THE WARGAMING COMMODITY COURSE OF ACTION AUTOMATED ANALYSIS METHOD

THESIS

William T. DeBerry, Captain, USAF

AFIT-ENG-MS-21-M-027

DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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THESIS

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Abstract

This research presents the Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM), a novel approach to assist wargame commanders in developing and analyzing courses of action (COAs) through semi-automation of the Military Decision Making Process (MDMP). MDMP is a seven-step iterative method that commanders and mission partners follow to build an operational course of action to achieve strategic objectives. MDMP requires time, resources, and coordination – all competing items the commander weighs to make the optimal decision. WCCAAM receives the MDMP's Mission Analysis phase as input, converts the wargame into a directed graph, processes a multi-commodity flow algorithm on the nodes and edges, where the commodities represent units, and the nodes represent blue bases and red threats, and then programmatically processes the MDMP steps to output the recommended COA. To demonstrate WCCAAM effectiveness, a wargame scenario compares COA outcomes within the Advanced Framework for Simulation, Integration, and Modeling (AFSIM) and statistical analysis. The AFSIM results demonstrate a 71% objective completion improvement with the WCCAAM COA versus a human-generated COA. Statistical analysis reveals that over a 300 run test matrix, WCCAAM produces the optimal, minimal risk COA.

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Maj Richard Dill, for his guidance and support throughout the course of this thesis effort. The insight and experience was certainly appreciated.

Captain W. Taylor DeBerry

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THE WARGAMING COMMODITY COURSE OF ACTION AUTOMATED ANALYSIS METHOD

I. Introduction

1.1 Background

Early in his tenure as Chief of Staff of the United States Air Force, General Goldfein emphasized four key areas to invest in to compete, deter, and win in multi-domain operational warfare. These areas included space, Joint All-Domain Command and Control, the ability to operate as a hybrid force, and safeguarding future logistics. The Air Force developed these capabilities through wargaming: “it was never a guarantee that if you moved first in space that you were going to win. But in every wargame, we played, if you were the second mover, you were guaranteed to lose” [27]. In response, Lt Gen James M. Holmes, USAF Chief of Strategic Plans and Requirements, references the term wargaming 37 times in the 2016 Air Force Strategic Planning Process. Each mention conjures the necessity of further wargame research, including “wargame new concepts and assess progress toward goals across the AF to gain insights, to influence future strategy, concept development, planning, requirements, operational capability requirements development, and programming” [28]. Effective wargaming is a clear and present need for the USAF.

We present the Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM), a novel approach to assist wargame commanders in developing and analyzing courses of action (COAs) through semi-automation of the Military Decision Making Process (MDMP). This method supports the goals outlined in the 2016 Air Force Strategic Planning Process by increasing military wargaming effectiveness. WCCAAM assists wargame commanders develop and analyze COAs quickly and efficiently by converting wargames into graphical representations and performing algorithmic analysis. WCCAAM generates as output a viable COA and evaluates prospective human crafted COAs. The MDMP is a systematic seven-step process that struggles to develop an optimal COA under time constraints due to the factors of a lack of staff member training, leadership decision bias, and wargame complexity [1,2,7].

Ineffective COA development with the MDMP is a known issue addressed in the past with tools such as paper decision-making products: decision support matrices and decision support templates [1]. Due to a lack of training and the slow behavior of these tools, the United States Army says that wargaming staffs "struggle with gathering these tools and making them available" for proper use before COA analysis [1]. Even with the issues surrounding the current toolset given to wargame commanders, these paper decision-making products are still considered "the most valuable tools" for COA development and analysis [1].

Four chapters make up this thesis. Chapter 1 provides the introduction and motivation behind this research. Chapter 2 provides a review of related work and tools. Chapter 3 presents the journal submitted to the Journal of Defense Modeling and Simulation, introducing WCCAAM which is produced through this research. Chapter 4 concludes the research with implications, recommendations, areas for future work, and final thoughts.

1.1.1 Wargaming 101

Rand Corporation defines wargaming as serious games that involve "human players or actors making decisions in an artificial contest environment and then living with the consequences of their actions" [7]. These games involve team commanders making decisions in an environment they seek to effect, rules determine the scope of decisions they can make, and models determine verdicts that specify how actions affect teams and units [7]. Rand explains that the purpose of wargaming is "to examine warfighting concepts, train and educate commanders and analysts, explore scenarios, and assess how force planning and posture choices affect campaign outcomes" [7].

Military wargaming was originally developed in the 1820s by Prussian officers under the name Kriegsspiel as a type of table-top exercise (TTX) for battle planning. After unprecedented military successes against much larger and more powerful forces, the world started to notice the small country. This innovative and decisive tactic of wargaming battles before engagements proved especially effective in teaching German military officer tactics between the world wars. Due to limited military forces stipulated in the Treaty of Versailles, it was necessary to keep German leaders trained, albeit virtually, commanding forces in battle [8].

Most historians credit these wargaming methods for the early successes of German U-Boat and Blitzkrieg strategies. Today it is an intractable part of the modern warfighting process and has saved countless lives for the countries that pursue it [8].

Wargame operational fundamentals have changed little in the last two hundred years -- the colors blue, red, and white represent friendly, enemy, and adjudication forces, respectively. The blue team commander has a list of specific goals that require completion for game victory or to reach specific learning objectives. The red team commander has a set of tasks in direct conflict with the blue team goals. The white team observes interactions between the blue and red teams, enforces wargame rules and procedures, and determines unit engagement outcomes [8].

Wargame adjudications determine the outcome of player decisions, such as the confrontation between forces. Two main philosophies exist to resolve conflicts: inductive and deductive adjudication. In inductive adjudication, the white cell uses military judgment, prior experience, and discussions to estimate the outcome of unit interactions [9]. In deductive adjudication, the randomness of dice, calculation tables, or computer simulations determine unit interaction outcomes [9]. The personal bias from the previous experiences of the white cell members commonly plagues inductive adjudication. Deductive adjudication is more objective but can be limited in scope due to a lack of automated tools. The combination of the two methods helps assuage the shortfalls of each.

