LIFTING OFF OF THE DIGITAL PLATEAU WITH MILITARY DECISION SUPPORT SYSTEMS

A Monograph

by

MAJ Stephen J. Banks
United States Army

School of Advanced Military Studies
United States Army Command and General Staff College
Fort Leavenworth, Kansas

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14. ABSTRACT

Armies have used wargames throughout history to increase their chance for victory by gaining an understanding how events might unfold. A Defense Advanced Research Projects Agency (DARPA) project called Deep Green, attempted to introduce wargames during the execution of military operations. DARPA envisioned Deep Green as a military DSS that compared friendly assumptions and predictions of enemy behavior with actual events as they unfolded. However, Deep Green did not achieve this goal due to the combination of two technical obstacles. The first technical obstacle was the underlying simulation and the predictability of warfare. The second technical obstacle was the information available to the decision support system. Developers must address both of these limitations to ascend from the current plateau to a level that would provide useful decision support to a commander.

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Name of Candidate: Major Stephen J. Banks

Monograph Title: Lifting Off of the Digital Plateau With Military Decision Support Systems

Approved by:

____, Monograph Director
Matthew Schmidt, Ph.D.

____, Seminar Leader
Thomas A. Shoffner, COL

____, Director, School of Advanced Military Studies
Thomas C. Graves, COL

Accepted this 23rd day of May by:

____, Director, Graduate Degree Programs
Robert F. Baumann, Ph.D.

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ABSTRACT

LIFTING OFF OF THE DIGITAL PLATEAU WITH MILITARY DECISION SUPPORT SYSTEMS, by MAJ Stephen J. Banks, 56 pages.

Armies have used wargames throughout history to increase their chance for victory by gaining an understanding how events might unfold. However, wargaming is not only a military undertaking, in the civilian world decision support systems are used in various fields including weather prediction, playing games, and stock trading. In the twenty-first century, having observed the success of civilian model-driven decision support systems and the advancement of computer-based simulations, military researchers proposed the idea of including wargames not only during planning, but also during operations to aid commanders as part of a model-driven decision support system (DSS). One experiment, a Defense Advanced Research Projects Agency (DARPA) project called Deep Green, attempted to make this leap. DARPA envisioned Deep Green as a military DSS that compared friendly assumptions and predictions of enemy behavior with actual events as they unfolded. However, Deep Green did not achieve this goal due to the combination of two technical obstacles.

The first technical obstacle was the underlying simulation and the predictability of warfare, which is the focus of this monograph. A simulation that supports a DSS must balance speed and fidelity. To provide a commander a correct analysis too late is of no value, but neither is giving him an inaccurate analysis quickly. This tradeoff between clarity and accuracy has existed throughout the history of wargames, and much of military theory.

The second technical obstacle was the information available to the decision support system. In the case of a United States (U.S.) Army DSS, information the Army Battle Command Systems (ABCS) provided this information. In their current form, ABCS do not provide the level of fidelity necessary to allow the DSS to “see” reality. This limiting factor is beyond the scope of this paper, but the U.S. Army must address available information in order to implement a military decision support system. If this information problem is solved and a simulation accepted, then model-driven decision support systems are feasible to augment military decision making by tracking staff estimates and assumptions to inform a commander when a decision must be made.

Developers must address both of these limitations to ascend from the current plateau to a level that would provide useful decision support to a commander. First, developers must implement rules that are flexible enough to respond to a changing battlefield yet rigid enough to provide useful decision support in a simulation. The rules must result in fast simulation if they are to enable a commander to make decisions more quickly than his adversary does. Second, the data necessary to enable the system must be available. This requires a robust commitment to upgrade and develop new ABCS designed to deliver the necessary high-fidelity data to the DSS. Decision support systems are effective in the civilian sector and present potential in the military sector if developers can pair the right set of rules with sufficient data.

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ACRONYMS

ABCS	Army Battle Command Systems
AMSO	Army Modeling and Simulation Office
BAA	Broad Area Announcement
CBS	Corps Battle Simulation
CJCS	Chairman of the Joint Chiefs of Staff
COA	Course of Action
COCOM	Combatant Commander
COTS	Commercial Off The Shelf
C2	Command and Control
DA	Decisive Action
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DJIA	Dow Jones Industrial Average
DSS	Decision Support System
EPW	Enemy Prisoners of War
GPS	Global Position System
IBM	International Business Machines
NEWS	Navy Electronic Warfare Simulator
NHS	National Hurricane Center
NYMEX	New York Mercantile Exchange
ODS	Operation Desert Storm
OM	Operations Monitor
OneSAF	One Semi-Automated Forces
OpSim	Operational Simulation
QDR	Quadrennial Defense Review

RAID	Real-time Adversarial Intelligence and Decision-making
SAGA	Studies, Analysis, and Gaming Agency
SEC	Security and Exchange Commission
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SME	Subject Matter Expert
STP	Sketch-Thru-Plan
TIGER	Tactical Inference GenERator
USAF	United States Air Force
USMC	Unites States Marine Corps
VBS2	Virtual Battle Space 2
WarSim	Warfighter's Simulation

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INTRODUCTION

All models are wrong, some are useful.

–George E. P. Box[1]

Armies have used wargames throughout history to increase their chance for victory by gaining an understanding how events might unfold. However, wargaming is not only a military undertaking, in the civilian world decision support systems are used in various fields including weather prediction, playing games, and stock trading. In the twenty-first century, having observed the success of civilian model-driven decision support systems and the advancement of computer-based simulations, military researchers proposed the idea of including wargames not only during planning, but also during operations to aid commanders as part of a model-driven decision support system (DSS). One experiment, a Defense Advanced Research Projects Agency (DARPA) project called Deep Green, attempted to make this leap. DARPA envisioned Deep Green as a military DSS that compared friendly assumptions and predictions of enemy behavior with actual events as they unfolded. However, Deep Green did not achieve this goal due to a combination of technical shortcomings.

The original motivation of this monograph was to explain, "Why Deep Green failed." However, after reviewing the success of DSS in the civilian sector and military simulations, the focus changed to understanding "How could Deep Green not succeed?" This may be a subtle difference, but the observed simplifications made in civilian DSS still allowed useful decision support in a variety of situations. It seemed that similar abstractions would be effective in a military decision support system; however, Deep Green ultimately ran into two technical obstacles. The first was the underlying simulation and the predictability of warfare, which is the

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[1]George E. P. Box and Norman R. Draper, *Empirical Model-Building and Response Surfaces* (Wiley: New York, 1987), 414.

focus of this monograph. A simulation that supports a DSS must balance speed and fidelity. To provide a commander a correct analysis too late is of no value, but neither is giving him an inaccurate analysis quickly. This tradeoff between clarity and accuracy has existed throughout the history of wargames, and much of military theory.

The second technical obstacle was the information available to the decision support system. In the case of a United States (U.S.) Army system, the Army Battle Command Systems (ABCS) provided the data to the DSS. In their current form, ABCS do not provide data with the level of fidelity necessary to allow the DSS to "see" reality. The limiting factor of data is beyond the scope of this paper, but the U.S. Army must address data available if it desires a military DSS. If this information problem is solved and a simulation accepted, then model-driven decision support systems are feasible to augment military decision making by tracking staff estimates and assumptions to inform a commander when a decision must be made.

This work has three parts. The first part presents the nature of the problem of applying a decision support system to the military domain. It begins with a presentation of terms used to describe and compare systems, models, and simulations. Part one continues with the story of military wargames. The history of wargames demonstrates the historical acceptance of the wargame as a tool, while highlighting the discourse between the primacy of rules or human judgment in addressing the nonlinear nature of warfare. This part concludes by defining the problem facing modern selection of a simulation that would drive a military decision support system in light of military theory.

Part two applies the terms introduced in part one to describe three decision support systems used in the civilian sector. The examples are all the same type of DSS, model-driven, but vary in terms of linearity, output from the DSS, and impact of human interaction. The examples build in terms of human interaction and complexity to an approximation of military decision-making. The three DSS demonstrate techniques to address reality sufficiently to provide useful decision support.

The story of Deep Green encompasses much of the third part. This story involved not only the historic practice of wargaming and established civilian DSS, but also the vision for the project and how it would interact with existing U.S. Army systems. Deep Green was envisioned as three components which would allow a commander to interact with a digital environment using a special pen, receive existing state information from other U.S. Army systems, and compare planned versus real states. Deep Green's challenges emerged not with human interaction, but with two technical issues. The first challenge was the underlying simulation and the tradeoff between speed and accuracy. The second challenge was interaction with existing U.S. Army digital command and control systems, the Army Battle Command System (ABCS). The information available from ABCS was insufficient to feed the simulation. Beyond these technical challenges, DARPA changed its focus away from command and control systems. The cumulative result was that the Deep Green project provided the military an innovative smart-pen tool for commanders to intuitively create portions of the operations order, but not a military decision support system.

The concluding section explores the implication of the two major technical obstacles to implementing a military decision support system: agreement on the underlying simulation and providing this simulation sufficient information. Simulations have demonstrated the ability to classify tactical situations in the same way as subject matter experts. Simulations have also proven to be unpredictable enough to be confused with human opponents in tactical scenarios. But, these successes were in experiments, in a laboratory, in which the simulations were not receiving information from actual operations. Ultimately, the overarching challenge to the success of a decision support system is to provide the quality of information that the system needs to enable good decision advice.

THE NATURE OF MILITARY SIMULATIONS

This section presents a three-part foundation to explain the nature of military simulations and the problem of selecting one to underpin a decision support system in the military domain. The first portion of the foundation provides the terminology necessary to describe models, simulations, and decision support systems. These terms provide the vocabulary for DSS comparison in section two. The second piece of the foundation, the history of wargaming, explains the development and some limitations of the wargame. These historic wargames are the basis of the modern models that underlie military model-driven decision support systems. A description of the problems facing the implementation of a decision support system in the military domain completes the foundation.

The primary concern with the underlying simulation is speed versus accuracy. In the realm of testing intricate models are developed and implemented in simulation with relatively little concern about the time or computer hardware necessary to run thousands of iterations to validate a design. In some training and education environments, on the other hand, some have advocated for simpler models that are easier to manipulate. These simpler models enable educator to tailor scenarios to meet their learning objectives, perhaps sacrificing accuracy for clarity, but generating the desired decision making situations to teach their students a particular habit of mind. Unfortunately, neither of these approaches is viable for the simulation underlying a DSS during an operation. The model must be simplified, but still reflect reality, and be able to run on common computer platforms that are rugged and durable enough to survive in a combat environment. The challenge is to determine an acceptable level of simplification that still provides a useful output for the decision maker. The simulation does not exist in a vacuum, but is only a portion of the DSS. Of equal concern, to the DSS as a whole, is how to input analog data from the real world into the digital system.

Terminology

Throughout this monograph, there are a variety of terms used to describe models, simulations, systems, and wargames. Most importantly, the terms introduced here describe and compare decision support systems in the following section. Although many of the terms exist in common language, they often have "multiple and contradictory meanings in common English."[2] For example, "model" could mean anything from a person wearing a fashionable coat to a mathematical representation of planetary movement. Terms used are consistent with Department of Defense (DOD) definitions, when one exists. When no DOD definition exists, a definition derived from scholarly work in the field is used.

