decisions. *Closed-loop simulation*s have totally automated the human decision-making processes in computer code and can simulate hours, days, weeks, or months of combat without any human intervention during the simulation's execution. Simulations that will produce the same output for a fixed set of input parameters are *deterministic*, while simulations that have one or more probabilistic parameters whose value will be determined during the simulation's execution using a random number seed are *stochastic*, which are sometimes referred to as "Monte Carlo" simulations. Simulations are also segregated by the level of war that they represent. A strategic simulation will represent an entire campaign, such as the European or Pacific theaters of war during World War II. An operational simulation will represent a specific operation that is part of a campaign, and a tactical simulation will represent some portion of an operation. In most cases, the higher the level of war, the more abstract the models of the simulation are. Most tactical simulations represent each weapon system and soldier of a unit and are called *entity* simulations. Many strategic simulations represent entire units, such as a company, battalion, or brigade, by aggregating the weapons systems and soldiers of a unit, and treating the unit as a single object with attributes derived by combining the attributes of the unit's entities into a single value that represents some combat capability of the unit. In ground combat simulations, the single value assigned to such a unit is often called the "combat power" of the unit. These simulations are predictably called *aggregate* simulations.

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1 DoDI 5000.61 "DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A)" December 9, 2009 w/Change 1, October 15, 2018, p.10.

2 DoDI 5000.61 "DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A)" December 9, 2009 w/Change 1, October 15, 2018, p.10.

3 US DoD Joint Publication 5-0, "Joint Planning" 16 June 2017, p. V-31.

Wargames are categorized by the purpose of the wargame, the manner in which players are engaged and the amount of information provided to players. There are three widely recognized purposes for defense wargames: *analytic, educational, and experiential*. Educational and experiential wargames seek to impart knowledge or experience, respectively, to its players. In other words, these wargames produce better educated or more experienced players. Analytic wargames are designed to address an objective and a set of issues that the wargame's sponsor provides. The products of an analytic wargame are findings that address the sponsor's objective and issues. Wargames are also categorized by the method that the players interact. Players are engaged directly in a *seminar* wargame and the facilitator of the wargame usually adjudicates any player interactions. Conversely, players engage each other indirectly in *system* wargames. In system wargames, there are usually models that are designed to adjudicate player interactions. Finally, wargames must provide players with information that they will then use to make their next decision. A wargame that only provides the players the information that would actually be available to them is called a *closed* wargame. In closed wargames, each side (typically red or blue) is sequestered in its own cell, and the wargame's white cell makes the determination of what information each side's collection assets would produce, and then communicates only that information to the appropriate cell. Wargames that allow all the players to have all available information are called *open* wargames.

And, as for the model or models that are used in simulations and wargames, users must heed the statistician George Box's warning: "All models are wrong, some are useful."[4]

An Abbreviated History of Wargames and Simulations

Before the rise of the computer, the primary form of combat simulation was wargaming. Wargaming has a rich history and has been used by many cultures and in many different forms. The ancient games of chess and Go are but a few of the games that were believed to have usefulness in training and testing military commanders' decision-making capabilities, and this belief led to the designing of games focused on modeling combat for the development of military leaders. In the nineteenth century, the Prussians developed Free and Rigid Kriegspiel as methods to educate their officers. Rigid Kriegspiel focused on the calculations of combat, with the hypothesis that good combat leaders had to be able to employ a type of "combat calculus" to mathematically understand what decisions should be made on the battlefield.[5] Free

4 Box, G. E. P. (1979), "Robustness in the strategy of scientific model building", in *Launer, R. L.*; Wilkinson, G. N. (eds.), Robustness in Statistics, Academic Press, pp. 201–236

5 Vego, "German War Gaming," p. 108.

Kriegspiel used battle-tested Prussian officers to assess junior officers' responses as they were presented with possible combat situations to which they had to react.[6]

In the early part of the twentieth century, F.W. Lanchester proposed two sets of differential equations that could be used to simulate combat, referred to as Lanchester's linear and square laws. Although he proposed these laws to simulate aerial combat, they gained traction for use in modeling ground combat. The square law rewards a combatant's ability to concentrate forces and was seen as relevant to modern warfare, and the linear law has been accepted as a model of ancient warfare where combatants were unable to mass fires.[7] Lanchester came to realize, through studying the Battle of Trafalgar, that if a battle can be decomposed into a series of concurrent and consecutive sub-battles, separated by space and time, then it is more appropriate to apply the square law to each sub-battle, and sum all sub-battle losses to gain a more accurate accounting of the entire battle than it is to apply the square law a single time to the entire battle.[8] As computer-based combat simulations were developed in the latter half of the century, many ground aggregate simulations used some adaptation of Lanchester's laws to model attrition.[9]

In the first half of the twentieth century, the US Navy made great use of wargaming to examine a potential war with Japan, beginning over two decades of focused wargaming in 1919 at the US Naval War College.[10] This detailed examination of war in the Pacific proved to be so successful that, after the conclusion of World War II, Admiral Chester Nimitz said "...nothing that happened during the war was a surprise – absolutely nothing except the Kamikaze..."[11]

Wargames and Computer-Based Combat Simulations: From the Cold War to Today

As the North Atlantic Treaty Organization (NATO)–Warsaw Pact "Cold War" consumed the US defense establishment for the latter half of the twentieth century, two events greatly impacted the use and characterization of combat simulations in the US DoD. One was the development of the closed-loop combat simulation. The

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6 Vego, "German War Gaming," p. 110.