The adjudication style or the game's purpose typically defines the type of wargame used for the needed application [7]. Wargamers organize the different styles into Seminar, Course of Action (COA), Matrix, Kriegsspiel, Historical/hobby, and Business [29]. The primary focus of this thesis is on COA wargaming.

1.1.2 COA Wargaming

COA wargaming is a planning method to identify risks and issues to form a strategy reinforced with systematic analysis. Military COA wargaming fine-tunes battle preparation plans, and the game will be under significant time stress [10]. The game should consider friendly and enemy forces, terrain considerations, and consequences to civilians [10]. This form of wargaming requires specific military decisions in a time-sensitive situation, such as before a military invasion or in response to an adversary military action. The United Kingdom's lead consultancy company for organizing professional wargames states, "COA Wargaming will, almost certainly, be carried out under significant time pressure; this impacts how and when it is best conducted” [2].

Time constraints make it challenging to develop and select an optimal decision. The United States Army's Center for Lessons Learned states: "the [wargame commander's staff] do not allocate enough time to conduct COA analysis. By doctrine, one-third of the planning timeline should be dedicated to COA analysis (the same time allocation as mission analysis) [however, they] will typically over-allocate planning time to mission analysis at the expense of COA analysis" [1]. Effective utilization of these time resources can mean the difference between life and death when put into practice [7]. Even with its importance recognized, COA wargaming is still largely met with confusion, and the technology that supports it is fundamentally underused [7].

Issues relating to time management led to this reflection by the United States Army on COA wargaming: "observations have shown that due to time, COA analysis is often rushed or not done at all" [1]. Without proper assistance, the decisions on COA development and selection solely come down to military judgment, so success is based ultimately on the commander's level of experience [2]. Wargame commanders' prior experience will always be the most important deciding factor and an intractable part of military wargaming; however, overreliance upon this single source can lead to unsatisfactory results.

1.2 Problem Statement

The lack of effective automated decision-making tools for COA development and analysis in military wargaming is a clear need; wargame commanders cannot quickly develop COAs and discern their differing outcomes based upon a list of inputs and desired outcomes. The current wargame COA analysis and development tools that exist are inefficient, ineffective, and require extensive resources. Also, the planning, execution, adjudication, and post-wargame analysis phases tend to be overly customized, such that SME-expert opinion supersedes recommendations that could be gained from technology. Through leveraging algorithmic analysis, more effective COAs can be crafted.

1.3 Research Objectives and Expected Contributions

The goal of this research is the development of WCCAAM, an algorithmic tool that assists wargamers with developing and evaluating COAs. WCCAAM analyzes human-generated COAs and compares them to a unique algorithm-generated COA. To our knowledge, this method of transforming wargames into a weighted directed graphical representation and performing algorithmic analysis with a multicommodity flow algorithm to aid military COA wargame commanders has never been done, making the endeavor novel.

The expected contribution to military wargaming is to produce WCCAAM. Our method fills a gap between paper and high-fidelity simulation methods for COA analysis, minimizing operator overhead, and reducing computational resources. WCCAAM assists military wargame commanders and planners in the design and feasibility of wargame COAs. This assistance takes place both before wargames begin and during the wargame to consistently assess COA viability. WCCAAM should become an asset to the United States Department of Defense to help prevent wasted wargames and improving others' effectiveness.

II. Background

2.1 Chapter Overview

Chapter 1 presented the motivation of this research and an introduction to military and Course of Action (COA) wargaming. This chapter includes an explanation and assessment of COA analysis and development tools developed by other efforts. The conclusion of this chapter shows the roles filled and the necessity of the Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM).

2.2 Related Simulation and Wargaming Tools Summary

The need for effective wargame simulation and COA development tools is an identified area of need for militaries here and abroad. Due to this void, some researchers have already worked towards its mitigation. The following are published works and tools developed by both national militaries and private businesses. Advanced Framework for Simulation, Integration, and Modeling (AFSIM) was used to create proof of concept simulations that demonstrate WCCAAM results and is explained fully in chapter 3. Otherwise, these tools have given this research some direction and conceptual inspiration, but none were directly adapted in this research's final methods.

2.2.1 OpSim

Cole Engineering's Dr. John Surdu explains how simulations can be used for United States Army command posts in the future to assist their planning, rehearsals, operations, and after-action reviews [30]. Surdu echoes the goal of this research with the statement: "simulations designed to facilitate COA development and analysis, rehearsal, and operations monitoring will enhance the effectiveness of staffs and commanders." His research explains that the wargaming process will be only as effective as the commander and staff members' skills. This research impresses the need for computer simulation analysis of COAs as another source of information [30].

Dr. Surdu explains these concepts further in that these processes eventually turned into the OpSim software from Cole Engineering. Surdu explains that the reason for his research is to fill the Army Modeling and Simulation Office's five modeling and simulation technology voids. These were "automated decision aids, COA tools, and tactical information aids" [31]. This lack of automated decision aids and COA tools by the Department of Defense is why we pursue this research. Surdu goes onto describe the objective of his research: develop a methodology for using simulations during operations. This methodology should support the construction of tools, help decision-makers react quickly, and allow accurate responses to a rapidly changing environment. These are similar to the goals of our research in developing WCCAAM. The primary difference is that this author primarily developed this system for US army decision making in tactical engagements, where our method provides a toolset for COAs in a wargaming environment [31].

2.2.2 SitaWare, OneSAF, and MTWS

The tools that support Cole Engineering's Course Action Analysis are SitaWare, One Semi-Automated Forces (OneSAF), and the Marine Air Ground Task Force Tactical Warfare Simulation (MTWS) [32]. SitaWare is an open architecture C4ISR platform that facilitates making complex joint and coalition battle decisions on networks. OneSAF is a toolkit that facilitates designing battle simulations in a live, virtual, or constructive environment. OneSAF is for brigade-level staff training, research, and experimentation. MTWS is a constructive simulation for higher-level staff officers and joint force training. MTWS models all aspects and domains of marine warfare [32]. SitaWare works as a COA analysis tool and can directly produce operational plans for battlefield commanders [32]. MTWS simulated SitaWare's output COAs to demonstrate the effectiveness of the tool [32]. We similarly demonstrate WCCAAM COA effectiveness with AFSIM simulations.