The terms "model" and "simulation," as used in day-to-day conversations, are often interchangeable, however, they have distinct meanings germane to this monograph. A model is a simplified version of reality, useful because it is easier to understand.[3] A map is an example of a model of real terrain. Simulations are "a method for implementing a model over time," they put the model into motion. [4] An example of simulation related to a map model occurs in a global position system (GPS) when it calculates the amount of time it will take a traveler to move from his current location to a desired destination.

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[2]Paul K. Davis and Donald Blumenthal, "The Base of Sand Problem: A White Paper on the State of Military Combat Modeling" (Santa Monica: RAND, 1991), 1.

[3]Department of Defense, *DoD Modeling and Simulation Glossary* (March 2010), 187. A Model is: A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. Analytical models consist of a set of solvable equations; for example, solvable equations that represent the laws of supply and demand in the world market. Structural models are representations of the physical or logical structure of a system such as a representation of a computer network as a set of boxes connected by communication lines. A symbolic model's properties are expressed in symbols. Examples include graphical models, mathematical models, narrative models, software models, and tabular models.

[4]Ibid., 218.

Attributes commonly used to describe models and simulations are: resolution and fidelity. In the realm of models and simulations, these terms take on an important distinction. Resolution is the amount of detail or precision in a simulation. Fidelity is the degree to which key parameters of the simulated system match a baseline system. For example, many military simulations model rifles. A high-resolution simulation would focus on how much the modeled rifle looked like a rifle, while a high fidelity simulation would focus on how much the modeled rifle acted like a rifle.[5]

Decision support systems are "interactive, computer-based systems that aid users in judgment and choice activities" that "support framing, modeling and problem solving."[6] Importantly, DSS "are usually viewed as tools which help people make decisions but do not automate decision making per se."[7] Practitioners categorize DSS into five general categories based on what drives the process: communication, data, document, knowledge, or model. Military, and the civilian examples in this monograph, fall into the final category of model-driven DSS. This category describes DSS that "use data and parameters provided by decision makers to aid decision makers in making a decision."[8]

Decision support systems create an output called a solution set. The solution set is a list of possible answers. A simple example is 2+2=Y. The solution set has a singular value Y=4. Adding a second variable could expand a solution set infinitely. For example X+Y=7. One

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[5]Ibid., 209, 213.

[6]Marek Drudzel, and Roger Flynn, "Decision Support Systems." Allen Kent, ed., *Encyclopedia of Library and Information Science* (Marcel Dekker Inc., 2002), 6.

[7]Steven Alter, *Computer Aided Decision Making in Organizations: A Decision Support Systems Typology,* Sloan White Paper (Massachusetts Institute of Technology, Cambridge: Center for Information Systems Research, 1976), 1.

[8]Daniel Power, "Web-Based and Model-Driven Decision Support Systems: Concepts and Issues" Americas Conference on Information Systems (Long Beach: AMCIS, 2000), 1.

possible solution set (x,y) is (3,4); but so are (-2,9), (0.5, 6.5), (1,6), … and so forth. In this case the value of one variable in dependent upon the other. To control the size of the solution set, one could place conditions on a variable. For example, X must be a positive integer with a value between 1 and 10. Given this limitation, a finite solution set for Y can now be determined: (x,y): (1,6), (2,5)…(10,-3).

Systems are either linear or nonlinear, and sometimes complex or chaotic. Linear systems are those "whose variables can be plotted against each other as a straight line," while nonlinear systems are those that violate these two conditions and "may exhibit erratic behavior through disproportionately large or disproportionately small outputs, or they may have 'synergistic' interactions in which the whole is not equal to the sum of the parts."[9] Types of nonlinear systems include: complex, dynamic, dissipative, adaptive, and chaotic.[10] For the purposes of this monograph, the distinction between types of nonlinear systems is unimportant. Human interaction often introduces nonlinearity to systems through cognitive biases and free choice. A model of a system, though, can maintain linearity even in the presence of human interaction through restrictive rules.

History of Wargames

The history of wargames is important to understanding the implementation of a decision support system (DSS) because wargames underlie the model of a model-driven DSS. Wargames developed along two major paths: strict *kriegsspiel* and free *kriegsspiel.* These paths highlight the tension between rules-focused and human-focused models for addressing the nonlinearity of

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[9]Alan Beyerchen, "Clausewitz, Nonlinearity, and War," *International Security* vol. 17, No. 3 (Winter 1992-93): 62.

[10]*Nonlinear Systems*, http://www.globalcomplexity.org/NonlinearSystems.htm (accessed 24 January 2013). Alan Beyerchen, "Clausewitz, Nonlinearity, and War," 65.

warfare. Throughout their history, armies largely used wargames in two distinct ways. The first was as a teaching tool to teach habit of mind to military leaders. The second was as a pre-execution tool to ensure sufficient forces and resources were available to undertake a military operation.

The use of a scored rehearsal or wargame seems to be as old a technique as organized combat. Roger Ames translated Sun Tzu's ancient Chinese treatise on warfare to include a "temple rehearsal of the battle" during which "the side that scores many points will win; the side that scores few points will not win."[11] Other translations did not include the word rehearsal but include the passages: "estimates made in the temple before hostilities indicate victory"[12] and "before the engagement, one who determines in the ancestral temple that he will be victorious has found the majority of factors are in his favor."[13] These three translations provided an ancient example of the use of wargaming. Sun Tzu's "temple rehearsals" likely grew into *Go*, a board game that reflects "Chinese philosophy, culture, strategic thinking, warfare, military tactics, and diplomatic bargaining."[14]

Ancient Indians developed their own wargame, *Chaturanga,* at about the same time, five thousand years ago. *Chaturganga* originally involved four players and added the randomizing factor of dice; with significant modification, many writers agree *Chaturganga* was the forbear of modern chess. The removal of dice eliminated chance and the reduction of the number of players

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[11]Sun Tzu, *The Art of Warfare,* trans. Roger Ames (New York: Ballantine, 1993), 105

[12]Sun Tzu, *The Art of War,* trans. Samuel B. Griffith (Oxford: Oxford University Press, 1963), 71

[13]Sun Tzu, *Art of War,* trans. Ralph D. Sawyer (Oxford: Westview Press, 1994), 168

[14]Go is the American name for this game. The Chinese name is *weiqi,* which means "a game of encircling territories." The game is known in Japanese as *Igo* and Korean as *Baduk*. David Lai, *Learning From the Stones: A Go Approach to Mastering China's Strategic Conept, Shi,* SSI Report (Carlisle: Strategic Studies Institute (SSI), 2004), v, 32.

to two resulted in a game that was too abstract for practical application, yet armies used *Chaturganga* as preparation for war for centuries.[15]

In 1664, the Prussian Christopher Weikhmann developed *koenigsspiel*, the ancestor of modern wargaming techniques. [16] Weikhmann developed *koenigsspiel* to teach military and political principles. Nearly a century later, in 1780, another Prussian, Dr. C. L. Helwig, modified the game to incorporate three critical concepts that remain in wargames today: aggregation, using one playing piece to represent multiple soldiers; abstract terrain, rather than all squares being equal; and a referee, to supervise the game.[17] These games taught the importance of "anticipating the consequences of one's possible moves and the opponent's possible responses, an essential skill in the deadly game of war," taking great abstractions of war, that minimized their fidelity in an effort to ease game play.[18]

In Prussia, Baron von Reisswitz led the next major step forward from 1811-1824 by introducing *kriegsspiel*. [19] The new game introduced two key concepts and was the direct precursor to modern wargames. First, Reisswitz separated the players and ensured each had their own terrain table on which only "such troops that were actually considered visible were represented" to replicate the lack of information available to a commander. Second, Reisswitz created complex tables that accounted for the affects of the battlefield, such as range and terrain, and attrition. Attrition was dependent on the roll of a die, which reintroduced chance to the

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[15]Peter P. Perla, *The Art of Wargaming* (Naval Institute Press: Anapolis, 1990), 16.

[16]King's Game.

[17]Peter, Perla, *The Art of Wargaming*, 17-18.

[18]Matthew Caffrey Jr., "Toward a History-Based Doctrine for Wargaming" *Aerospace Power Journal* (Fall 2000): 34.

[19]Wargame.

simulated battlefield.[20] Reisswitz's son further enhanced the tool by moving game play from cumbersome sand tables onto easily transportable paper topographic maps. These changes enabled the Prussians to have a tool that could teach habit of mind to their commanders without requiring a war or deploying large numbers of troop to a training event.[21]

Following their success in the Franco-Prussian War (1870-1871), much of the rest of the world imitated the Prussian military including their system for wargaming. In the U.S. Army, however, General William T. Sherman rejected wargaming, as early as 1869, because it ignored human factors such as fear and leadership. Sherman warned against the "insidious and most dangerous mistake" that one could "sit in ease and comfort in his office chair and ... with figures and algebraic symbols, master the great game of war."[22] These concerns were echoed in Germany, where Colonel (later General) Jules von Verdy stripped away the complex rules and tables, and relied on the military experience of an umpire to determine the effects of movement and firing on units. Verdy's stated that the goal of his modification was to make wargaming available to officers that "have been hitherto frightened away by the Dice and Tables of Losses and Rules."

Verdy released his version of *kriegsspiel,* now called free *kriegsspiel,* in a series of books from 1873 to 1876.[23] To distinguish between the two forms of *kriegsspiel*, Reisswitz's rules-

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[20]Baron von Reisswitz, *Kriegsspiel: Instructions for the Representation of Military Manoeuvres with the Kriegsspiel Apparatus,* trans. Bill Leeson (Hertfordshire: Bill Leeson, 1983), 11-17.

[21]Caffrey, "Toward a History-Based Doctrine for Wargaming," 34-35.

[22]William Tecumseh Sherman, *Address to the Graduating Class of the U.S. Military Academy, West Point, June15th 1869* (New York: Van Nostrand, 1869), 8. Quoted by Harry G. Summers Jr. "Clausewitz: Eastern and Western Approaches to War," *Air University Review* (March-April 1986), http://www.airpower.au.af.mil/airchronicles/aureview/1986/mar-apr/summers.html.