7 Lanchester F.W., *Mathematics in Warfare* in *The World of Mathematics,* Vol. 4 (1956) Ed. Newman J.R., Simon and Schuster, 2138–2157

8 Perry, Nigel. "Verification and Validation of the Fractal Attrition Equation," *Defence Systems Analysis Division, Defence Science and Technology Organisation, DSTO-TR-1822, PO Box 1500 Edinburgh South Australia* 5111, Australia, January 2006.

9 Appleget, J. "The combat simulation of Desert Storm with applications for contingency operations" *Naval Research Logistics (NRL)*, Volume 42, Issue 4, Pages 710–711, 1995.

10 Edward Miller. War Plan Orange: the U.S. Strategy to Defeat Japan 1897–1945 (Annapolis. MD: Naval Institute Press, 1991), 156.

11 Donald C. Winter, remarks at Naval War College Current Strategy Forum, Newport, RI, 13 June 2006.

earliest computer simulation of ground combat is believed to be CARMONETTE, developed by the US Army's Operations Research Office in 1953, and used to inform defense decisions from 1956 to 1970.[12] The other was the US DoD's embracing of Defense Secretary Robert McNamara's "Systems Analysis" philosophy (McNamara served as SECDEF from 1961 to 1968), which led to the thinking that every important defense concept or procurement program required quantifiable justification.[13]

In the late 1950s, the use of CARMONETTE, a stochastic tactical-level closed-loop combat simulation was still referred to as a "wargaming" technique. It was used for research purposes such as "testing the value of new weapons, fighting techniques, or war plans."[14] The developers of CARMONETTE realized that the concept of repeatability combined with modeling some of the processes of combat probabilistically could be used to remedy one of the identified shortcomings of wargaming: the results of a wargame are only a single realization of a range of potential outcomes. They determined it would be necessary to "repeat the battle calculations allowing nothing but the play of chance to vary and so identify the spectrum of the possible outcomes and the associated frequency distribution." They also realized that the scientific method would be useful if they were to attempt to compare battle outcomes of forces equipped with two different weapons systems; in particular, "we must be able to repeat the battle simulation many times while holding fixed all parameters except that one under investigation."[15]

However, these same developers also came to the realization that simulations such as CARMONETTE could not reproduce the complex decision process a military commander uses in combat:

> The design of the simulation is such that it can create a realistic representation of close combat during the brief intense engagement phase lasting for approximately 1 hour or so. Continuation of the simulated combat beyond 1 hour becomes unrealistic because a decision fundamental to the execution of the maneuver would undoubtedly be made at that point. CARMONETTE has no capability to reproduce a military commander's mind, and thus the simulation must be terminated, and the results reviewed. The simulation may then continue with an appropriate order from a commander if desired.[16]

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12 "A History of Serious Games" powerpoint presentation, Roger Smith, Chief Technology Officer, US Army PEO STRI.

13 John Hanley, Changing DoD's Analysis Paradigm," Naval War College Review, 70, 1 (2017): Article 5. pp. 65-66,

14 CARMONETTE, A Concept of Tactical War Games, Operations Research Office TACSPIEL Group, Department of the Army, *Staff Paper ORO-SP-33*, November 1957, p.1.

15 CARMONETTE, A Concept of Tactical War Games, Operations Research Office TACSPIEL Group, Department of the Army, *Staff Paper ORO-SP-33*, November 1957, p.1.

16 CARMONETTE Volume I General Description Prepared By General Research Corporation Operations Analysis Division Westgate Research Park Mclean, Virginia 22101 Under Contract DAAG 39-74-C-0128 For US Army Concepts Analysis Agency 8120 Woodmont Avenue Bethesda, *Maryland* 20014, November 1974 p 1.

The implication here is that CARMONETTE could be integrated into a larger iterative process where a commander's human decision-making process would shape the approximately hour-long CARMONETTE engagement, and then, after the commander reviewed the engagement results, another human decision would be made that would shape the next CARMONETTE engagement.

In the 1970s, independent of the budding combat simulation community, military wargamers realized that some of the book-keeping functions that wargames required could be better performed by computers. In 1976, the Training and Doctrine Command Systems Analysis Activity integrated a Wang 2200 minicomputer into the Dunn–Kempf manual wargame to create BATTLE, the Battalion Analyzer and Tactical Trainer for Local Engagements. They used the computer to calculate the results of simultaneous direct and indirect fire engagements, and to perform "book-keeping functions" such as tracking movements and ammunition expenditures. They realized that the computer could be leveraged to lessen the burden on wargaming staff to free them up to focus on more vital aspects of wargaming such as the tactical decision-making process.[17]

In the 1980s, the use of computerized combat simulations became ubiquitous in the defense analysis community. The dominant scenario that the US DoD used to underpin acquisition decisions was the NATO–Warsaw Pact fight for Western Europe. This projected conflict had been analyzed continually for decades and both sides' intelligence had been so well developed that, by the mid-1980s, nearly the entire world understood how the battle on the north German plain would unfold: attack corridors, force compositions, and equipment, even opposing commanders were all known. Tom Clancy's novel "Red Storm Rising" (Putnam, 1986) provided a realistic description of what that encounter would have looked like and demonstrated the amount of information commonly available about that potential conflict.[18] Quantifying the kinetic combat capabilities of forces became the focus of the analysis that underpinned the US defense acquisition decisions, and this played perfectly into the strength of closed-loop combat simulations.[19] However, US Army analytic organizations realized that closed-loop combat simulations could not be relied upon as the single tool needed to do analysis. While the automated decision rules allowed for the development of stochastic models that could be run numerous times to ensure there was a representative set of battle outcomes, the automation of the human decision-making process was recognized to be too simplistic to rely on for a complete assessment of combat operations.