Cole Engineering explains that their tools show COA development and analysis while hiding the simulation and all code complexity from the user [32]. Incorporating a similar design may be necessary for prolonged military use, as most users of tools like WCCAAM and SitaWare require one that is intuitive and has a user-friendly interface [32].

Cole Engineering explains the design specifics, assumed ground rules, and expectations that they took while designing these tools. The first objective was that an operator could not manipulate the simulation except through the Graphical User Interface (GUI). As a second objective, the simulation must run faster than in real-time. This speed requirement is because a commander must have his COA test results in time to use. Imposed numerical constraints assist with automating decisions and populating values. These constraints are casualties, ammo, fuel, equipment, and overall. SitaWare generates output graphs to visualize the COA analysis outcome, and the author claimed that the results showed that the embedded COA simulations were successful. The main variations from here were the different speeds at which the team could simulate the results and still maintain fidelity of COAs [32].

2.2.3 Deep Green

Deep Green, a Defense Advanced Research Projects Agency (DARPA) project, intended to develop decision-making support systems for United States Army commanders [33]. The resulting system included predictive capabilities to enable efficient and accurate predictions of possible future scenarios through computer simulation. Based on an analysis of the current situation, the goal was to give commanders an improved observation of possible outcomes for their decisions [33].

Deep Green includes three modules: Blitzkrieg, Crystal Ball (CB), and Commander's Associate (CA). Blitzkrieg, a battlefield model, analyzed the current situation and presented potential outcomes for developing a response. After selecting a plan, Blitzkrieg analyzed the likely results of that COA. This tool presented the calculated results of a human-generated plan, but it does not develop a viable COA. That is the role of CB; this tool performs an analysis of possible outcomes and determines the most promising choice. It chooses this based upon the factors of flexibility, usefulness, and likelihood in the generated future. In CA, the commander views and interacts with a battlefield visualization module. It provides the commander with a list of options that the tool generates with the previous modules. CA appears to be similar in function to SitaWare, giving army commanders guidance on upcoming engagements [34]. The Deep Green program lost traction and funding around 2011 with senior leadership changes at DARPA and is not used currently for tactical or wargaming in the DOD.

Table 1. Summary of Related Simulation and Wargaming Tools

	AFSIM	OPSIM	MTWS	SitaWare	OneSAF	Blitzkrieg	CB	CA	WCCAAM
Battlefield Simulator	**X**		**X**		**X**	**X**			
COA Analysis		**X**		**X**				**X**	**X**
COA Generation							**X**		**X**
OPLAN Generation				**X**					
Multiple Domains	**X**		**X**						**X**

2.6 Summary

The tools and methods covered in this chapter ensure the reader has the background necessary to understand the current wargame and COA simulation applications previously available to military wargamers. The study of these past works is invaluable in understanding the wargaming and military COA development communities' needs. Table 1 summarizes the capabilities of each of the tools covered in this section. WCCAAM identifies the abilities of the tool created by this research. Chapter 3 presents a full explanation of WCCAAM, including its purpose, roles filled, and effectiveness demonstration.

III. Scholarly Article:

The Wargame Commodity Course of Action Automated Analysis Method

Journal of Defense Modeling and Simulation (JDMS Special Issue 2021)

William DeBerry, Richard Dill PhD, Kenneth Hopkinson PhD, Douglas Hodson PhD,
Michael Grimalia PhD

Abstract

This research presents the Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM), a novel approach to assist wargame commanders in developing and analyzing courses of action (COAs) through semi-automation of the Military Decision Making Process (MDMP). MDMP is a seven-step iterative method that commanders and mission partners follow to build an operational course of action to achieve strategic objectives. MDMP requires time, resources, and coordination – all competing items the commander weighs to make the optimal decision. WCCAAM receives the MDMP's Mission Analysis phase as input, converts the wargame into a directed graph, processes a multi-commodity flow algorithm on the nodes and edges, where the commodities represent units, and the nodes represent blue bases and red threats, and then programmatically processes the MDMP steps to output the recommended COA. To demonstrate its use, a military scenario developed in the Advanced Framework for Simulation, Integration, and Modeling (AFSIM) processes the various factors through WCCAAM and produces an optimal, minimal risk COA.

1 Introduction

Course of Action (COA) Wargaming requires a commander to make a specific military decision in a time-sensitive manner, such as before a military invasion or in response to an adversary action. The paper decision-making products and full battlefield simulations that wargame planners use to analyze and recommend military action are time intensive and may yield sub-optimal results [7]. Paper methods, such as decision support matrices and decision support templates, require extensive training, are bias influenced, and do not allow for precision when dealing with large numbers of units [1,2,7]. Modeling and simulation (M&S) methods that rely on physics models take longer to develop and often require massive computational resources [7]. The United Kingdom's lead consultancy company for organizing professional wargames states, "COA Wargaming will, almost certainly, be carried out under significant time pressure; this impacts how and when it is best conducted [2]."

Commanders and their staff have traditionally applied the seven-step Military Decision Making Process (MDMP) to produce a COA response or support military action. The steps of MDMP are Receipt of Mission, Mission Analysis, COA Development, COA Analysis, COA Comparison, COA Approval, and Orders Production [11]. Time constraints, lack of staff member training, leadership decision bias, and wargame complexity challenge the process to develop an optimal course of action [1,2,7]. Due to the complexity and resources required, the commander's staff prioritizes post-mission analysis over COA development and analysis [1]. The result increases operational risk, putting military lives in unnecessary danger [11].

In this research, we present the Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM) to increase military wargaming effectiveness by assisting wargame commanders in developing and analyzing COAs through automating part of MDMP, specifically the COA Development, Analysis, and Comparison steps. WCCAAM fills a gap between paper and high-fidelity simulation methods for COA analysis, minimizing operator overhead and reducing computational resources. The method relies on Gurobi's multi-commodity flow algorithm (MCFA) and provides a simple graphical user interface (GUI) for the wargame planner [3,4]. WCCAAM produces an unbiased and optimal COA for a wargame commander, minimizing risk to achieve intended operational objectives.

In this paper, section 2 provides a background on wargaming, graph theory, multi-commodity flow algorithms, MDMP, and the statistical analysis of wargaming analysis algorithms. Section 3 details the design and analysis of WCCAAM. Section 4 shows the military scenario that is the basis of evaluation. Section 5 concludes and discusses future applications.