[23]Jules von Verdy, *Free Kreigspiel,* ed. John Curry, trans. J. R. MacDonnel, Lulu.com, 2008, 18.

based version became strict *kriegsspiel*. Verdy's free *kriegsspiel* offered an advantage over Reisswitz's in terms of gameplay, but it had a critical requirement: a combat experienced umpire, easily available in Germany in the 1870s, but less so as the veterans of the Franco-Prussian War retired. However, the number of available combat experienced veterans in the U.S. decreased more quickly, as the U.S. Civil War had ended five years prior to the Franco-Prussian war, making free *kriegsspiel* a less attractive option in the U.S.[24]

It is important to not overstate the distinction between strict and free *kreigsspeil*. Strict *kriegsspiel* was not without human factors. For example, Riesswitz developed detailed descriptions and distinctions between troops including repulsed, defeated, totally defeated, or shaken.[25] Although free *kriegsspiel* did not include tables governing the affects of direct fire or movement, Verdy included a detailed discussion of movement rates throughout the text of free *kriegsspiel*. The British army conducted a wargame, in 1896, using a hybrid of the two systems by combining a series of tables that governed many aspects of the wargame with an umpire who oversaw the event.[26]

The U.S. Army took two separate approaches to wargaming. The first approach, led by Major W. R. Livermore in 1883 and entitled "The American *Kriegsspiel*," was little more than a translation of Reisswitz's strict *kriegsspiel* into English. Importantly, Livermore updated the data tables based on experiences from the U.S. Civil War. Lieutenant C. A. L. Totten furthered American wargaming in his 1895 work, "Strategos" by dividing the game into two parts: The Battle Game and the Advanced Game. Totten's Battle Game was a simpler version of the full Advanced Game, much as developers use a simplified tutorial for instruction in many games

[24]Perla, *The Art of Wargaming*, 31-34.

[25]Reisswitz, *Kriegsspiel*, 61-65.

[26]Verdy, *Free Kreigspiel*. Movement: 48-52; affects of fire: 83, 87; British use of tables: 133-152.

today. The U.S. Army did not warmly receive these games due to their inherent complexity and strict focus on rules; the U.S. Army sought a simpler game, similar to free *kriegsspiel*.

The second U.S. approach,led by Eben Swift, filled the desire for a simpler game. Swift translated Verdy's "A Simplified War Game," into English in 1897, introducing free *kriegsspiel* to the U.S. Army. The U.S. Army War College adopted wargaming in 1899. It remains in the curriculum today. [27] Wargames required standardized inputs to the umpire for control. These formatted inputs to the umpire contributed to the operations order structure and map overlays that are still in use today.[28]

Although there was little development of wargames during the first half of the twentieth century, militaries continued to use wargames to prepare for the future. Famously, in 1905, Germany's Count Alfred von Schlieffen wargamed his plan to invade France and destroy its army before Britain could intervene. During the same year, British wargamers reached the same conclusion, that they could not reinforce France quickly enough. The results of the wargame led to British adjustments to mobilization and cross-channel plans. Actual execution of this plan, in 1914, exposed some of the risks of wargaming. The wargame focused on military variables such as rates of march or when units would expend their ammunition, which allowed the Germans to effectively adapt their resupply plans. However, the decisive diplomatic and political consequences of military actions were outside the scope of the wargame, which led to unexpected actions during the war including Belgian civilians destroying their own railroads and the United

[27]John P. Young, "A Brief History of War Gaming: Reprinted from Unpublished Notes of the Author," 14-18.

[28]Eben Swift, *Orders*, (Fort Leavenworth: Staff College Press, 1905), 21-22. William McCarty Little. "Strategic Naval Wargames or Chart Maneuver," *United States Naval Institute Proceedings* (December 1912): 1223.

States' entry into the war. Both sides conducted detailed wargames, but failed to address many critical human factors.[29]

Following its defeat and limited to a skeletal military, Germany revisited wargaming following World War I. The Germans elevated the level of the wargame from tactical to strategic and expanded the participants to include: industrialists, attaches, diplomats, and journalists. During these wargames the Germans developed the concept of "mobile operations," later dubbed *blitzkrieg* by the Allies during World War II. Before and during World War II, both sides used wargames extensively; but after the war, wargaming development came to a worldwide halt, except in the Soviet Union. The Soviets expanded and added a level of rigor to wargaming that the United States did not match until the 1950s.[30]

In the U.S., following World War II, little happened with wargaming for nearly a decade. In 1954, the RAND Corporation, at the request of the U.S. Air Force (USAF), gamed through a nuclear war. In 1958, the Navy computerized wargaming with the Naval War College's computerized Navy Electronic Warfare Simulator (NEWS), while the U.S. Marine Corps (USMC) established a series of amphibious landing wargames at Quantico, Virginia. While wargames were growing more complicated with the addition of nuclear weapons and modern technology, they failed to address the debate between detail and human factors. Detail was certainly increasing to address accuracy and fidelity, but human factors were largely not included in these wargames. This would change following the failure at the Bay of Pigs.[31]

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[29]Caffrey, "Toward a History-Based Doctrine for Wargaming," 41.

[30]Ibid., 41-46.

[31]Ibid., 47-48.

President Kennedy "believed that he had been badly advised, and that the military had little understanding of how the political world worked."[32] To address this shortcoming, the military developed a series of top-secret wargames under the Studies, Analysis, and Gaming Agency (SAGA) to conduct non-predictive wargames that included a variety of considerations from real-life to stimulate politico-military discussions. This type of wargame continues to be useful to senior leaders. The Chairman of the Joint Chiefs of Staff (CJCS) led "strategic seminars" in 2012 with the U.S. military's regional combatant commanders (COCOM). During the seminars the senior military leaders "worked their way through a series of potential national security crises, locked in debate over what kind of military—its size, its capability—the nation will require in the next five years."[33] This strategic-level wargaming does not lend much assistance, though, to a project determined to provide a leader, engaged in combat, with a recommended course of action.

The 1970s saw a new phenomenon in wargaming and simulations. The civilian market expanded from a single publisher selling a paltry two thousand copies of a game in 1953 to several publishers selling a combined two million units in 1979. This growth in commercial gaming combined to accelerate progress in the 1980s. One critical step was simply establishing simulation centers at installations, which allowed commanders to train more efficiently. However, commercial, paper-based wargames would see their peak sales in 1980 at 2.2 million units, as a new platform entered the market: personal computers.[34]

Wargaming for Operation Desert Storm (ODS), 1991, took place, partially, using a modified commercial off the shelf (COTS) wargame called *Gulf Strike*. The developer, Mark

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[32]Allen, Thomas B., *War Games* (New York: McGraw Hill, 1987), 29.

[33]Shanker, Thom, "Mapping Military Needs, Aided by a Big Projection," *The New York Times* (12 September 2012), A4.

[34]Caffrey, "Toward a History-Based Doctrine for Wargaming," 50-51.

Herman, was able to modify the board game within one day to facilitate a classified wargame. Wargaming for ODS also highlighted some of the dangers of computer wargames. This exercise highlighted a limitation of wargaming: the wargamer can only measure what is in the model. For example, planners failed the need to secure enemy prisoners of war (EPWs) from *Gulf Strike*, because EPWs were not part of the model. Additionally, numerous DOD wargames predicted tens of thousands of coalition casualties, resulting in aircraft being prepared for medical evacuation missions, rather than the critical resupply missions that were required when the pace of the attack exceeded what the wargames foretold. While coalition forces were liberating Kuwait in 1991, RAND published a paper, "The Base of Sand," that contained the warning that simply applying more computing power without a more comprehensive understanding of military science would not produce a better wargame or simulation. Interestingly, this RAND study explicitly ignored human-factors models while addressing "general-purpose forces fighting at the battalion through theater level."[35]

This separation of human factors from combat hearkened back to Sherman's concern about wargames that were divorced from leadership and morale. During the 1990s the commercial gaming market exploded to approximately 2.5 billion dollars in 1997 as the power of the personal computer grew.[36]

The use of wargames and simulations has continued throughout the U.S. Army since the turn of the twenty-first century. Before attacking Iraq as part of Operation Iraqi Freedom in 2003 V Corps held a large scale, computer-based wargame at Grafenwoer, Germany called Victory

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[35]Davis and Blumenthal, "The Base of Sand Problem: A White Paper on the State of Military Combat Modeling," v, 2.

[36]Caffrey, "Toward a History-Based Doctrine for Wargaming," 51.

Scrimmage. By this point, the use of computer-based wargames was so accepted and prevalent that V Corps expected the exercise to accomplish several critical training objectives, including:

- Rehearse V Corps and selected headquarters go-to-war C4ISR [Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance] functions.
- Rehearse key ground maneuver tasks.
- Rehearse the Corps' deep operations command and control skills.[37]

V Corps conducted the rehearsal using the Army's Corps Battle Simulation (CBS) software, a simulation developed for force on force combat. However, this simulation lacked the capability to include the important insurgency and stability tasks the Army found itself executing as the war progressed.[38]

Armies have used rehearsals or some form of wargames throughout recorded military history. These wargames have become more complex and shifted along a continuum between focus on detail and rules versus human agency and abstraction. To take advantage of the introduction of computers to wargaming, wargamers shifted the focus to the detail and rules, strict *kriegsspiel*, side of the spectrum. Since at least 2007, there has been an idea to move the wargame from before an operation to during the operation to provide commanders a tool to assist with decision-making.

[37]Gregory Fontenot, E. J. Degen, and David Tohn, *On Point: The United States Army in Operation Iraqi Freedom* (Annapolis: Naval Institute Press, 2005), Chapter 2, figure 29.

[38]Sherry Mertens, "The Corps Battle Simulation for Military Training" (Pasadena: Jet Propulsion Laboratory, 1993), 1055. The selection of this simulation was not necessarily indicative of the mindset of military leaders at this time, as simulations were not available to facilitate a wargame against an insurgency.

Simulation Selection

The tensions between strict *kriegsspiel* and free *kriegsspeiel* came down to techniques for addressing the inherent nonlinearity of war. Advocates for strict *kriegsspiel* approached the problem by creating tables that introduce nonlinearity and randomness primarily through the roll of a die. Advocates for free *kriegsspiel*, based on their experience, addressed nonlinearity through an umpire that evaluated the events. This tension between quantitative rules and qualitative experiences continues to influence the development of simulations. A simulation must underlie a military decision support system (DSS) so this tension must be resolved.

Not only did nineteenth century military theorists discuss this tension, at least one twenty-first century theorist has updated the discussion. Before agreement is achieved on an appropriate DSS, consensus must be reached on the nature of the model of warfare to be used. Armies have used wargames to educate leaders in habit of mind in schools and academies and to provide the general idea of how an operation may unfold to facilitate planning forces and resource availability. Historically, armies have not used wargames to provide a situational reality based on dynamic information.

The tension surrounding an acceptable model for warfare has played out in the writings of military theorists. The challenge is at least as old as the debate between nineteenth century military theorists Antoine-Henri Jomini and Carl von Clausewitz and their respective approaches to use theory to prescribe or describe warfare. Jomini generally subscribed to the idea that winning is simply a matter of applying a set of steps, which Jomini extrapolated from observing Napoleon, to the problem of war. Jomini asserted that whichever side applies the principles and tactics he describes better will win. Moreover, Jomini reduced the options available to a commander to only three:

> The general theater of operations seldom contains more than three zones the right, the left, and the center…The proper selection of one of these three simple alternatives cannot, surely, be considered an enigma.[39]

Clausewitz, on the other hand, suggested that the outcome is more vague due to three properties: moral forces and effects, positive reaction, and the uncertainty of all information. Clausewitz summed these ideas together: "it is simply not possible to construct a model for the art of war that can serve as scaffolding on which the commander can rely for support at any time."[40] The direct impact of both of these theorists on modern doctrine is unquestionable, but their divergent descriptions of war and the choices of commanders cause significant cognitive tension. This tension is an important component in understanding the challenge of creating a decision support system for the military.