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17 TRADOC Systems Analysis Activity. (undated). Battle Analyzer and Tactical Trainer for Local Engagements, White Sands Missile Range, New Mexico (development of the BATTLE simulation was initiated in August 1976).

18 Jeff Appleget and Fred Cameron," Analytic Wargaming on the Rise," Phalanx 48, No.1, (March 2015): 28–32

19 Jeff Applegte, Robert Burks, Fred Cameron, The Craft of Wargaming: A Detailed Planning Guide for Defense Planners and Analysts. (Annapolis, MD: Naval Institute Press, 2020): 17–18.

Both the Army's Center for Army Analysis (CAA) and the Training and Doctrine Command (TRADOC) Analysis Center (TRAC) developed analysis protocols that first used wargames to thoroughly examine different courses of action (COAs) or concepts of operations (CONOPS) before deciding on a single scheme of maneuver that was then instantiated in their closed-loop combat simulations.[20]

Wargaming has taken on a more prevalent role in DoD since the beginning of the US irregular warfare (IW) campaigns in Afghanistan (2001) and Iraq (2003), although there have also been major efforts to develop computer simulations to model IW operations such as counterinsurgency and stability operations. Initially, some modelers attempted to add IW complexity to existing kinetic-focused combat simulations. They added a third side to their simulation to represent the population. Others added civilians on the battlefield, so kinetic engagements between two uniformed, armed forces had the potential to cause "collateral damage" among the populous. They were missing the point. The whole dynamic of warfare changes when the center of gravity shifts from defeating an adversary's military to influencing a civilian population. In an IW campaign, kinetic engagements between armed combatants are infrequent, small, sporadic, and often counterproductive. The Counterinsurgency Field Manual FM 3-24 said it best: "You can't kill your way out of a counterinsurgency." Whole of government approaches and modeling civilian populations' attitudes and behaviors are required, and modeling these attributes presented significant challenges to defense modelers.[21] DoD stood up the Human Social Culture Behavior Program in 2009 to address some of these challenges, specifically "to develop, implement, and demonstrate forecasting and predictive models of human behavior for both analytic application and warfighter training in support of non-traditional warfare operations."[22] The United Kingdom's Defence Science and Technology Laboratory developed the Peace Support Operations Model (PSOM).[23] This is not a closed-loop simulation, but a simulation that requires periodic decision-making by human subject matter experts – a computer-hosted wargame. PSOM was used in 2010 and 2011 for training UN peacekeepers in Central Asia[24] and to assess

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20 Appleget and Cameron, 30–31.

21 Appleget, J., C. Blais and M. Jaye, "Best practices for US Department of Defense model validation: lessons learned from irregular warfare models," *Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, 10(4) 395–410, 2013.

22 http://www.pacific-science.com/ad7/sites/default/files/HSCB%20Project%20Summary_13Mar12_0.pdf, referenced 06/27/2019.

23 Body, H. and C. Marston "The Peace Support Operations Model: Origins, Development, Philosophy and Use," *Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, 8(2) 69 –77, 2010.

24 Nannini, Christopher J., Jeffrey A Appleget and Alejandro S Hernandez. "Game for Peace: progressive education in peace operations," Journal of Defense Modeling and Simulation: Applications, Methodology, *Technology*, 10(3) 283–296, 2013.

campaign options in Afghanistan.[25] A survey of simulation tools used to model conflict in Iraq and Afghanistan was completed by RAND in 2014.[26]

As the conflicts in Iraq and Afghanistan approached their first decade, the US DoD began to realize that both wargames and closed-loop combat simulations have important and distinctly different roles in the analytic process. The United States' involvement in Iraq and Afghanistan has highlighted that counterinsurgency and stability operations cannot be modeled well in existing closed-loop combat simulations. While agent-based simulations show promise for modeling human behavior in regions of conflict,[27] there are no closed-loop IW simulations that parallel the quantitative analytic capability of those used by DoD to assess major kinetic combat operations. In historical terms, modern-day wargames are much like the Prussians' Free Kriegspiel, while today's closed-loop combat simulations are more similar to Rigid Kriegspiel. Each tool has its purposes, and in most cases those purposes are not overlapping. Wargames should not be used for quantitative assessments and closed-loop combat simulations cannot replicate human commander's decision-making processes.

Wargames Today

As analytic wargames began to regain some traction in the 2010-time frame, they were attacked by combat simulation advocates. Analysts who teethed on closed-loop combat simulations derided wargames as "a simulation of one replication" or a "sample size of one," noting that you could not run a particular wargame multiple times, varying random variable values to generate quantitative output for statistical analysis. What they failed to understand was that a wargame's focus is on qualitative data, decisions produced by human players, while the computer-based closed-loop combat simulations are focused on quantifying the attributes of a force engaged in high-end kinetic combat.