2 Background

This section presents background information and foundational concepts to understand the Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM). A primer on military wargaming, graph theory, and multi-commodity flow algorithms (MCFA) provides a precursor to WCCAAM.

2.1 COA Wargaming

Rand Corporation defines wargaming as serious games that involve "human players or actors making decisions in an artificial contest environment [7]." Team commanders execute decisions for the desired effect, rules establish the scope of actions, and models determine verdicts of player and unit interactions [7]. The military relies on wargaming "to examine warfighting concepts, train and educate commanders and analysts, explore scenarios, and assess how to force plan and posture choices to affect campaign outcomes [7]."

Wargame fundamentals have changed little in the last two hundred years -- the colors blue, red, and white represent friendly, enemy, and adjudication forces, respectively [8]. The blue team commander has a list of goals to achieve victory or participant learning objectives.

Similarly, the red team commander has a set of tasks, usually in direct conflict with the blue team goals. The white team observes interactions between the blue and red sides, enforces wargame, and determines unit engagement outcomes [8].

The primary wargame characteristics define them, specifically, the adjudication style [7]. Wargame adjudications determine the outcome of player decisions, such as the confrontation between forces. Two main philosophies exist to resolve conflicts: inductive and deductive adjudication. In inductive adjudication, the white cell members apply military judgment, experience, and discussions to estimate the outcome of unit interactions [9]. In contrast, deductive adjudication depends on stochastic methods (e.g., dice outcome, calculation tables, or computer simulations) to determine unit confrontations [9]. Personal bias is a common plague of inductive adjudication because it relies upon the white cell members' previous experiences [9]. Deductive adjudication is more objective but has limited applicability due to a lack of automated tools.[9]

Militaries typically use COA wargaming to fine-tune operational battle plans, placing the game planners and commanders under time constraints [10]. Wargame planners consider friendly and enemy forces, terrain texture, and consequences to civilians [10]. This form of wargaming requires the commander to make time-sensitive decisions to thwart adversary actions.

An essential consideration in COA wargaming is the assessment of risk levels. The US military assesses risk by the probability and severity of loss linked to hazards [19]. Risk levels come from assessing opportunities from planned events, anticipated events, unforeseen events, and chance [19]. WCCAAM minimizes every blue unit's risk while still achieving the required mission objectives.

2.2 Weighted Directed Graphs

Understanding WCCAAM relies on a fundamental understanding of graphs and their applications. A graph mathematically displays relationships among a set of objects [5]. A graph *G* can be referenced as the sets *(V, E),* where *V* refers to the collection of nodes (i.e., objects) and *E* refers to the set of edges, each of which connects two nodes.

Edges connect a pair of nodes in a graph for specific reasons, indicating the nodes relate to each other. In a simple graph, the relationship between these nodes is bidirectional, whereas, in a directed graph, the edges indicate that the relationship between connected nodes occurs only in one direction. The directed graph indicates the connected nodes' strength with an annotated edge weight. Weighted directed graphs model transportation systems, communications networks, information networks, social networks, and dependency networks [5]. Figure 1 shows an example weighted directed graph with a single weight labeled per edge.

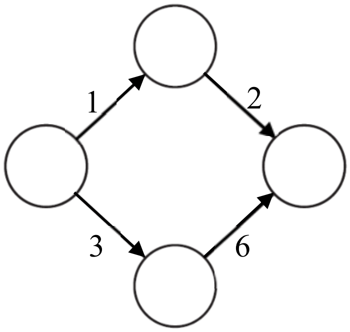


Figure 1. Example Weighted Directed Graph

WCCAAM relies on the weighted directed graph properties to model wargame decision making. It represents blue bases/red threats as nodes, unit travel paths as edges, and risk as weights between them.

2.3 Multi-commodity Flow Algorithm

An algorithm represents steps a computer follows to calculate results, gather information about complex problems, or automate processes for efficiency gains [5]. WCCAAM depends on a multi-commodity flow algorithm (MCFA) to process a weighted directed graph representing wargame artifacts. The output reveals the optimum flow along the edges from each node, providing insight into the complex wargame system that the weighted directed graph models.

A single-commodity flow problem represents the desire to find the optimum path to move a single resource (e.g., commodity) from source (e.g., origin) to sink (e.g., destination). A maximum flow algorithm, such as Ford-Fulkerson, computes the optimum path in polynomial runtime [5].

In the multi-commodity flow problem (MCFP), a network efficiently sends different types of commodities across a network that has a shared edge capacity. MCFP algorithms typically support transportation or scheduling problems, such as airline systems that schedule commercial flights [23].

MCFP appears to be a combination of single-commodity flow problems, but it is more complicated due to interactions between the commodities [6]. The commodity costs to flow along an edge, and the supply and demand vary. Each commodity can have multiple sources and sinks.

The two primary constraints when solving an MCFP are the travel demand (TD) and the edge capacity (EC). TD is the sum of the single-commodity flow problems where all commodities reach their destinations. EC is the shared flow along an edge that cannot be exceeded and is considered by all commodities [6]. The following formulas mathematically define MCFP:

$$minimize\ z(x)\ = \boldsymbol{c}^T \sum_{k=1}^{t} \boldsymbol{X}^k \quad (1)$$

$$subject\ to\ \ \sum_{k=1}^{t} \boldsymbol{X}^k \leq \boldsymbol{cap} \quad (2)$$

$$\boldsymbol{BX}^k = \boldsymbol{b}^k,\ \ k = 1,2,\dots,t \quad (3)$$

$$\boldsymbol{X}^k \geq \boldsymbol{0},\ \ k = 1,2,\dots,t \quad (4)$$

Expression (1) represents the objective function of the total cost. It states that MCFA outputs the minimum value equal to the total cost multiplied by the summation of the flow amounts over *t* commodities [6]. Expression (2) constrains the MCFA output such that the commodity flow sum is less than or equal to that edge's capacity. Expression (3), the node flow equilibrium equation, states that the incidence matrix *B* (between all nodes and edges) multiplied by the k^{th} commodity flow amount must equal the k^{th} commodity amount at its origin and demand nodes [6]. Expression (4) requires a non-negative number for every commodity flow [6].