Using a twenty-first century American lens, the conflict between prediction and description is further manifest when reviewing Brian Linn's archetypical guardians, heroes, and managers. In his book, The Echo of Battle, Linn described the American way of war and how American leaders tend to make decisions. Heroes, who are focused primarily on human agency, would weigh in on the side of description. Guardians and managers would weigh in on the side of prescription due to their respective foci on scientific problem-solving and organizational solutions.[41] The primacy of Jominian

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[39]Henri de Jomini, "Jomini and His Summary of The Art of War," in *The Roots of Strategy Book 2*, ed. J. D. Hittle, 387-557 (Harrisburg: Stackpole Books, 1987), 461-462.

[40]Carl von Clausewitz, *On War*, trans. Michael Howard and Peter Paret (Princeton, NJ: Princeton University Press, 1976), 137-140.

[41]Brian Linn, *The Echo of Battle: The Army's Way of War* (Cambridge, MA: Harvard University Press, 2007), 7-9. For guardians war is an engineering project, guardians strive for predictability and the problems raised in war as engineering problems to be solved. For heroes war is battle and determined by qualitative characteristics such as: courage, strength, discipline, skills, honor, and so forth; and the problems raised in war to be overcome by human spirit. For managers war is the rational coordination of resources both human and material, managers seek

prescriptionists and Linn's managers and guardians was evident in the 2006 Quadrennial Defense Review (QDR) that mandated "the Department [of Defense] must provide information and analysis necessary to make timely and well-reasoned decisions."[42] The 2006 QDR specifies "Corporate Decision Making" as a focus area targeted on governance, processes, and analyses. The 2006 QDR provided strategic-level guidance focused on creating an environment focused on prescription at the highest levels. This strategic-level focus on prescription could have trickled down to the tactical level and created a bias toward process-based solutions to nonlinear to problems that are not appropriate to the application of a process. [43]

Debate between the advocates for prescription and description continued through the computerization of wargames. The discourse continued along familiar lines with descriptionists contending that a simulation only has to be good enough to accomplish its task. The prescriptionist argued that good enough is a dangerous and difficult to define standard, and that all military simulations should be subject to the same rigorous standard. This debate hinged on whether, for certain applications such as classroom instruction, it would be acceptable to use a simulation with less fidelity to achieve a learning objective. The argument became one of degree because models, simplifications of reality by definition, underlie simulations. The issue at hand was how much fidelity

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to make war more effective; and the problems raised in war to be overcome through organizational arrangement.

[42]Department of Defense, *The Quadrennial Defense Report* (Washington, DC: Government Printing Office, 2006), 65.

[43]Ibid., 66.

developers could sacrifice in a given application tailored for a specific purpose.[44] One rule, proposed by RAND was:

> If analysis is to be accomplished largely at a given level of detail, then analysts and modelers should thoroughly understand the phenomena to at least one deeper level and recognize when more depth is needed.[45]

Summary

Computer-based simulations are the modern incarnation of the historical practice of wargaming. As wargames transitioned from tabletops and maps to computers, they became more abstract from warfare. This abstraction came from the detailed algorithms that computer-based simulations require to address the nonlinear nature of warfare. These simulations were automated versions of strict *kriegsspiel* and removed much of the human judgment aspects of free *kriegsspiel*. Linn described the tension with abstraction in light of an American way of war, describing heroes as the champions of human judgment while guardians and managers championed a more rules-based, abstract approach to problem solving. This rules-based approach required a significant amount of data about the modeled system. The next section will present three civilian decision support systems to show how they deal with systems with varying degrees of linearity, solution sets, human involvement, and availability of data.

DECISION SUPPORT SYSTEMS

This section presents three non-military DSS to explore proposed subcategories within the models-based DSS class. The established five driver-based categories of DSS (communication, data, document, knowledge, and model) lack the fidelity to compare systems

[44]John R. Surdu, James Sterrett, and Jim Lunsford, "The Gaming Debate," *Training & Simulation Journal* (December/January 2010/2011): 46-48.

[45]Paul K. Davis, Jonathan Kulick, and Michael Egner, *Implications of Modern Decision Science for Military Decision-Support Systems* (Santa Monica: RAND Corporation, 2005), 42.

within a given class. This section explores three characteristics of DSS to further refine the category into subcategories: the linearity of the system, the size of the solution set, and whether human interaction affects the system. The linearity of the system is determined based on predictability of an outcome given a certain input. The size of the solution set is either small or large. Human interaction is absent if unable to significantly affect the system being modeled, present if able to do so. Each DSS subcategory example concludes with a corresponding military application.

The three examples of civilian DSS used are: weather prediction, game playing, and securities trading. Hurricane predictors offer an example of a nonlinear system with a large solution set unaffected by human interaction. The International Business Machine Corporation (IBM™) DEEP BLUE™ project is an example of a linear system with a limited solution set with heavily controlled human interaction. Stock market automated trader's model a nonlinear system with a limited solution set and loosely controlled human interaction. The examples will demonstrate the daunting tasks required in each case and the challenges in growing to a DSS that is able to provide useful decision support in combat, a nonlinear system with a large solution set with loosely controlled human interaction.

Table 1. Representative Decision Support System

Decision Support System	Linearity	Solution Set Size	Human Interaction
Hurricane Prediction	Nonlinear	Large	No
DEEP BLUE	Linear	Limited	Yes
Automated Stock Trader	Nonlinear	Limited	Yes
Military	Nonlinear	Large	Yes

Source: Created by author.

Nonlinear without Human Interaction

Hurricane forecasting is a significant undertaking due to the many variables involved and the tremendous impact of these storms on life and property. The National Hurricane Center (NHC) is responsible for Hurricane forecasting in the U.S. The NHC uses a variety of simulations to predict a hurricane's trajectory and estimate its impact on land. The simulations used differ in their sophistication and their predictions. To simplify the potential problem of a large solution set, hurricane forecasters employ a secondary, deterministic simulation to answer the ultimate question: whether or not to evacuate a given coastal area. The primary tradeoff is the cost of evacuation versus the potential loss from the effects of a hurricane making landfall. The lack of agreement of projections demonstrates the difficulty of predicting a nonlinear system, even when humans cannot affect the system.

In 1955, the United States established a group to specifically address hurricanes. This group, the National Hurricane Center (NHC), is primarily responsible for hurricane prediction and warning systems.[46] Over time with advancing modeling and simulation tools and modern measurement techniques, the forecasts have become increasingly accurate. In the 1970s the mean error for a 48-hour forecast was 250 nautical miles, while from 2000-2008, the average error was reduced 60 percent to 100 nautical miles.[47] Unfortunately, due to population growth in coastal areas complicated by weekend, seasonal, and holiday travel, existing roadways could become overwhelmed in an emergency evacuation scenario. This means that two days are insufficient for

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[46]Robert C. Sheets, "The National Hurricane Center-Past, Present, and Future," *Weather and Forecasting* (1990): 186-188.

[47]Edward N. Rappaport, et al, "Advances and Challenges at the National Hurricane Center," *Weather and Forecasting,* (2009): 401-402 and figure 3.

an evacuation notification, and in many areas, four to five days are necessary.[48] This impact on the time horizon was significant to the NHC because before 1999, maximum forecasts were three days and the mean error at three days was over 200 nautical miles. From 2000-2008, the NHC established five-day forecasts, with an average error of 275 nautical miles.[49] Hurricane forecasts are further complicated, because they are not a single simulation, but the amalgamation of several.

When determining the track of a hurricane the NHC uses a variety of models in an attempt to divine the path the hurricane will take. In 2008, the official predicted path of Hurricane Ike took into account seven different models.[50] These models come from three categories: statistical, dynamic, and a statistical-dynamic hybrid. Statistical models base their prediction on the behavior of similar previous storms, based on their location and the time of year combined with the assumption that the way a storm is currently behaving will be similar to its behavior for the next day. Dynamic models, on the other hand, are based solely on data about the storm and current weather conditions based on a variety of complex equations that account for a wide range of physical conditions focused on hydrodynamics, thermodynamics, and continuity (the volume

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[48]Michael J. Brennan and Sahranya J. Majumdar, "An Examination of Model Track Forecast Errors for Hurricane Ike (2008) in the Gulf of Mexico," *Weather and Forecasting*, (2011): 848.

[49]Rappaport, et al, "Advances and Challenges at the National Hurricane Center," 401-402 and figure 3.

[50]Michael J. Brennan, and Sahranya J. Majumdar, "An Examination of Model Track Forecast Errors for Hurricane Ike (2008) in the Gulf of Mexico," *Weather and Forecasting,* (2011): 850. Models considered include: NCEP Global Forecast System (GFS), Met Office—Global (UKMET), European Centre for Medium-Range Weather Forecasts (ECMWF), Navy Operational Global Atmospheric Prediction System (NOGAPS), Geophysical Fluid Dynamics Laboratory (GFDL) Hurricane Model, Hurricane Weather and Research Forecasting Model (HWRF), the navy version of the GFDL model (GFDN), Global Ensemble Forecast System (GEFS), and the multimodel variable consensus model (TVCN). The TVCN is an average of at least two of the interpolated versions of the following models: GFS, UKMET, ECMWF, NOGAPS, GFDL, HWRF, and GFDN.

of air entering of leaving an area). Weather predictors adopted a variety of assumptions and simplifications to ease the calculations. The hybrid model is, of course, a blend of the preceding techniques, weighted to the statistical model for short term (one day) prediction with increased weighting to the dynamic model as the term of the prediction increases.[51]

The error of predicting the path of hurricane may appear to be mostly academic as this information does not provide sufficient information to support the crucial decision of whether or not to evacuate a coastal area, but it is the most crucial input to the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, which does. The deterministic SLOSH model assists with the evacuation decision. This model, when run post hoc, is incredibly accurate. When run post-storm for Hurricane Katrina, "more than 70 percent of the SLOSH-calculated values are within 1.5 feet (0.46 meters) of the observations; the correlation coefficient is 0.94." Unfortunately, SLOSH is not useful to decision-makers after the storm when perfect knowledge of the path of the storm is available. Before the storm, the output from SLOSH is very sensitive to its predicted behavior in terms of storm track, intensity, and size. For example, a 30 nautical mile error in landfall location could result in an error of 20 feet in level of surge. The challenges become obvious, when attempting to account for numerous models that predict vastly different paths for a hurricane. This error is significant and demonstrates the challenges with predicting a complex natural system and tying this prediction to the decision of whether to evacuate a location.[52]

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[51]Bob Sheets and Jack Williams, *Hurricane Watch* (Vintage Books: New York, 2001), 203-209.

[52]Edward N. Rappaport, et al, "Advances and Challenges at the National Hurricane Center," 407.