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25 Connable, Ben; Walter L. Perry, Abby Doll, Natasha Lander, Dan Madden, *"Modeling, Simulation, and Operations Analysis in Afghanistan and Iraq: Operational Vignettes, Lessons Learned, and a Survey of Selected Efforts" RAND Corporation*, National Defense Research Institute, Santa Monica,CA, 2014, p. 26.

26 Connable, Ben; Walter L. Perry, Abby Doll, Natasha Lander, Dan Madden, *"Modeling, Simulation, and Operations Analysis in Afghanistan and Iraq: Operational Vignettes, Lessons Learned, and a Survey of Selected Efforts" RAND Corporation*, National Defense Research Institute, Santa Monica,CA, 2014.

27 Appleget, Jeffrey, Robert Burks, and Michael Jaye, "A demonstration of ABM validation techniques by applying docking to the Epstein civil violence model," *Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, 11(4) 403–411, 2014.

Running a series of wargames to generate multiple replications or running wargames to compare and contrast different concepts or technologies is problematic. Running any simulation for multiple replications is typically done by holding most variables fixed and introducing randomness for certain, identified random variables (such as system-on-system probability of hit) so the statistics of the multiple replications can be calculated to examine the range of expected outcomes, given the introduced randomness. It is difficult, if not impossible, to produce multiple replications of a wargame because of the learning effect that the players experience, so the difference in replications is confounded by the players learning more about the operating environment and the opponent's method of prosecuting combat with every subsequent replication. If the first replication of the wargame produced clear winners and losers, would the loser use the exact same strategy for the second replication? Would the winner expect the loser to not learn and try the same course of action? You could attempt to eliminate the learning bias by having different players play each replication, but that would assume you could find a large supply of players with identical experiences. In practice, some organizations that utilize wargames do play them multiple times with the same players, but these cannot be considered multiple replications, at least not in the traditional sense. When the TRADOC Analysis Center ran the H-I-T-L simulation JANUS to develop a concept of operations (CONOPS), for later instantiation in the closed-loop simulation CASTFOREM, the blue side had around 30 "pucksters" plus a command and staff, and the red side had around 10 pucksters and their own command element. Pucksters typically maneuvered and fought elements of the force, such as a tank company in a brigade operation. In order to obtain a "record run" that could be instantiated in the simulation, they would need four to five runs to familiarize all the pucksters with the operational plans. One or both sides would usually petition to move the starting locations of their forces between runs, so these cannot be considered "replications" in the pure sense. Only the results of the final record run were used to inform the CONOPS instantiation in the simulation.[28]

At the Office Secretary of Defense (OSD) Office of Net Assessment, players play a wargame multiple times where the players' learning is one of the subjects of study. Understanding how a command and staff's thinking evolves when combating an adversary's new technology or concept in a wargame allows the evolution of doctrine without putting forces at risk.[29]

In DoD today, there are few in uniform who can design, develop, conduct, and analyze a wargame. What used to be an integral part of a professional military officer's education and experience is now an afterthought, at best. This has caused

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28 Personal experience of Jeff Appleget, Commander of Troops, TRAC-WSMR, 2001-2004.

29 Communication with Phillip Pournelle, CDR, USN (retired), former office of Net Assessments analyst, 17 June 2020.

a fair amount of "BOGGSAT" wargaming to be conducted, a Bunch of Guys and Gals Sitting Around a Table. The term BOGGSAT is a pejorative term that implies that a group of people tasked to conduct a wargame produces results that meet the tasker with minimal rigor and resource expenditure. There are two reasons BOGGSATs occur. The first is that the command does not give the wargaming team the resourcing to do a proper wargame. The second is that no one on the wargaming team has any wargame design experience, so the team simply improvises as best it can. In many cases, both lack of resources and experience spur the occurrence of BOGGSATs. We often hear of BOGGSATs being used to conduct planning wargaming at some US Combatant Commands (CCMDs).

Some of our CCMDs have contracted out some of their wargaming requirements to make up for the lack of uniformed wargamers. This can present a challenge. Some contracting organizations have their own methods of doing a wargame; so if a command's wargaming requirements do not quite match the method of the contracted wargaming organization, the organization may only wargame the part of the required wargame that their methods can accommodate. Most wargaming requirements are unique, and a wargaming best practice is to design the wargame around the organization's wargaming requirement, instead of trimming the requirements of the organization to fit a predetermined wargaming method.

Wargames have multiple points of failure. Wargames fail when the wargaming team and the sponsor do not come to an agreement of the wargame's objective and key issues. This often occurs when the wargaming sponsor is a senior official whose subordinates are reluctant to force the official to clarify and refine the initial wargaming tasking. The best-designed wargame can be a failure if the wargaming team cannot secure the appropriate players. Wargames can also fail if not executed properly. Keeping the players immersed in the wargaming environment, ensuring the game stays on schedule, managing the game's adjudication and data collection, and solving the inevitable glitches that often occur require an experienced and adaptive wargaming team. Analytic wargames depend on accurate and detailed data collection, so a well-designed wargame with the best players can still be a failure if the data collection effort is flawed. Finally, a wargame may be well designed, flawlessly executed with clear and concise data collected, and the game's analysts may fail to conduct useful analysis.