The two primary algorithmic methods to solve the MCFP are column generation and Lagrangian relaxation. The column generation method breaks the graph into columns based on the number of commodities and edges, sums the columns, and produces the optimal solution. The Lagrangian relaxation method uses Lagrange multipliers to find the maxima and minima of each arc, subject equality constraints and moves towards the optimal solution step-by-step [6]. WCCAAM uses software licensed and produced by Gurobi Optimization [3,4]. This solver supports either solving method but completes quicker with column generation [6].

2.4 Military Decision Making Process

Traditionally, commanders and their staff follow the Military Decision Making Process (MDMP) to produce a COA response to a wargame initiation [11]. Seven steps compose MDMP (Figure 2), where the outputs from each step contribute to an improved understanding of the situation [11]. Commanders and staff typically follow each step sequentially, but they may repeat a set of steps before creating the plan or order as the battlefield situation unfolds.

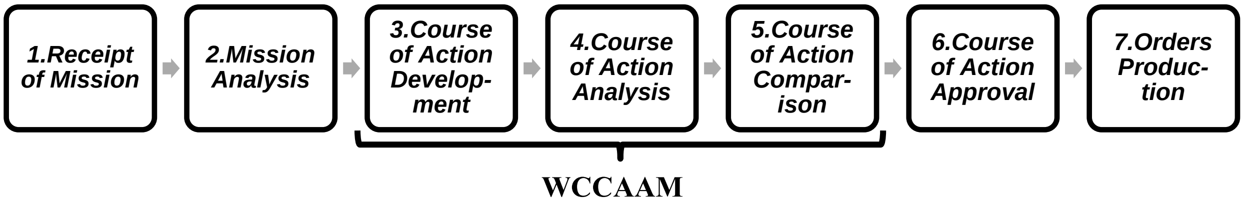


Figure 2. MDMP Flow Chart [11] with WCCAAM

Upon receipt of a wargame mission (Step 1), MDMP units conduct Mission Analysis (Step 2) to frame the problem space and establish potential enemy COAs based on available intelligence. As intelligence reports update the commander's battlespace view, refreshing enemy unit placement and movement, the commander and staff revise their strategy. After establishing enemy COAs, blue team COAs are generated (Step 3) to achieve the desired end-states defined by mission parameters. The team then assesses these blue COAs against an enemy COA (Step 4) to decide if the friendly COA can be successful. Based on these analysis results, the commander compares blue COAs options (Step 5) and then approves a COA (Step 6). Finally, the commander staff disseminates the authorized COA to the friendly forces as orders (Step 7) [20].

Unfortunately, this process is also slow and cumbersome. It may work well for divisions with a large staff of dedicated members but is not practical for a small inexperienced team with time-constraints. The complexity of most wargames requires developing and comparing multiple COAs to obtain the best possible solution to each problem [21].

This research aims to recreate MDMP so that a multi-commodity flow algorithm can process the initial inputs derived from the Receipt of Mission and Mission Analysis phases into the outputs traditionally generated from the COA Development, COA Analysis, and COA Comparison phases. The result reduces the time and stress on wargame staff, making the wargame and wargamers more effective.

2.5 Wargames as Analytical Simulations

Analytical modeling is a quantitative data analysis technique for answering specific questions or making design decisions. Analytical models address different aspects of systems, such as changes in their performance, reliability, or mass. Users of analytical techniques need to express the models accurately to gather useful results [12].

A team from the US Naval Post-Graduate School examined the possibility of using wargames as analytical models to gain strategic military insights [13]. The researchers performed a computer-assisted wargame scenario with a human in the loop, took the resultant data, and turned it into a closed-form computer model. Using simulation, the team ran a full factorial statistical design of experiments (DOE) to generate data [13].

Table 2. DOE Full Factorial Design Example[15]

Run	A	B	C
1	+	+	+
2	+	+	-
3	+	-	+
4	+	-	-
5	-	+	+
6	-	+	-
7	-	-	+
8	-	-	-

Run	A	B	C
1	High	On	Yes
2	High	On	No
3	High	Off	Yes
4	High	Off	No
5	Low	On	Yes
6	Low	On	No
7	Low	Off	Yes
8	Low	Off	No

A full factorial DOE measures each response of the potential combination of gathered factors and levels. These responses are then analyzed to provide information about each primary effect and every primary interaction. A full factorial DOE is practical when examining five or fewer factors [14].

The primary factors measured were the ones that had the most effect on successful wargame outcomes. Following a design of experiments approach of changing one factor for each simulation, the collected data built a statistically significant model. Typically, one wargame with a single result is not statistically relevant because it could be an error or outlier. However, an analytical model of a wargame can be simulated over a full factorial to gain statistical relevance [13,15]. Table 2 shows an example of a full factorial DOE model that shows digital factors associated with their human-readable format [15].

When considering more than five factors or a high number of levels, fractional factorial designs are practical. Because full factorial design experiments are often time and cost-prohibitive when many factors are involved, many choose to use fractional factorial designs. These designs assess a subset of factor and level permutations. Fractional factorial designs look like full factorial designs with fewer factors [24].

The following approach evaluates the results from a DOE statistical test. Factor inputs and response outputs are plotted in a Y by X manner, revealing trendlines and correlations [22]. Correlation between factors and responses occur when data points appear close to a linear trendline [22]. This result implies that inputted factors contribute to measured response levels [22]. R^2 measure correlation and is a value between zero and one [22]. An R^2 value closer to one shows a strong correlation, whereas ^{a} value near zero shows a weak correlation [22]. A successful DOE statistical test should reveal a strong correlation between factors and responses.

The analytical modeling approaches taken in these works provide the framework for verifying WCCAAM. These works demonstrate that turning computer-assisted wargames into models is a statistically appropriate analysis technique. This research utilizes a fractional factorial DOE design to evaluate WCCAAM. The primary reason was that our test scenario had eleven factors, meaning a full factorial DOE design would be infeasibly large.