Predicted paths Hurricane Ike might take in 2008 diverged by as much as 500 nautical miles, ranging from northern Mexico to Galveston, Texas.[53] In another example, Hurricane Allen in 1980, three models predicted the hurricane would remain over Cuba while a fourth projected landfall near Fort Meyers, Florida. The hurricane, ignorant of these decrees, entered the Gulf of Mexico and hit Padre Island, Texas nearly 600 nautical miles from Florida.[54]

Hurricane forecasting, like military wargaming, has grown more complex with the development of computer models. Edward Lorenz in 1961 described the weather as chaotic due to its sensitivity to initial conditions. Meteorologists face a challenge of scale, weather takes place at the molecular level, but they must make predications based on initial conditions measured from mile-sized grids. Due to the chaotic nature of the weather and the variety of models and simulations available, the final decision on a forecast is "often more art than science."[55] Forecaster feed this data into the deterministic SLOSH model to assist a decision maker with an evacuation order, a binary choice of whether or not to evacuate a coastal community. The SLOSH models help reduce the decision to a type of cost-benefit analysis, in which the cost of evacuation is weighed against the potential cost of not evacuating with the knowledge that no prediction is 100 percent accurate.

There is no one-for-one example of a military simulation that shares the same characteristics as weather prediction, except for weather prediction. Military units have weather prediction elements to assist with determining the effect of weather on military operations. These elements can work on airfields to establish times when weather can negatively impact the air

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[53]Michael J. Brennan and Sahranya J. Majumdar, "An Examination of Model Track Forecast Errors for Hurricane Ike (2008) in the Gulf of Mexico," *Weather and Forecasting,* (2011): Figure 1, 850.

[54]Sheets and Williams, *Hurricane Watch,* 209.

[55]Ibid., 211.

operations. Weather sections also work with artillery units to determine the affects of weather on their long-range fires. Weather prediction illustrates the tremendous challenge of attempting to predict a nonlinear system, with a large solution set reduced to a binary one, without the puzzling factor of human interaction. The following example involves a simpler system, but is confounded by human interaction.

Linear with Human Interaction

On 11 May 1997 IBM's chess super computer, DEEP BLUE, defeated world champion chess player, Garry Kasparov. Chess, a distant relative to many wargames, has been described as "nothing less than a silent duel between two human engines using and abusing all faculties of the mind—the will, the imagination, logic, memory, caution, cunning, daring, foresight, hindsight, perspective, detail, unity and courage."[56] Based on this description, it seems unlikely or even impossible for a machine to defeat a human player, let alone a world champion.

The desire for a chess machine was not new. As early as 1769, a chess machine appeared in the Austrian court. In this machine, however, rather than a set of microchips, a human hid inside. IBM created DEEP BLUE specifically to win a regulation chess match against a Grandmaster in a regulation match. The important factors of a regulation match were that it consisted of six games and that a turn consisted of three minutes. Time was not limiting to the computer in fact computers excelled in a time-constrained environment having defeated a chess Grandmaster as early as 1977, in a blitz game that lasted only five minutes. The time permitted in a regulation match allowed the Grandmasters to observe patterns and learn from their computer opponents. In 1996, during their first match, Kasparov and DEEP BLUE were even after four

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[56]Irving Chernev and Fred Reinfeld, *The Fireside Book of Chess* (Simon and Schuster: New York, 1949), 7.

games, two games each, but Kasparov observed DEEP BLUE's tendencies and won the last two games to win the match.[57]

The designers of DEEP BLUE observed that their machine was limited versus the human factors of a Grandmaster. DEEP BLUE did not exhibit all of the characteristics described in chess. The computer excelled at some features such as logic and memory, but it lacked others such as imagination and daring. Most importantly DEEP BLUE did not, and could not, have common sense. To make up for this, the team at IBM developed special microchips specifically designed for chess that imbued DEEP BLUE with raw computational power: the ability to process 200 million chess positions per second. This combined with the strict rules of chess, the fixed number of pieces, and size of board reduced the game to an engineering problem. Linn's guardians would approve of the ability to reduce a problem thought to require intangible traits such as imagination, cunning, and daring to a solvable puzzle. A member of DEEP BLUE's design team, Feng-hsiung Hsu, acknowledged this advantage for the computer observing, "the difficult game of Go, or Wei-chi, however, might still be well beyond a computer's reach in the near future."[58]

Since DEEP BLUE's success, IBM has continued to push the envelope of artificial intelligence. Two such projects are Blue Gene and Watson, which advances in technological capability follow Moore's Law, the number of electrical components on a chip will double over a specified time,[59] currently about 24 months.[60] IBM designed Blue Gene to help simulate protein

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[57]Feng-hsiung Hsu, "IBM's DEEP BLUE Chess Grandmaster Chips," *IEEE Micro* (March-April 1999): 70-71.

[58]Ibid., 70-71.

[59]Gordon E. Moore, "Cramming More Components onto Integrated Circuits," *Electronics* (April 1965).

[60]Ana Aizcorbe and Samual Kortum, "Moore's Law and the Semiconductor Industry: A Vintage Model," *Scandinavian Journal of Economics* (2005): 604.

folding and gene forming. Blue Gene, as of June 2012, holds the title of the world's fastest supercomputer and four of the world's ten fastest supercomputers are in the Blue Gene family.[61] Despite its incredible capabilities, 478 trillion operations per second, IBM designed to solve a problem more similar to hurricane forecasting than predicting the nonlinear interaction of two open systems such as war.

IBM designed Watson to win the game show Jeopardy. It has the capacity to search the equivalent of 200 million pages of data and return an answer with in three seconds.[62] Truly an amazing accomplishment, but this specially designed piece of hardware would be of little use to a military decision maker who must determine a course of action or whether to commit a reserve element. It is more appropriate to problems such as "diagnosing disease, handling online technical support questions, and parsing vast tracts of legal documents," challenging problems in which a flowchart type of solution is available. [63] The increased performance of these machines does not indicate that they are able to better gauge the interaction of two military forces.

An example of a computer application that does seem to approximate human interaction is the genre of commercial computer war games. In many of these games players exist in an "open world' or "sandbox" in which they have freedom to choose when and how to complete the game. A classic example of the genre is *Civilization*, produced by Sid Meier, now on its fifth version. The premise of the game is that the player has risen as the leader of a prehistoric group of people and then leads them forward through history to achieve victory in one of four ways. The paths to victory are military, technological, diplomatic, or cultural domination. A player can face

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[61]Hans Meuer, et al, *Top 500 Supercomputer Sites*, http://www.top500.org/ (accessed 10 October 2012).

[62]Ibid.

[63]*Watson—A SystemDesigned for Answers*, IBM White Paper (Somers, NY: IBM Systems and Technology, 2011).

from one to ten opponents, who can be a mix of other humans and those controlled by a computer. Once the game begins, the only constant is the terrain, which the player selected at the outset as randomly generated or from a library of existing maps. While playing, there are no restrictions on the player as to where to build cities, what research to pursue, or which opponents to befriend or attack. With this freedom and variety of paths to victory, *Civilization* appears to be very free flowing and even to approximate an actual geo-political situation.

To enable the game, though, a limited number of states exist. In the most recent release, *Civilization* V, makes use of a variety of rules to accomplish this simplification: the game world is broken into hexagons, each hexagon can only contain one unit, units have certain strengths and weaknesses, and so forth. Described this way, similarities between chess and *Civilization* abound despite the fact that modern computer games bring a simplified, virtual world to a player, unlike the DEEP BLUE project, which required programmers to determine a way to replicate a real world activity in a computer. Both chess and *Civilization* simplify and apply simplifying rules to reality in a way that limits the options that players have, which eases the requirement on the simulation. Developers of military simulations used for training, such as Virtual Battle Space 2 (VBS2), Decisive Action (DA), Warfighters' Simulation (WarSim), or One Semi-Automated Forces (OneSAF); enable their simulation in much the same way as these games. [64] The developers model terrain and units to differing levels of fidelity and accuracy depending on the intended use of the simulation. The following example combines the previous two adding the nonlinearity and large solution set of hurricane prediction to the human interaction of chess.

[64]For more information on these simulations: Virtual Battle Space 2: http://www.peostri.army.mil/PRODUCTS/USAGFTP/home.jsp; Decisive Action: http://www.decisive-point.com/images/Battle_in_Every_Classroom_-_Infantry_Magazine_MAR_2012.pdf; Warfighters' Simulation: http://www.peostri.army.mil/PRODUCTS/WARSIM/ One Semi-Automated Forces: http://www.peostri.army.mil/PRODUCTS/ONESAF/.

Nonlinear with Human Interaction

Hurricane forecasting provided an example of a nonlinear system with no human interaction. Chess, and games in general, provide examples of linear systems that are built around human to human or human to machine interaction. The next example, automated securities trading, combines these to examine a nonlinear system, wrought with human interaction. The 2010 "Flash Crash" is an example of the danger of a decision support system gone awry. The exploration of stock trading concludes with the similarities between combat decision-making and security trader decision-making. Stock trading is a near substitute for combat decision making in terms of human interaction, lack of information available, and short time horizon for decision-making; with the obvious difference of losses being measured in dollars rather than lives.

Automated traders dominate modern security trading, computer programs that attempt to execute high frequency, large volume trades based on microscopic differences in prices between different markets, an arbitrage. In 2011, approximately 70 percent of daily stock-trading volume came from high-frequency trades.[65] Controlling such a large volume of daily trading, the impact of trade triggers set off in the automated traders can impact ordinary investors who may react to the actions of the automated traders. Automated traders, like any model or simulation, simplify reality in order to provide useful decision support.

Many automated traders function purely on arbitrage trades, a trade that does not actually need to predict the future performance of a particular security or of the market as a whole. The premise is that with many markets available to trade (over fifty in 2011) there occur different prices for the same security in different markets. [66] By nearly simultaneously buying in the lower

[65]Edward Kaufman Jr. and Carl M. Levin, "Preventing the Next Flash Crash," *The New York Times*, 6 May 2011, A27.

[66]Ibid.

priced market and selling in the higher priced market one gains “riskless profits that can be obtained without investing one’s own money.”[67] Automated traders are not truly decision support systems, as they often do not inform a decision maker. Traders program the automated systems with a variety of rules to execute the trade when certain conditions arise. Once the computerized trader has structured the trade, there is no longer a human-in-the-loop because by the time a human approved the trade an arbitrage opportunity may be lost.[68]

There is an inherent danger when a system is setup to run without human interaction. This became evident on 6 May 2010 when the Dow Jones Industrial Average (DJIA) dropped 574.27 points in five minutes, representing a 5.49 percent decline. More dramatically, the market reversed itself gaining back 543 points in a minute and a half. At the lowest point, the DJIA lost 9.16 percent from the previous day’s close; and for the day closed down only 347.80, down only 3.20 percent. To a casual observer, who checked the close at the end of the day on 6 May 2010, it may not have appeared that anything was amiss at all. The holder of an individual stock may have been oblivious to the occurrence as well; one stock opened at over $40 per share, traded at a penny during the day, and then closed the day back above $40. The media dubbed the events of 6

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[67]Renee M. Stulz, *Risk Management and Derivatives* (Mason, Ohio: South-Western, 2003), 645.