In conclusion, there are many more wargames being conducted since 2015 in DoD than before, thanks to the reinvigoration spawned by the Office of the Secretary of Defense's stewardship. However, more does not necessarily mean better or useful. Wargames designed by teams with no wargaming experience or education will most likely encounter two or more of the points of failure enumerated above. If wargaming is to again become a part of the US DoD culture, wargaming education and wargaming experience must be directed and driven by DoD leadership.

Simulations Today

Introduction

Closed-loop simulations provide the means to assess the combat capabilities of a collection of entities (weapon systems and formations) given that the decision that those forces will engage in battle has been already been made. These simulations are not wargames, as there are no dynamic human decisions that impact the flow of events of the operations simulated in the computer model. While it is true that there are algorithms in closed-loop simulations that represent some decisions that humans make in combat, they are rudimentary, IF-THEN type of decisions.

Simulation Types

For the ease of simplicity, we will use ground combat simulations as the basis for our discussion. Ground combat simulations are used by both the US Army and the US Marine Corps and are arguably the most complex of the combat simulations used throughout DoD, both in the sheer numbers of combat platforms and in the complexity of the operating environment.

Aggregate Simulations

These simulations typically array forces linearly in a series of sectors (often referred to as "pistons") where, in each sector, algorithms will assess if an attack will occur, and if so who will be the attacker. In each sector, the simulation calculates a combat power score (also known as a firepower score) for each force to assess the combat power ratio that exists between the forces. The first simulations that used combat power scores calculated the combat power comparison assuming that each side had perfect information on all the forces, friendly and adversary, in that sector. In other words, not only did each side have perfect intelligence on its adversary's force composition, but each side also had perfect communications because it knew the status of each and every friendly unit in that sector. Also note that the combat power assessment assumed that the opposing commanders each had an identical assessment of the combat power value of each of the systems of all the forces. That is, there was no modeling of a commander's misperception that the adversary's force is more or less formidable than the specified combat power values. Also note that surprise could not be modeled with this construct. Each side was omniscient with respect to its adversary, so there was no way for a commander to maneuver an unseen force to a position of advantage to attack the enemy from an unexpected direction. Quite simply, if a force has a 3 : 1 or better advantage in combat power over their adversary, then that force would attack that adversary. Attrition of each side's combat power was then assessed based on the calculated combat power ratio, and each side's combat power was then decremented accordingly. Movement of both forces was then assessed

based on the amount of combat power lost and the type of terrain the sector consists of. Movement may have been mitigated so that a unit's movement in one sector did not expose the flank of a friendly unit in an adjacent sector. As simulations became more sophisticated, combat power scores were modified. The Marine Corps' Tactical Warfare Simulation, Evaluation, and Analysis System (TWSEAS) and MAGTF (Marine Air Ground Task Force) Tactical Warfare Simulation (MTWS) took into account "perceived combat power," which limited each side's calculation to only its current knowledge of the opposing force. Some simulations calculated dynamic combat power values, updating values based on the remaining forces on the battlefield after each time step, so, for example, an air defense weapon might have no combat power once all opposing aircraft had been destroyed.

Entity Simulations

In an entity simulation where individual combatants (systems or personnel) are engaging, each entity is assigned to travel from a starting position, via a series of waypoints, to a destination that it will reach if it survives. If the entity detects an adversary's entity, and current rules of engagement (ROE) permit, it will fire at that entity. An algorithm will then assess the probability that the entity hit the adversary's entity (P(hit)), and if it did hit, the amount of damage the hit inflicted (P(kill/hit)) where "kills" are typically categorized as "catastrophic," "mobility," "firepower," or "mobility and firepower."

Simulations and Prediction

The late, great Air Force analyst, Clayton Thomas, described simulation-based analysis as an IF-THEN statement. Both the simulation and the data comprise the IF side. The simulation and the data are then used to produce the simulation's output, the THEN side. If the simulation represented reality and if the data were precise, then the result would be an accurate prediction.[30] In general, neither is true. In the following paragraphs, we will examine how well our simulations represent reality and how precise our data are.

Standard Assumptions

There are standard assumptions for most closed-loop computer simulations. Human factors, such as leadership, morale, combat fatigue, and training status are typically not explicitly represented in these simulations. If not represented explicitly, then the implicit assumptions are that both sides have exactly the same characteristics with respect to human factors. While there have been attempts to represent human factors

30 Chapter 13, "Verification Revisited" in Military Modeling for Decision Making, MORS 1997, edited by Wayne P. Hughes, Jr.

such as training status and morale, the value of such explicit representation needs to be justified. If the simulation is attempting to assess the value of a new weapon system and the study team is using a scientific-method approach, having outcomes differ due to human factors makes it more difficult to determine the true cause of the difference between two sets of replications. In most combat simulations, the human factors are either ignored or standardized and mirrored so as to make the basis of comparison as free from confounding factors as possible.