2.6 AFSIM

The Advanced Framework for Simulation, Integration, and Modeling (AFSIM) is a software simulation tool for research and development, operations analysis, and experimentation communities [16]. It is typically used to simulate specific missions, many-on-many or one-on-one engagements, and test new engineering ideas, systems, or concepts in a risk-free environment. AFSIM models air, space, surface, and sub-surface warfighting domains. Also, the simulation framework supports tactical development through concept assessments and operational evaluations [16].

The AFSIM package includes a suite of tools: Wizard, Mission, Warlock, Engage, Weapon Tools, and Sensor Plot. This research primarily used Wizard, Mission, and Warlock. Unit creation and placement occurs in Wizard, the scenario creation tool. Mission rapidly simulates engagements and supports post-execution replays. Warlock allows an operator to run scripts during simulation execution to affect results in a wargame environment.

Schwartz et al. compare a manually produced COA with one from a US Army battlefield AI simulation tool [20]. The researchers compare the results to assess the increase in friendly force strength at the end of the scenario [20]. In this way, they demonstrated their AI tool's effectiveness. Likewise, we design and simulate a wargame in AFSIM's Wizard and compare the results from a user-developed COA with a WCCAAM produced one.

2.7 Background Summary

The concepts and tools presented in this section are the basis of WCCAAM and its capability demonstrations. WCCAAM relies on weighted directed graphs to represent wargames as analytical models so that MCFA can process them. The method's principal task is creating a repeatable process that turns wargames into these analytical models. After modeling a wargame, WCCAAM demonstrates its capabilities through two methods. First, an AFSIM simulation establishes the basic concepts behind WCCAAM. Then, a fractional DOE statistical analysis tests WCCAAM to show model correlation and COA generation efficacy. The following section covers the steps of WCCAAM and how this method develops the graphical version of a wargame.

3 Methodology

This section details how the Wargame Commodity Course of Action Analysis Method (WCCAAM) transforms a wargame into a computational model that a multi-commodity flow algorithm (MCFA) analyzes to produce a recommended COA. WCCAAM augments the Military Decision Making Process (MDMP) method by ingesting the output from the MDMP Mission Analysis phase and produces a COA that is pushed into the MDMP COA Approval phase, replacing the MDMP COA Development, Analysis, and Comparison phases. WCAAM automates the former steps by applying an algorithmic solver, replacing time-consuming paper tools and team discussions. The three steps automated by WCCAAM are the most time-consuming and arduous tasks presented by MDMP [25]. WCCAAM replaces these with straightforward, practical solutions.

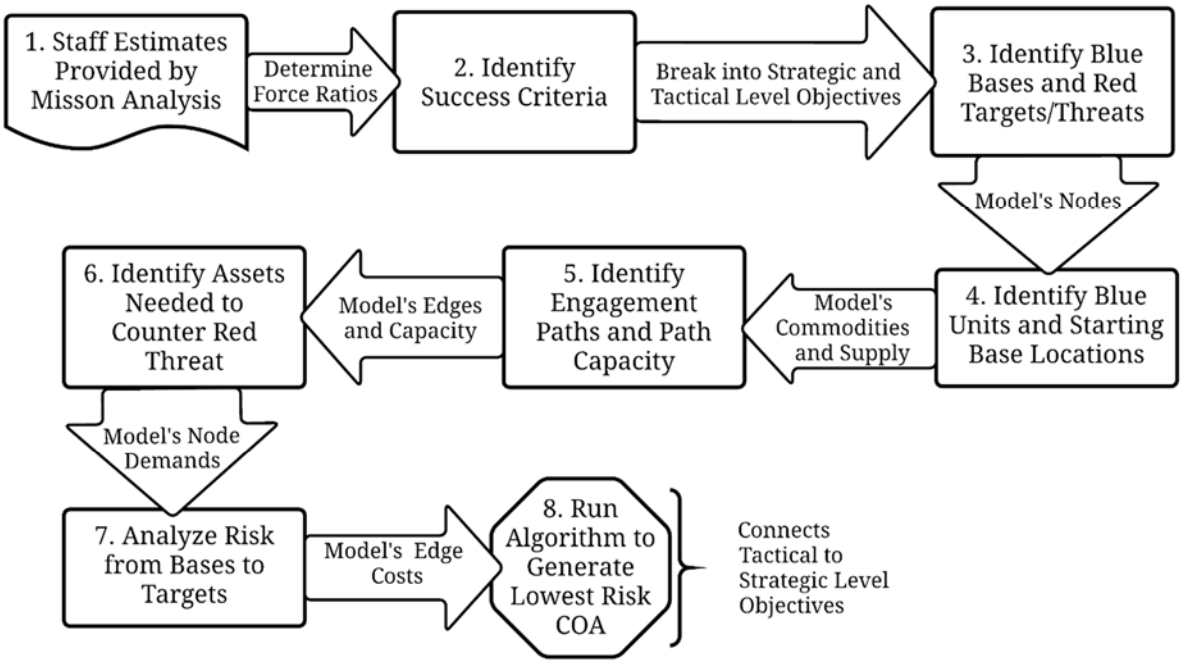


Figure 3. WCCAAM Flow Chart

Following the eight steps of WCCAAM ensures accurate wargame conversion into an analytical model. This analytical model is a weighted directed graph presenting a multi-commodity flow problem (MCFP). Figure 3 shows the WCCAAM steps in a flow chart, where the boxes describe the primary steps, and the arrows depict the outputs as parts of the MCFP graph. The rest of this section explains the inputs, operations, and outputs of each WCCAAM step.

3.1 Mission Analysis Staff Estimates

The MDMP Mission Analysis phase outputs the staff estimates. These estimates are concise reports that wargame designers develop from the mission intelligence [11]. The typical list of staff estimates provided to the commander includes the Operations Estimate, Personnel Estimate, Intelligence Estimate, Logistics Estimate, Civil-Military Estimate, Signal Estimate, Information Operations Estimate, and Special Staff Estimate [25]. Each of these estimates is of varying levels of importance based upon the type of wargame. The staff estimates and the wargame map provide the information needed to convert the wargame into a graphical representation for algorithmic processing.