[68]United States Commodity Futures Trading Commission (CFTC) & United States Securities & Exchange Commission (SEC). *Findings Regarding the Market Events of May 6, 2010.* Washington D.C.: Joint CFTC-SEC Advisory Committee on Emerging Regulatory Issues, 2010, 3. Generally, a customer has a number of alternatives as to how to execute a large trade. First, a customer may choose to engage an intermediary, who would, in turn, execute a block trade or manage the position. Second, a customer may choose to manually enter orders into the market. Third, a customer can execute a trade via an automated execution algorithm, which can meet the customer’s needs by taking price, time or volume into consideration. Effectively, a customer must make a choice as to how much human judgment is involved while executing a trade.

May 2010 as a "Flash Crash" and governing institutions have carefully studied the events of that day in an attempt to understand what happened and prevent a recurrence.[69]

The Security and Exchange Commission (SEC) disproved numerous possible causes of the cause of the Flash Crash ranging from a terrorist attack to a mistaken order entry.[70] The SEC identified the likely candidate for causing the Flash Crash as the high volume traders.[71] These firms provide much of the liquidity to security exchanges, as their computerized traders "place buy and sell orders while avoiding taking significant inventory positions."[72] These market makers are highly exposed to order flow toxicity.[73] The Wall Street example was not selected as a warning against modern high frequency trading tools or intended as a review of finance classes, but because trading has been used as an analogy to military decision making.

In December 1995, United States Marine Corps (USMC) officers participated in an exchange with traders at the New York Mercantile Exchange (NYMEX). The Marines and NYMEX traders shared some commonalities in the decisions they had to make, both require quick reactions to incomplete or limited information. Both groups shared a difficulty with cutting

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[69]Michael Corkery, "SEC Chairman Admits: We're Outgunned By Market Computers," *The Wall Street Journal*, 11 May 2010, http://blogs.wsj.com/deals/2010/05/11/sec-chairman-admits-were-outgunned-by-market-supercomputers/ (accessed 31 July 2012).

[70]Ibid.

[71]A large fundamental trader chose to execute this sell program via an automated execution algorithm ("Sell Algorithm") that was programmed to feed orders into the June 2010 E-Mini market to target an execution rate set to 9% of the trading volume calculated over the previous minute, but without regard to price or time. From: United States Commodity Futures Trading Commission (CFTC) & United States Securities & Exchange Commission (SEC). *Findings Regarding the Market Events of May 6, 2010.* Washington D.C.: Joint CFTC-SEC Advisory Committee on Emerging Regulatory Issues, 2010, 3.

[72]David Easley, Marcos M. Lopez de Prado, and Maureen O'Hara, *The Microstructure of the Next Flash Crash* (Cornell Univesity, Tudor Investment Corporation, 2010), 13.

[73]David Easley, Marcos M. Lopez de Prado, and Maureen O'Hara, "Flow Toxicity and Liquidity in a High Frequency World," *Review of Financial Studies* 25, no. 5 (February 2012): 1457.

their losses.[74] Other similarities include beginning with a plan, knowing that it will vary once the "enemy gets a vote" or the "market takes over."[75] Perhaps this is fitting provided Carl von Clausewitz's comment that "rather than comparing (war) to art we could more accurately compare it to commerce, which is also a conflict of human interests and activities."[76]

There were also some significant differences between military decision-making and that required of the traders. As one trader noted, "we play the same game of risk-reward analysis, only your stakes are much higher."[77] This sentiment echoed in one of the official responses to the Flash Crash. The Security and Exchange Commission (SEC) was able to review the trades conducted the afternoon of the Flash Crash and cancel "erroneous" trades in 286 different equity securities.[78] This is clearly an option not available to a military decision-maker.

The decision-making used in stock trading is similar to that made by military leaders in combat in terms of lack of information, timeliness of decisions, and human interaction. The tools used to provide decision support for traders, though, are not appropriate to the military domain. Although both domains deal with a lack of information, automated traders succeed through arbitrage, which requires perfect, real-time information from at least two markets. Automated traders simplify the nonlinear world of investing by comparing discrete facts from at least two (and up to fifty) markets and automatically execute arbitrage trades.

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[74]Jay Matthews, "Semper Buy!" *The Washington Post*, 6 December 1995.

[75]Mike Snyder, "Virtual Stress," *Marines* (February 1996): 25-26.

[76]Clausewitz, *On War*. 149.

[77]F. J. West Jr., "War in the Pits: Marine-Futures Traders Wargame," *Strategic Forum* (February 1996): 3.

[78]Corkery, "SEC Chairman Admits: We're Outgunned By Market Computers."

Summary

These three decision support systems, widely used and accepted in the civilian sector, provide examples of capabilities and limitations. Hurricane forecasting attempts to tackle the nonlinear world of weather, an arena in which humankind has little influence. Hurricane prediction provides insight into combining several simulations and simplifying the solution set to a manageable size. DEEP BLUE, and all computer games, simulates an abstract world and set of human choices limited through the rules of the game. Automated traders enter the fray along side and against human competitors in a world nonlinear and time compressed enough that the United States Marine Corps used it as a proxy to wartime decision-making. Complex human factors influence stock pricing and trading, but regulations limit their impact. Trades focused on arbitrage opportunities further simplify the role of many automated traders. Based on the success of these types of simulations, the U.S. Defense Advanced Research Projects Agency (DARPA) released a requirement in 2007 for Deep Green, a tool to help battlefield commanders with decision-making during execution of a mission.

MILITARY DECISION SUPPORT SYSTEM

The DARPA Deep Green project attempted to replicate the success observed in the civilian world with predictive modeling in the military domain. The use of wargames remained firmly rooted in military practice and computer-based simulations were ubiquitous in the military by 2007 when DARPA released the Broad Area Announcement (BAA). The design focused on technical capability and the challenges of addressing combat void of human factors, applying the strict *kriegsspiel* scheme of reliance on rules and tables. The BAA provided the specific requirements for Deep Green as a decision support system that straddled the line between planning and execution.

The idea for Deep Green seemed to have originated during an Army Modeling and Simulation Office (AMSO) video teleconference in 1998 during which a variety of voids were identified, including one for automated decision aids. In 2001, a major challenge identified was the lack of an appropriate simulation to drive the DSS. The U.S. Army developed simulations to provide leaders, in a constrained budgetary environment, the experiences necessary to develop a habit of mind for making battlefield decisions. These simulations enabled leaders to develop a *fingerspitzengefuhl* "feel of the battlefield"[79] or *coup d'oiel* the "ability to see things simply."[80] These simulations provided experiential realities rather than a real or situational reality. Simulation professionals coined the term Operational Simulation (OpSim) to identify the transition to a simulation run during operations, to provide a situational reality rather than an experiential one. The focus for OpSim in 2001, was primarily on the planning portion of an operation as the OpSim was offered as a tool that "a single user can operate on a single workstation" to facilitate experimentation with courses of action (COAs).[81] Moreover, OpSim assisted with the complicated and time consuming process of the Military Decision Making Process (MDMP) step of COA Analysis, usually referred to as its primary sub-task: "War Game." The automating of this critical step, while perhaps more efficient is contrary to the historical and doctrinal importance of planning.

In understanding the importance of planning, the danger of automating parts of it becomes evident. From 2012 U.S. Army doctrine:

> The understanding and learning that occurs during planning have great value. Even if units do not execute the plan precisely as envisioned—and few ever do—the process of planning results in improved situational understanding that facilitates future decisionmaking.[82]

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[79]John R. Surdu and Udo W. Pooch, "Simulations During Operations," *Military Review* (March-April 2001): 38, 45.

[80]Carl von Clausewitz. *On War*, 578.

[81]Surdu and Pooch, "Simulations During Operations," 40.

[82]Department of the Army, Army Doctrine Reference Publication (ADRP) 5-0, *The Operations Process.* Washington, DC: Government Printing Office, 2012, 2-2.

Although this doctrine was not available to those developing the OpSim concept, General of the Army Dwight D. Eisenhower's often quoted adage that "plans are worthless, but planning is everything," certainly was available. [83]

One of the outputs of the COA Analysis step, "identify potential decision points," will highlight the danger of automating this step of the MDMP. A decision point is "a point in space or time the commander or staff anticipates making a key decision concerning a specific course of action."[84] If an automated system selected decision points, the commander and his planners trade efficiency for efficacy. During the wargame, commanders and planners develop an understanding of the intricacies of the plan, which facilitates their *fingerspitzengefuhl* as the plan unfolds. In execution, most plans diverge from reality due to the combination of the environment, their own forces' internal friction, and the actions of an actively resisting adversary. An automated system could analyze the system and generate new decision points for the commander. However, automating the process denies the commander and his staff the opportunity to understand why a point in time or space is a decision point. Rather than automate critical cognitive functions of the staff, a better use of an automated system would be to enhance the staff by conducting tasks that are mundane and cumbersome. A task appropriate for an automated system would be monitoring assumptions about friendly and adversary conditions made during planning to determine the validity of a current plan or to determine whether a decision point has occurred.

At the heart of the concept of automating staff monitoring functions is concept use of an operations monitor (OM), which would "monitor the simulation's progress and compare it with the real operations." The more audacious goal stated for an OM was to "determine whether

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[83]General Services Administration, *Public Papers of the Presidents.* Washington DC: Government Printing Office, 1999, 818.

[84]Chairman, Joint Chiefs of Staff, Joint Publication (JP) 5-0, *Joint Operation Planning*. Washington, DC: Government Printing Office, 2011, GL-8.

preconditions are likely and assess the probability that the goal can be accomplished." DARPA proposed a system of automated tools to facilitate this comparison of information from the real world to a simulation running to provide the OM its predictive capability. Technical challenges to this proposal ranged from the selection of a simulation to methods for dealing with unanticipated forces appearing on the battlefield.[85] The models used for decision support must both be simple enough to be easily and quickly understood by the user while providing enough fidelity to be of use to a decision maker.[86] Much as most subway maps sacrifice accuracy of depicting stops and routes geographically to facilitate a more useful tool that represents the stops and lines relative to each other.

Deep Green

In 2007, DARPA released a Broad Agency Announcement (BAA) with a stated goal to:[87]

Provide a technology that allows the commander to:

- Generate and analyze options quickly, including generating the many possible futures that may result from a combination of friendly, enemy, and other courses of action;
- Use information from the current operation to assess which futures are becoming more likely in order to focus the development of more branches and sequels; and
- Make decisions cognizant of the second- and third-order effects of those decisions.[88]

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[85]Surdu and Pooch, "Simulations During Operations," 42-43.

[86]Davis and Blumenthal, *The Base of Sand Problem*, 23.

[87]A BAA is used to acquire "scientific study and experimentation directed toward advancing the state-of-the-art or increasing knowledge or understanding," 48 CFR 36.106(a).

[88]Defense Advanced Research Projects Agency (DARPA), *BAA 07-56 Deep Green Broad Agency Announcement* (Arlington, 2007), 5.