Data

The simulations described above usually need between three to six months to instantiate a new scenario, and will cost around one million US dollars to get the simulation ready to run (terrain and performance data developed, quality controlled, and input, and scheme of maneuver developed, instantiated, and tested). Data is always challenging. Performance data must be developed to account for every interaction that could happen between all systems that will be represented on the battlefield. Performance data development can be especially challenging when examining future scenarios with emerging technology. Even developing data to simulate today's forces comes with challenges. The US Army has perhaps one of the most robust processes to develop performance data, but even that process uses only about 10% of actual data. This data is collected from ranges such as Aberdeen Proving Grounds where, in a controlled environment, US Army weapon systems are fired at captured enemy systems to determine their vulnerability to US weapons. They also use captured enemy systems to fire at actual US Army systems to determine their vulnerabilities. Often several US ground combat vehicles are rolled off the production line with the expressed intent of testing their vulnerabilities to enemy systems. After test firing is conducted, engineers determine the damage caused and record that information, which becomes the basis for the performance data that is generated for ground combat simulations. The other 90% of the data is then "surrogated," that is, interpolated, extrapolated, or otherwise estimated from that existing test data. This data is often developed using engineering-level simulations. Ground combat weapon systems are relatively inexpensive and numerous so testing their vulnerabilities can be done given the availability of the appropriate enemy weapon systems and ammunition. The Navy and the Air Force are challenged to come up with test data that can be used to develop performance data against their platforms. Firing captured adversary anti-ship missiles at a multibillion-dollar Ford class aircraft carrier to see how many hits it can withstand before sinking just is not possible, so often the data used is more of an educated guess than a mathematical approximation. One of the biggest threats to today's naval vessels is the anti-ship missile (ASM), but there have been less than 300 recorded instances of ASM hits on vessels that could be used to develop data.[31]

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31 Faucett, J.E. (2019) " Shore-based Anti-Ship Missile Capability and Employment Concept Exploration," Master's Thesis, Naval Postgraduate School,Monterey, CA, June 2019.

Simulating the Reality of Combat

Many, if not most, of today's computer-based combat simulations are extraordinarily complex (the Concepts Evaluation Model, a theater-level deterministic closed-loop combat simulation used by the US Army's Concepts Analysis Agency in the late twentieth century was over 250 000 lines of computer code). However, that complexity does not translate into a model that can accurately predict the outcome of combat. This complexity has given rise to two different schools of thought. Simulation skeptics refer to them as "black boxes," which means that the users of these simulations have little to no understanding of the simulation's processes that convert inputs into outputs. Some simulation advocates believe that with the complexity that these simulations have, all the processes of combat are modeled to a high degree of precision, thus the simulation's outputs must be believed without question or debate. Subscribers to either school miss the fundamental truth that the models in these simulations are abstractions and approximations of some specific aspects of combat that the simulation was originally designed to model. All simulations are comprised of one or more models, and all models are an abstraction of reality, with some processes modeled explicitly, some implicitly, and some processes not modeled at all because the simulation's designer did not intend for the simulation to address those excluded processes. Prospective simulation users need to do some research and come to at least a basic understanding of what a simulation under consideration for use in a particular study was originally designed to model, and what its strengths and shortcomings are before they select a simulation that will be useful for the purpose at hand. In a RAND paper examining non-monotonic, chaotic output from a very simple deterministic, Lanchester-based combat simulation (2 variables, 18 data elements, and 8 rules), the authors state "The typical model simulates combat between opposing forces at some level of abstraction. No combat model is seriously expected to be absolutely predictive of actual combat outcomes. It is common, however, to expect models to be relatively predictive. That is, if a capability is added to one side and the battle is refought, the difference in battle outcomes is expected to reflect the contribution of the added capability."[32] This concept of relative predictability underpins the usage of simulations to conduct Analyses of Alternatives, or AoAs, studies that are used to justify weapon system acquisitions in DoD.

The Capability and Capacity of Modern Computing to Represent Combat

Moore's law, the idea that the processing power of computers doubles every 18–24 months, has led to the school of thought that our simulations are accurate

32 Dewar, J.A., J.J. Gillogly, and M.L. Juncosa, *Non-Monotonicity, Chaos, and Combat Models*, RAND, Santa Monica, CA 1991, p. 1.

representations of kinetic combat. However, most of the combat simulations in use today have their roots in the 1960s or 1970s, and in most cases, the computer code has not been optimized to take advantage of this increase in processing power. But even more significant is the notion of artificial intelligence (AI) and the idea that we can accurately represent, to the minute detail, every aspect of combat. The advances in AI that should dissuade us of this notion begin with IBM's computer "Deep Blue" that was programmed to play chess. In 1997, Deep Blue was able to beat Garry Kasparov, at the time a reigning chess champion.[33] A more recent AI triumph was "AlphaGo." AlphaGo was programmed to play the ancient game of Go, and was able to beat world Go champion Ke Jie in 2017.[34] "As Deep Blue and AlphaGo have demonstrated, in games of finite size with well-specified rules, computers can use artificial intelligence (AI) techniques to top human performance."[35]

Let us now begin to examine ground combat and see if it fits the description of the type of games AI has successfully mastered, specifically finite size and well-specified rules.

Finite Size

For finite size, we need to consider the number of pieces, or entities, and the size of the game board, or terrain box.