The first two components required by WCCAAM from these estimates are the mission strategy and red peer levels. These components determine the force exchange ratios for unit engagement adjudication. The mission strategy levels considered in WCCAAM are offensive, balanced, or defensive. Offensive tasks require 25% more units than a balanced approach, where defensive missions require 25% less. The red peer levels are peer, near-peer, and asymmetric. A red force that is a peer-level opponent needs a one-to-one force exchange ratio. A red team determined as a near-peer opponent requires 80% of blue force strength. Only 50% of blue forces are necessary to counter the red threats in an asymmetric-level peer. These calculations are based roughly upon the Lancaster Equations that approximate force ratios in historical combat [17].

3.2 Identify Success Criteria

The first staff action identifies the mission's success and failure criteria. Next, the staff divides the criteria into quantifiable strategic and tactical level objectives. A Strategic Objective (SO) is a high-level statement that outlines what needs to be achieved, with a clearly stated goal (e.g., defend all bases or achieve air superiority over a region) [18]. A Tactical Objective (TO) is a short-term desired result of an assigned unit mission, such as destroying a single threat or defending a base. Understanding objectives and dependent sub-objectives form the foundation form the rest of the wargame COA analysis process.

3.3 Identify Blue Bases and Red Targets/Threats

The wargame commander establishes the blue bases of operation from the staff estimates, including unit locations supporting offensive or defensive missions. Examples include physical bases with troops or carrier groups with available aircraft. Next, the commander identifies red team threats and targets. Examples are red bases, an attacking tank force from a given direction, or a unique high-value target. The identified red and blue assets form the nodes of the wargame's direct graph.

3.4 Identify Blue Units and Starting Base Locations

The Personnel Estimate provides the blue team commander a list of assets before wargame initiation. The organization of these assets into domains and unit types is essential for proper positioning. There are two types of unit pre-positioning options that are used by wargame designers: locked and unlocked.

For wargames with locked starting locations for blue units, the commander positions units at the bases given by the Personnel Estimate. In the unlocked case, the commander can choose unit starting positions at any of the bases identified in step 3. The commander can also use WCCAAM to automatically pre-position blue units to optimal bases in the unlocked case. These optimal base assignments are those WCCAAM calculates the most advantageous outcome for the blue team.

If the Intelligence Estimate changes, step 4 can be repeated after step 8 to further optimize the blue COA by repositioning units before wargame turn initiation. The commodity types and supplies at the starting nodes are this step 4's output in the wargame's graphical representation.

3.5 Identify Engagement Paths and Asset Capacity

The blue command staff identifies the possible engagement paths from the wargame map and the staff estimates. These paths connect each blue base to the red target and identify inter-threats as nodes on the engagement path. If the blue base can send units to counter a red threat, then that path is also determined. Engagement paths vary based upon the warfighting domain. In the air domain, the capacity limitation is the number of units that the base can simultaneously support air operations. In the ground domain, the path capacity depends on map terrain. Highways or road availability contribute to a high ground troop movement capacity where uncleared forests or swamps limit movement capacity. In the graphical representation of the wargame, these factors represent the edges and associated capacities.

3.6 Identify Assets Needed to Counter Red Threat

The red threats and targets identified as nodes in step 3 require a neutralizing blue opposing force. The blue commander's assessment of the red asset list and projection of red COAs identifies the number of blue units needed to counter each red threat. Commanders need to project at least three red COAs by listing the most likely red COA, the red COA that is most harmful to blue objectives, and the red COA that is most beneficial to blue objectives. The blue staff analyzes these COAs and develops mitigation strategies. The blue staff identifies unit types and estimates totals in each threat from the mitigation strategies and the Intelligence Estimate. With this information present, the blue commander identifies the minimum number of units in each domain necessary to counter the red threat or destroy the red target. The commodity demand at each red node represents the required amount of force to neutralize blue units in the wargame's graphical representation.

3.7 Analyze Risk from Bases to Targets

The engagement paths identified in step 5 have another necessary variable: risk. WCCAAM represents risk through these levels and point totals: low (1), medium (2), and high (3). Wargame commanders assess risk levels for each unit type's engagement path from blue bases to red threats. WCCAAM completes this process by measuring engagement paths' distance and vulnerability to an attack. A wargame map measurement determines the engagement path distance. The commander determines the attack's vulnerability by weighing the likelihood of a red COA that attacks units along the path. The model's edge costs represent these numerical risk levels.

3.8 Run Algorithm to Generate Lowest Risk COA

In this step, WCCAAM analyzes the wargame model using MCFA and outputs an employable COA that minimizes risk. The WCCAAM MCFA minimizes and aggregates the risk total of units sent along engagement paths associated with each TO and SO. The blue COA output includes:

- Unit pre-turn assignments (dependent upon wargame design)
- The path of each blue asset assigned from its base to a red threat or target based on minimizing total risk
- The list of multiple TOs providing their risk requirements
- The list of multiple SOs reporting their risk requirements

3.9 Methodology Summary

WCCAAM manually incrementally transforms a wargame into a weighted directed graph with steps 1-7. These actions correspond to step 3 of MDMP. An automated MCFA then analyzes this graph to produce a COA based upon the lowest total risk while completing all objectives. This action, step 8, corresponds to steps 4 and 5 of MDMP. The inputs come from the MDMP's Mission Analysis staff estimates. WCCAAM's incremental definition of steps 3-5 of MDMP is novel. The outputs are read as a single COA for all units under the blue commander's control.

4 Validation and Verification

This section demonstrates the plan to verify and validate the Wargame Commodity Course of Action Analysis Method (WCCAAM). A military scenario is first designed, converted into an Advanced Framework for Simulation, Integration, and Modeling (AFSIM) simulation, and then fractional design of experiments (DOE) statistical analysis testing is performed on the same scenario. These methods parallel the verification and validation methods employed by the US Army Combat Capabilities Development Command and US Naval Post-Graduate School [15, 20].

Accomplishing the following three goals validate WCCAAM:

Goal 1: The WCCAAM models wargames correctly
Goal 2: The WCCAAM produces a viable COA for a wargame commander
Goal 3: The WCCAAM offers the best COA possible from a risk reduction point of view

The following two-step approach is used to achieve these goals:

Step 1: An AFSIM COA simulation and evaluation (goals 1 and 2)
Step 2: A DOE statistical test (goals 1 and 3)

Step 1 details an approach similar to the one taken by the team from the US Army Combat Capabilities Development Command to verify their artificial intelligence wargaming tool [20]. In this case, we simulate a wargame in AFSIM with a generic COA, then AFSIM runs the same scenario with a WCCAAM generated COA. In this case, a generic COA means a user-developed COA without the assistance of WCCAAM. A results comparison shows the difference in the number of objectives completed and the total risk reduction. An increase in objective completion and a reduction in cumulative risk by WCCAAM's COA demonstrates the first two goals.