DARPA envisioned Deep Green as a technology that kept the commander at the center of the decision-making process, a concept that remained in 2012 U.S. Army doctrine.[89]

Three major components comprised the envisioned Deep Green system. First was the Commander's Associate, which consisted of two subcomponents Sketch to Plan and Sketch to Decide. Second was Blitzkrieg, designed to quickly generate a broad set of possible futures based primarily on friendly and enemy COAs. Finally, Crystal Ball, designed to control Blitzkrieg, integrated information from the real world, pruned COAs developed by Blitzkrieg, and identified upcoming decision points. The BAA also mentioned a desire for a COA generator, but this is included as a desired future addition to the system, not a requirement as part of Deep Green.[90]

DARPA required the Commander's Associate component to "convert a commander's hand-drawn sketch with accompanying speech of his intent into a Course of Action (COA) at the brigade level." To accomplish this task, the Commanders Associate consisted of two subcomponents: Sketch to Plan and Sketch to Decide. Sketch to Plan was the commander's interface with Deep Green and an automated option generator. Since automated option generation was not the major thrust of Deep Green, the BAA required only that the automated option generator be able to mutate plan created by users to "increase the breadth of the futures generated." The Sketch to Decide subcomponent allowed a decision maker to explore options by playing out various decisions, branches, and sequels to plans, informed by Blitzkrieg-generated futures. Commanders could have explored critical dimensions such as "likelihood, risk, utility, resource usage, etc." Developers renamed this component Sketch-Thru-Plan and it emerged as a "smart pen" which digitally captured the user's drawings and voice. Sketch to Decide was the

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[89]Department of the Army, ADRP 5-0, *The Operations Process*, 1-2.

[90]DARPA, BAA 07-56 Deep Green Broad Agency Announcement, 13, 18, 21.

application that presented the future states generated by Blitzkrieg to the commander, in an intuitive way, to assist decision-makers.[91]

Blitzkrieg, was the simulation portion of Deep Green that explored future states by comparing friendly and enemy courses of action and exploring a large set of feasible future states. During development the name SimPath replaced Blitzkrieg, as a more accurate description of the component.[92] SimPath determined the likelihood of a branch and continued to model each until it reached a culminating point. DARPA graded Blitzkrieg's performance as the time taken to complete the comparison of three friendly COAs against three enemy COAs. The goal for was completion of the comparisons less than three minutes.[93] The next challenge is similar to the one faced by hurricane forecasters. A nonlinear system, weather or forces interacting on a battlefield, is modeled and simulated with, possibly, divergent results. The forecaster then must present the results in an understandable way to the decision maker. Hurricane forecasters use SLOSH, for Deep Green DARPA called the component to allow a commander to look into the future Crystal Ball.

Crystal Ball was the incorporating portion of Deep Green. It took options from Sketch-Thru-Plan, possible future states from SimPath, incorporated current information, and updated the likelihood metrics of the possible future states. As operations developed, Crystal Ball recommended futures for pruning futures due to low likelihood or excessive risk to the operation. Combined with the other components of Deep Green, the system would "ensure the commander never reaches a future with no options." The metrics for Crystal Ball were more complicated than simply filling in a matrix, as SimPath was required to do. Crystal Ball was required to provide

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[91]Ibid.,12-18, 24.

[92]Todd Hughes, interviewed by author, Fort Leavenworth, Kansas, 12 February 2013.

[93]DARPA, BAA 07-56 Deep Green Broad Agency Announcement,18-21.

sufficient early notice to prevent a commander from entering a "blind alley, " defined as heading into an unexpected direction and reaching a state with less than three good options available. For testing, staffs with Crystal Ball competed against staffs without it. The metric for testing required the Crystal Ball equipped staffs to end up in a blind alley only one-fifth of the time those without it would.[94]

Development and Performance

The BAA allowed DARPA to retain two companies to develop Deep Green. The two competed through an initial phase after which DARPA elected to continue development with the more promising project. After three years of development a change in the focus of DARPA away from command and control (C2) systems caused a severe defunding of Deep Green. Following the defunding, DARPA released the most mature portion of the project, Sketch-Thru-Plan, which is being used by the U.S. Army Second Infantry Division. There was interest and enthusiasm for the project from the Mission Command requirements developers and numerous U.S. Army general officers, but failed to receive sufficient funding to be fully developed.[95]

The first phase of Deep Green pitted two developers, BAE and SAIC, against each other to realize DARPA's vision of a military DSS. The two began from a common project developed at Texas A&M University. Following Phase I, a year of development, in 2009 a third company, ARA, evaluated the performance of the offerings. During the evaluation subject matter experts operated the systems to approximate military commanders and staffs. DARPA selected BAE's offering and renamed SAIC as the evaluator for the Phase II test in 2011.[96]

[94]Ibid., 21-23.

[95]Todd Hughes, interview.

[96]Ibid.

On 5 April 2011, DARPA tested Deep Green at the U.S. Army's Mission Command Battle Lab at Fort Leavenworth, Kansas. This test marked the shift from Phase II to Phase III. Media and developers touted the demonstration as a success.[97] The individual components, though, were at different significantly differing levels of development. The Commander's Associate, renamed Sketch-Thru-Plan (STP), had achieved much of the Sketch to Plan requirements from the original BAA. The most mature of the three components, STP consisted of a high tech pen that captured writing and audio and used them to create digital overlays and a synchronization matrix.[98] SimPath had made great strides, reducing the time necessary for COA comparison from hours or days to fifteen-twenty minutes. Unfortunately, the abstractions necessary increase the speed of the simulation resulted in occasional unrealistic outputs. Crystal Ball was the least developed of the three components. This component concept suffered from a fundamental mismatch of information required and that provided by the U.S. Army's Battle Command Systems (ABCS). More than technological challenges faced Deep Green going forward, as DARPA had undergone a change to leadership since the project began.[99]

In June 2009, the Secretary of Defense appointed a new director, Dr. Regina Dugan, to lead DARPA.[100] As part of her vision for the organization, DARPA defunded command and control systems research throughout the organization.[101] This policy resulted in a seventy-five

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[97]Bob Kerr, "DARPA demos Deep Green," *Fort Leavenworth Lamp*, 7 April 2011. Charles River Analytics, *Decision Management Systems Case Study: Deep Green*, https://www.cra.com/government-services/decision-management-systems-deep-green.asp (accessed 30 January 2013).

[98]Defense Advanced Research Projects Agency (DARPA), *Success Stories* (Arlington, VA, 2010), 7-8.

[99]Hughes, interview.

[100]Defense Advanced Research Projects Agency, *Official Biographies*, http://www.darpa.mil/WorkArea/DownloadAsset.aspx?id=2391 (accessed 20 February 2013).

[101]Hughes, interview.

percent reduction in Deep Green's funding from 2011 to 2012.[102] Due to the new policy, DARPA decided to complete the final phase of Deep Green pursuing the most mature portion of the project, STP. Gone from the program was any predictive or simulation capability, along with the names Commander's Associate, SimPath, and Crystal Ball.

Throughout the process the Deep Green team focused and reiterated the idea that "Deep Green was meant to be a commander-driven technology, rather than building technologies to remove the commander."[103] Perhaps this was partially to avoid fear of some of the fantastic scenarios provided in science fiction. By keeping a human involved and as the key decision maker no fictional War Operation Plan Response (WOPR) computer could hijack the U.S. nuclear arsenal as happened in the movie *Wargames*[104] or attempt to exterminate human life on earth as in the *Terminator* franchise.[105] Preventing the disturbing image "of a series of malfunctions setting the holocaust in motion without human intervention: of the end of the world resulting from the flick of the wrong switch."[106] More than simply a reaction to these extreme situations presented in science fiction is the more fundamental concern about the predictability of war.

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[102]Defense Advanced Research Projects Agency, *Department of Defense Fiscal Year (FY) 2012 Budget Estimates,* Research, Development, Test & Evaluation, Defense-Wide, (Washington, DC: Government Printing Office, 2011).

[103]John R. Surdu and Kevin Kittka, "The Deep Green Concept," Spring Simulation Multiconference 2008 (SpringSim'08), Military Modelling and Simulation Symposium (MMS) (Ottawa, 2008), 3.

[104]Lawrence Lasker and Walter F. Parkes, *WarGames*, directed by John Badham, performed by Matthew Broderick, 1983.

[105]James Cameron, *Terminator*, directed by James Cameron, performed by Arnold Schwarzenegger, 1984, 1991, 2003, 2009.

[106]Lawrence Freedman, "Escalators and Quagmires: Expectations and the Use of Force," *International Affairs* (January 1991): 22.

Implied in the pursuit of Deep Green is the assumption that given sufficient information about friendly and enemy forces and their expected intentions, predictions would be accurate enough to drive leaders to make decisions. One tremendous challenge ended up as the information itself. Hurricane forecasters have placed sensitive instruments in the ocean, on satellites, and even on airplanes that can fly into hurricanes to provide desired data; and still there is great divergence in their predictions. The second portion of this question is whether machines can make the decisions better than humans can. Miller's Law argues that most humans can only simultaneously consider seven factors, and that the extraordinary could consider at most nine.[107] It would seem, then, that if a machine can analyze ten factors at once it should outperform any human. Other attempts at a military DSS explore this possibility.

The Problem for Military Decision Support Systems

The problem for military decision support systems is not the underlying model or simulation that runs the DSS, but the information necessary to enable the model. Deep Green's predictive component, SimPath, made abstratctions to enable quick courses of action (COA) comparison. Other projects have been undertaken to develop alternate models. From 2004-2008 DARPA pursued a project called Real-time Adversarial Intelligence and Decision-making (RAID) that proposed courses of action (COA) for tactical leaders. Dr. David Ezra Sidran's 2009 Tactical Inference GenERator (TIGER) project at the University of Iowa, attempted to create a computer program that could analyze a battlefield situation and classify it in the same way as a group of subject matter experts. Although successful in trials, these systems would face the same paucity of information issue faced by Deep Green's Crystal Ball component: there is

[107]George Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *The Psychological Review* (1956): 81-97.

insufficient information readily available on the Army Battle Command System (ABCS) to enable a DSS. This is a follow on to the “Base of Sand” issue raised by RAND in 1991 regarding the science of the underlying model, raised to the level that if a military DSS is desired then its necessary inputs must be determined and supplied either automatically by the ABCS or manually.