Number of Pieces/Entities

Chess has six different types of pieces: pawn, knight, bishop, rook, king, and queen, for a total of 16 pieces per side, or 32 total pieces. The US Army's Armored Brigade Combat Team (ABCT) has over 4700 soldiers and over 1300 vehicles, including 90 tanks, 90 infantry fighting vehicles, 112 armored personnel carriers, 18 self-propelled howitzers, and 4 unmanned aerial vehicles.[36] This does not include other assets that would support the ABCT in combat, such as Army and Air Force attack aircraft, and Army logistics assets. When an ABCT is represented in a combat simulation, only the primary combatants are represented, which would be about 300 vehicles and 200 infantry, or 500 of the 6000 entities that would actually be on the battlefield. Assuming the ABCT's adversary was similarly equipped and a similar size, the total entities that would be represented in the simulation would be around 1000, as compared to the 32 chess pieces.

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33 https://en.wikipedia.org/wiki/Deep_Blue_versus_Garry_Kasparov

34 https://techcrunch.com/2017/05/24/alphago-beats-planets-best-human-go-player-ke-jie/

35 "AlphaGo: Using Machine Learning to Master the Ancient Game of Go," 27 January 2016, Official Google Blog, googleblog.blogspot.com/.

36 The U.S. Military's Force Structure: A Primer, July 2016, p22-27, Congressional Budget Office, July 2016.

Terrain

The game of chess has 64 squares, alternating in color but identical otherwise. The chess board is two-dimensional, that is the 64 squares all occupy the same plane. The modern battlefield whether it be the mountainous terrain of Afghanistan, Korea, or Iran; the open and rolling terrain of the North German Plain; or the deserts of Iraq and Kuwait is a three-dimensional terrain: mountains, hills, plains, and valleys. That terrain is broken up by water: rivers, streams, lakes, swamps. There can be vegetation and man-made objects that sit on top of the terrain. The terrain and these objects, unlike the chess board, change over time. Rain and snow change the trafficability of the terrain for combat systems, and it can be different for different types of systems (wheeled versus tracked and dismounted infantry). The terrain can be deformed by digging trenches, building obstacles, and explosions. Vegetation can change over time – a deciduous forest has much better lines of sight after the trees have dropped their leaves. Man-made objects can be rubbled or destroyed. For the time being, we will ignore the airspace above the terrain, but fixed and rotary wing aircraft, manned and unmanned, are an integral part of modern ground combat, given the weather permits. And if we do represent aircraft, we cannot forget that rounds fired from artillery and mortars do share the same airspace as aircraft.

Rules

Let us now consider rules. For ease of understanding and simplicity, we will only cover the major rules for movement, attack, adjudication, and victory conditions.

Movement

The movement rules of chess are fairly straightforward: each of the six pieces has unique movement rules. Moves are alternated between the two players, that is one player moves, and that move is observed and then analyzed by the opponent before the opponent moves. There is really no time–distance factor in a chess move, only one piece can be moved in a turn, and it must conform to the movement rules for that given piece. In a move, the more mobile pieces (queen, bishop, rook) can move from one end of the board to the other, while the king is limited to one square per move. If we considered chess as a wargame, it would be an open wargame, all information is available to all players.

Ground combat systems' movement is dictated by the terrain and the objects that rest on the terrain. As in chess, the different weapon systems have different movement "rules." Tanks and other tracked vehicles are better in open and rolling terrain, and struggle in mountainous and forested terrain. Wheeled vehicles move well on roads and can move well in open and rolling terrain if it is firm, that is, not impacted by weather or torn up by tracked vehicles. Dismounted infantrymen can go almost anywhere, but not very quickly. All movement may also be modified by a commander's orders. Units may be ordered to stop at a certain point or to proceed until a given

objective has been accomplished. Movement in a ground combat environment can be simultaneous and almost constant. Unlike chess, there are no discrete, alternating moves – movement is fluid and nearly nonstop. The observation of one side's moves by the other depends on the sensors deployed to observe, and observations may be mitigated or obscured by deception as well as environmental effects.

Attack

In chess, an opponent's piece can be attacked if it occupies a space that the attacker can move one of its pieces to using the proscribed move for the attacking piece.

In ground combat, a system must first acquire an opponent's system before attacking. Unlike chess, where all pieces are seen by both sides and all possible attacks can be easily identified, combat systems have to find an enemy entity before attacking. Once that entity is acquired, it can then be attacked. The acquisition process can be from the attacking system, from a third party, or from a combination of systems on the battlefield. A tank or an infantryman typically acquires its own targets to attack, where indirect fire assets such as attack aircraft, mortars, and artillery usually attack targets that have been identified by another entity on the battlefield. Once it is decided, a system will engage a target, there may be different attack mechanisms that can be employed and must be specified. Systems often have more than one weapon. A tank has a main gun and a coaxial machine gun. An infantry fighting vehicle has a 25-mm chain gun and an anti-tank missile. An infantryman has a rifle, grenades, and a bayonet. A tank's main gun has different types of main gun ammunition for different purposes.

Adjudication

In chess, if the piece is attacked, the adjudication is simple: it is removed from the board, in essence destroyed. It does not matter what the two pieces are, a lowly pawn can attack and destroy an opponent's pawn or its queen. In ground combat, systems can be removed from the battlefield if destroyed, but systems can also be damaged (or wounded for human "systems"). A damaged system may still be able to move and/or fire, so the amount of damage and remaining functionality of the system must be determined. Damage can be cumulative, so a damaged system can be subsequently destroyed if attacked again, depending on the attacking system and the damage that it can deliver. Damaged systems can also be repaired and returned to the battlefield depending upon the amount of damage sustained and the availability of resources needed to repair the system.