The objective for RAID DARPA published in a 2004 Broad Agency Announcement (BAA) was to “develop a real-time adversarial predictive analysis tool that operates as an automated enemy predictor providing a continuously updated picture of probable enemy actions in tactical ground operations.” DARPA designed the program as an experiment to prove three theses:

1. That adversarial reasoning can be automated
2. That automated adversarial reasoning can include deception
3. That automated adversarial reasoning can account for doctrinal and cultural biases

In addition to proving the theses, the system must be able to “integrate these predictive analysis tools into a warfighter’s C2 and intelligence support system.” The RAID contract sought to prove the feasibility of a during operations simulation.[108]

The RAID project generated courses of action that were largely indistinguishable and often more successful compared to those created by humans. The experiment approximated a U.S. infantry company facing a group of insurgents. The infantry company consisted of thirty to thirty-five fire teams augmented by Stryker vehicles and helicopters. The insurgent elements were comprised of thirty teams of various sizes. The developers and DARPA conducted a series of experiments in 2005 and 2006 using the OneSAF simulation. During the culminating experiment in July 2006, the experimental controllers of the U.S. forces, the Blue Cells, followed the RAID-

[108]Defense Advanced Research Projects Agency (DARPA), *Broad Agency Announcement 04-16: RAID*, 1 March 2004, https://www.fbo.gov/ (accessed 21 February 2013).

generated COA exactly, while the control group planned and executed without RAID. The insurgent controllers, the Red Cells, had no access to RAID. Eighteen paired simulations would be run for a total of thirty-six simulated battles.[109]

The most telling data collected was that in sixteen of the thirty-six simulated battles the Red Cell commander incorrectly identified his opponent. RAID performed so human-like, or humans performed machine-like, that forty-four percent of the time the Red Cell commander was unable to determine whether he faced a human or a machine. This indicated that, in the scenarios tested, machine-generated courses of action were often indistinct from human-generated ones. Other metrics measured the overall success rate of RAID based on percentages developed for the experiment, in which RAID outperformed the human staffs in fourteen of the eighteen paired simulation runs, seventy-eight percent of the time. RAID made a strong showing, but was enabled in a way that would make tactical implementation challenging.[110]

In September 2008, DARPA acknowledged some of the limitations of RAID and released a follow-on solicitation based on RAID's performance, stating that "It would be undoubtedly valuable to scale RAID up to permit it to deal with battalion, or even brigade size units, but it is not immediately obvious that this is feasible." The solicitation specified three areas for further research. The first was the addition of rules and models to grow RAID from a tactically focused company-level simulation to a more complex brigade-level organization that must operate across all of the warfighting functions. The second area was growing the area of interest to accommodate the large area a brigade-sized unit may operate in both in terms of geographic and human terrain factors. The final area for further research was increasing the problem size that

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[109]STILMAN Advanced Strategies, *Linguistic Geometry Tools LG-Package* (Denver, CO: STILMAN Advanced Strategies, 2009), 4.

[110]Ibid., 5-6.

RAID is able to address, again addressing the variety of challenges faced by larger echelon units.[111]

Another issue facing RAID, not mentioned in the solicitation, was implementation, during which it was susceptible to the same obstacles as Crystal Ball. While operating in an experimental setting with complete situational awareness of friendly units, observable enemy units, and terrain; RAID outperformed human staffs. In execution outside a computer lab in a tactical environment, the challenge of getting the required information to RAID in a useful format exceeds the information available through ABCS. Rather than focus on the output of a COA, another useful function of a DSS could be to help a decision maker understand the type of battle he is facing.

Tactical Inference GenERator (TIGER) provides an example of a specific focus on the underlying model. Dr. David Ezra Sidran developed TIGER as "an unsupervised machine learning tactical inference generator." Simply stated, TIGER would classify tactical situations in the same way that a group of subject matter experts would. Not as all encompassing as the Deep Green project or COA focused as RAID, TIGER addressed classification of a tactical situation, which could assist a decision maker gain situational understanding.[112]

To develop TIGER's database, subject matter experts (SME) evaluated historical tactical situations on a number of attributes. The attributes ranged from whether a unit had anchored or unanchored flanks to the ratio of the weighted strength of the adversaries. The historical examples created ten clusters based on the SME evaluations, of like tactical situations. TIGER then placed

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[111]Defense Advanced Research Projects Agency (DARPA), *Solicitation Number: W91CRB-08-WP-003* (11 September 2008), https://www.fbo.gov/index?id= b7111ea2b8dd18800fb12a4d47b1636f (accessed 21 February 2013).

[112]David Ezra Sidran, "TIGER: An Unsupervised Machine Learning Tactical Inference Generator" (Dissertation, University of Iowa, University of Iowa, 2009), 1-2.

five hypothetical situations into clusters. Finally, SME evaluated the five hypothetical situations to validate TIGER's classification.[113]

TIGER analyzed and evaluated tactical situations using data expected to be available through ABCS. TIGER used four layers of data: topographical, terrain, elevation, and units. For the experiment, TIGER could not import this data, so it was manually inputted. TIGER classified four of the five hypothetical situations in the same way as the SME, achieving success for the experiment but raising an important question: why not the fifth time? The TIGER developer proposed two biases that may have led to the discrepancy. First, humans must prioritize the information that they consider. Second, the SMEs may have "chose a satisfactory, rather than an optimal, answer." The fact that there was a discrepancy between TIGER and the SMEs provided a strong argument for further considering the implementation of DSS in the military domain.[114]

RAID and TIGER are two of many projects focused on applying the power of computers to assist military decision makers. Unlike the comprehensive Deep Green project, these two focused on the model, which might underlie a DSS. RAID performed well at the company-level, but not to complete the additional tasks set necessary to grow it into a higher echelon tool. TIGER helped categorize the type of tactical situation faced by a commander, providing a tool to frame the tactical problem the commander faces based on static data. Both of these projects were successful in the laboratory, the larger challenge they face is incorporating real, often limited, dynamic data into their algorithms.

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[113]Ibid., 2-5. Attributes used were: anchored or unanchored flanks, interior lines, avenue of approach, choke point, ratio of weighted strength, and weighted slope of attack.

[114]Ibid., 25-28, 62-63.

Summary

The U.S. Army sought a decision support system (DSS) as a way of increasing the efficiency and effectiveness of commanders. However, the fidelity of data available to the DSS limits its potential. Deep Green was an attempt at a system solution from planning to execution that would assist commanders along the way. Real-time Adversarial Intelligence and Decision-making (RAID) succeeded at the company-level, in a laboratory, by outperforming human staffs and often being indeterminable from a human opponent. Tactical Inference GenERator (TIGER) attempted to categorize tactical situations and succeeded in agreeing with subject matter experts in four of five trials. The information available through the Army Battle Command Systems (ABCS) provided a practical limitation to all of these systems. For decision support systems to be acceptable for the U.S. Army, the fidelity delivered by the ABCS must meet that required for the models and simulations that drive the DSS.

CONCLUSION

Armies have used wargames since antiquity to prepare for combat through planning and mental preparation but wargames are not useful in helping leaders make decisions during battle due to two limitations. The first limitation is the set of rules that govern the wargame. The second limitation is the data input into the system. Theoretically, the discourse surrounding rules and warfare is on the predictability of warfare. Practically, this discussion focuses more on mechanics and the degree of adherence to rules versus human interpretation of an event. This discussion persists into modern simulations in terms of the tradeoff between accuracy and speed in the form of acceptable abstraction in a simulation.

These limitations present two major hurdles to implementing a decision support system. The first, lower, hurdle is the model that drives the DSS and is dependent on understanding the rules that govern the underlying system. In hurricane forecasting, scientists derive the rules from observation and the laws of physics and not confused by human agency. Still, due to different interpretations and weighting of available data, the scientists do not agree. In chess, the detailed rules of the game provide a limiting factor to the environment and human interaction to enable effective decision support. The environment of automated traders is closer to that of combat in that it involves human interaction, but unlike combat, the human participants in the system are unable change the rules governing the system. The participants complicate the environment facing a military DSS because they are able to change the rules while events unfold. To be effective, a military DSS must be flexible enough to adjust to a changing rule set, while being fast enough to deliver useful decision support to a commander.

An inherent danger for a military DSS is the level of abstraction necessary to make the simulation fast enough to be useful to a commander in combat. This may differ by echelon, as demonstrated by the occasional invalid outputs from SimPath at the brigade-level and successful courses of action generated of RAID at the company-level. Philosophical discussions as to whether war is predictable will continue, but if programs such as RAID are able to outperform humans, then armies should use them to enhance military planning. Even if DSS do not provide courses of action, military leaders could use simulations similar to TIGER to help frame tactical situations to better understand the problems they are facing. The model, though, is the lower hurdle to DSS; the higher hurdle is the availability of data.

To clear the second, higher, hurdle ABCS must provide the decision support system the data it requires. The specific data required varies by the decision being supported and could require an elaborate information gathering system as in the case of hurricane forecasting. Hurricane forecasters place sensors under, on, and above the ocean to obtain the information they need to run their simulations. DEEP BLUE on the other hand had access to perfect information about the chessboard: the location of pieces and their capabilities. Automated stock traders have access to real-time, uninterrupted information to attempt to take advantage of arbitrage opportunities. In contrast, the experiments with military DSS have been laboratory bound and fed information from simulations or manually. Although these simulations may be useful for testing purposes, the capabilities of the ABCS to deliver data limits their potential.

Developers must address both of these limitations to ascend from the current plateau to a level that would provide useful decision support to a commander. First, developers must implement rules that are flexible enough to respond to a changing battlefield yet rigid enough to provide useful decision support in a simulation. The rules must result in fast simulation if they are to enable a commander to make decisions more quickly than his adversary does. Second, the data necessary to enable the system must be available. This requires a robust commitment to upgrade and develop new ABCS designed to deliver the necessary high-fidelity data to the DSS. Decision support systems are effective in the civilian sector and present potential in the military sector if developers can pair the right set of rules with sufficient data.

APPENDIX A

CONSENT AND USE AGREEMENT FOR ORAL HISTORY MATERIALS

You have the right to choose whether or not you will participate in this oral history interview, and once you begin you may cease participating at any time without penalty. The anticipated risk to you in participating is negligible and no direct personal benefit has been offered for your participation. If you have questions about this research study, please contact the student at:________________________ or Dr. Robert F. Baumann, Director of Graduate Degree Programs, at (913) 684-2742.

To: Director, Graduate Degree Programs
Room 3517, Lewis & Clark Center
U.S. Army Command and General Staff College

1. I, ________________________, participated in an oral history interview conducted by __________________________, a graduate student in the Master of Military Art and Science Degree Program, on the following date [s]: __________________________________ concerning the following topic: ____.

2. I understand that the recording [s] and any transcript resulting from this oral history will belong to the U.S. Government to be used in any manner deemed in the best interests of the Command and General Staff College or the U.S. Army, in accordance with guidelines posted by the Director, Graduate Degree Programs and the Center for Military History. I also understand that subject to security classification restrictions I will be provided with a copy of the recording for my professional records. In addition, prior to the publication of any complete edited transcript of this oral history, I will be afforded an opportunity to verify its accuracy.

3. I hereby expressly and voluntarily relinquish all rights and interests in the recording [s] with the following caveat:

_____ None _____ Other: ____

____

I understand that my participation in this oral history interview is voluntary and I may stop participating at any time without explanation or penalty. I understand that the tapes and transcripts resulting from this oral history may be subject to the Freedom of Information Act, and therefore, may be releasable to the public contrary to my wishes. I further understand that, within the limits of the law, the U.S. Army will attempt to honor the restrictions I have requested to be placed on these materials.

____

Name of Interviewee Signature Date

____

Accepted on Behalf of the Army by Date

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