Victory Conditions

A chess game ends when a player's king is in check and under attack by the opponent and cannot move to a space where it is safe from attack on the next move. In ground combat, victory conditions are highly dependent on the objectives of the combatants. Each side may have a "breakpoint" designated, that is, lose no more than x percent of your force executing this mission. Usually an attacker has a goal that either has to do

with seizing terrain or destroying an enemy formation. A defender may have the goal of retaining the terrain it defends, inflicting a certain amount of damage to the attacker before yielding the terrain, or delaying the attacker for a length of time before yielding the terrain. Note that the objectives of attacker and defender may both be met (seize terrain and inflict a certain amount of damage before yielding terrain).

Summary

Today's closed-loop combat simulations are useful for assessing the goodness of adding capability to a formation through use of scientific method-like process for comparison. They cannot predict future outcomes of battle. They are tremendously more complex than chess or Go. The complex decision calculus a battlefield commander goes through that results in forces maneuvering and attacking is greatly simplified to IF-THEN types of decisions. In summary, closed-loop combat simulations are good at comparing different force options given the assumptions and simplifications are known and acceptable.

Campaign Analysis

In other literature, you will be able to find comparisons of wargames and computer-based combat simulations with lists of attributes and an assessment of which of the two tools is "better" vis-*à*-vis a particular attribute. This is a false dichotomy. Wargames and combat simulations are two different tools that are designed to produce two very different types of outputs. Wargames are used to investigate the human decision-making process and are not the primary tool to be used for making quantitative assessments or comparisons. Combat simulations are used to quantify the differences in forces, often using the scientific method process, but have little utility to investigate the human decision-making processes. Professional analytic agencies have recognized the utility of both tools and have often used a combination of tools to produce a more thorough and complete study of the phenomena of combat. This process can be described as "campaign analysis." The process of designing a campaign analysis is described by Kline, Hughes, and Otte:

> The campaign's objectives come from direction provided by political and military leadership at the national level. Derivation of a concept of operations to achieve those objectives, and metrics to measure their achievement, is done in collaboration with the commander and his staff. Assumptions are agreed to and provide a bound on the analytical study.[37]

37 Kline, J., Hughes, W., and Otte, D., 2010, "Campaign Analysis: An Introductory Review," Wiley Encyclopedia of Operations Research and Management Science, ed Cochran, *J. John Wiley & Sons, Inc* Vol 1 pp 558–566.

Once the goals of the campaign are thoroughly understood by all through a series of interactions between the stakeholders and the analysts, then the design process begins. A campaign analysis can be as simple as a wargame conducted to develop a CONOPS that is then instantiated in a closed-loop simulation for quantitative analysis, or it can be far more complex. The analysis done for the US Army's Future Combat Systems used over 50 different wargames and simulations.[38] As Kline et al. describe: "We concurrently select a model or series of models to represent the campaign environment. Broadly speaking, models bound the campaign in either a series of engagements (pulses of power) or a continuous operation where many small engagements create a larger effect (cumulative warfare)."[39] "Model categories range from closed-form probabilistic equations, computer simulations, optimization, and wargames to field experiments and operational rehearsals."[40] "For example, a wargame may help to develop concepts of operation and employment for the opposing sides. The wargame's interactions may be adjudicated by tactical simulations, equations, historic engagements or professional judgment. Once an employment concept or course of action is generated, it may be programmed in a larger campaign simulation to conduct analysis on many model variations."[41]

The realization that a campaign is a series of engagements or many small engagements that create a larger effect reinforces the realization that Lanchester made studying the battle of Trafalgar, and the conclusion that the CARMONETTE mathematical modelers came to about half a century after Lanchester: applying a closed-form computer simulation to combat should only be done for small, short engagements, because the human decision-making is such an important element of combat that to ignore it and presume that algorithms alone could accurately model the complexity of a campaign of modern combat's decision processes is pure folly.

Conclusion

Both wargames and closed-loop combat simulations will continue to have roles in analysis. Wargames will continue to help us understand trade-offs in CONOPS and courses of action development and will play a major role in the creation and development of new employment concepts and new tactics, techniques, and procedures

38 Future Combat System (FCS) Milestone B Analysis of Alternatives (AoA), TRAC-TR-03-018, ft Leavenworth, KS, 14 May 2003, P.Z.

39 Kline, J., Hughes, W., and Otte, D., 2010, "Campaign Analysis: An Introductory Review," Wiley Encyclopedia of Operations Research and Management Science, ed Cochran, *J. John Wiley & Sons, Inc* Vol 1 pp 558–566.

40 Kline, J., Hughes, W., and Otte, D., 2010, "Campaign Analysis: An Introductory Review," Wiley Encyclopedia of Operations Research and Management Science, ed Cochran, *J. John Wiley & Sons, Inc* Vol 1 pp 558–566.

41 Kline, J., Hughes, W., and Otte, D., 2010, "Campaign Analysis: An Introductory Review," Wiley Encyclopedia of Operations Research and Management Science, ed Cochran, *J. John Wiley & Sons, Inc* Vol 1 pp 558–566.

as new weapon systems and capabilities are integrated into our fighting forces. Closed-loop combat simulations will continue to provide the capability to assess the physics-based qualities of our forces and will allow us to tabulate, in the absence of any human input, the relative technological merits of new weapon systems and new formations.