Step 2 details an approach similar to the US Naval Post-Graduate School team's to verify wargames expressed through statistical models [15]. In this approach, we verify WCCAAM via a fractional DOE statistical test. These test results demonstrate goals one and three through proper wargame unit correlation and significant total risk reduction.

Matthew Caffrey developed the wargame scenario used in both verification and validation steps. Mr. Caffrey modeled this scenario after a former United States military conflict, and it includes unit specifications, base locations, and clear objectives. These attributes present it as an excellent scenario to model in AFSIM and to evaluate WCCAAM.

4.1 Wargaming Scenario

The Wargaming 101 scenario describes two fictitious nations, Phoenicia and Sumer, on the brink of conflict [26]. Phoenicia, a small, wealthy, free-market democracy, is a longtime ally of the US Sumer is an aggressive, large dictatorship that desires nuclear weapons and Phoenicia's wealth and resources. Oceans surround the area of conflict, with a neutral nation to the north.

The Wargaming 101 scenario's geopolitical setup lends itself to a straightforward and effective conversation into a wargame with historical context [26]. This context supports AFSIM's requirement for a real-world location to simulate wargames. The Wargaming 101 scenario directly transforms into the 1990 Gulf War [26]. The dictatorship, Sumer, with the desire to acquire weapons of mass destruction, large size, and poor economy, translates to Iraq under Saddam Hussain's government. The role of Phoenicia translates to Kuwait, a US ally with a strong economy, a small population, and land area.

Other aspects of the geopolitical setup also fit in this scenario. Turkey, primarily neutral during the Gulf War, represents the large neutral nation to the north. The Persian Gulf surrounds these nations' southeastern border and allows for US Navy asset participation.

4.2 AFSIM Simulation

Due to AFSIM's Warlock tool's limitations, the number of units decreases in the wargame from four hundred to twenty-one. The unit reduction results in nine red units (five air-to-air fighters, two bombers, and two tanks). The resulting blue force is twelve units (seven air-to-air fighters, three C-130 cargo planes, and two bombers). These unit numbers still gave the necessary amounts to model the wargame while allowing conversion into AFSIM's complex modeling environment.

WCCAAM step 1 determines that the mission strategy level is balanced and that the opposing red force is a peer. The blue team's success criteria are to protect all blue bases, deliver one C-130 to Base 2 and two C-130s to Base 3, and achieve air superiority. In direct conflict, the red success criteria are to destroy all blue bases and cargo planes. Step 2 of WCCAAM divides the blue objectives into tactical and strategic levels, as seen in Table 3.

Table 3. Wargame Test Scenario Tactical and Strategic Objectives

Tactical Objectives (TOs)	**Strategic Objectives (SOs)**
1. Defend Base 1	1. Defend all Bases (TOs 1-3)
2. Defend Base 2	2. Achieve Air Superiority (TOs 4 & 5)
3. Defend Base 3	
4. Eliminate All Red Fighters	
5. Deliver All Cargo	

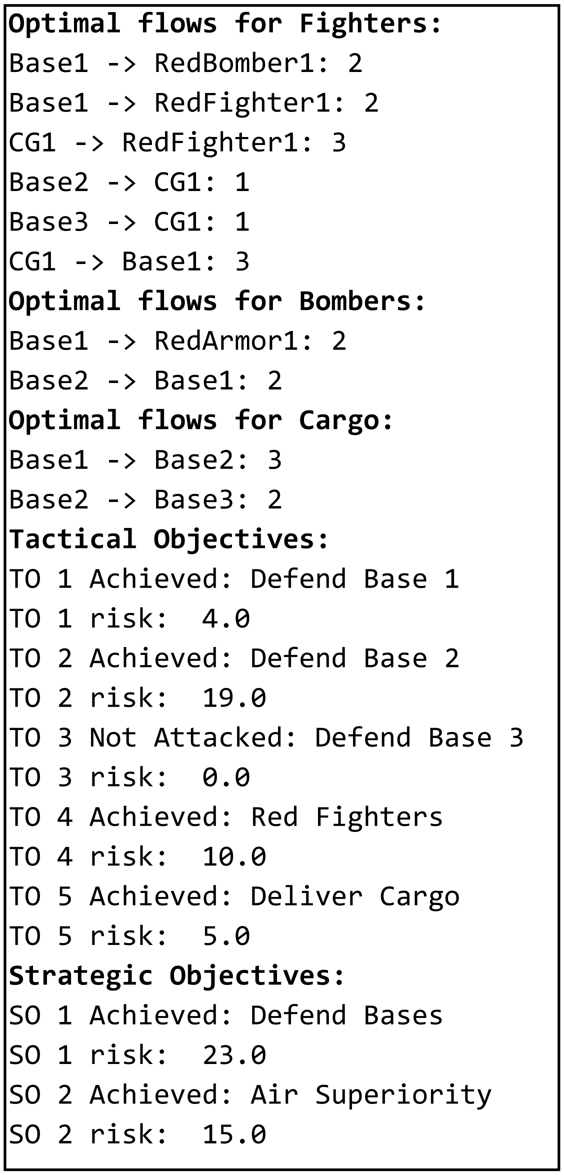
For the base and unit breakdown for WCCAAM steps 3 and 4, the scenario has three friendly bases, a carrier group, and five enemy bases. At these bases, fighters, bombers, tanks, and cargo planes are combatants in the wargame. WCCAAM step 5 establishes all possible blue engagement paths that exist between the blue bases and red threats. WCCAAM step 6 concludes from the intelligence estimate that the red commander would perform one of three COAs:

1. Attack with all forces from Northern Base
2. Attack with units split with a North and South force
3. Attack with all forces from the Southern Base

WCCAAM step 7 establishes a risk amount on each engagement path for each commodity based upon the path distance and susceptibility of attack.

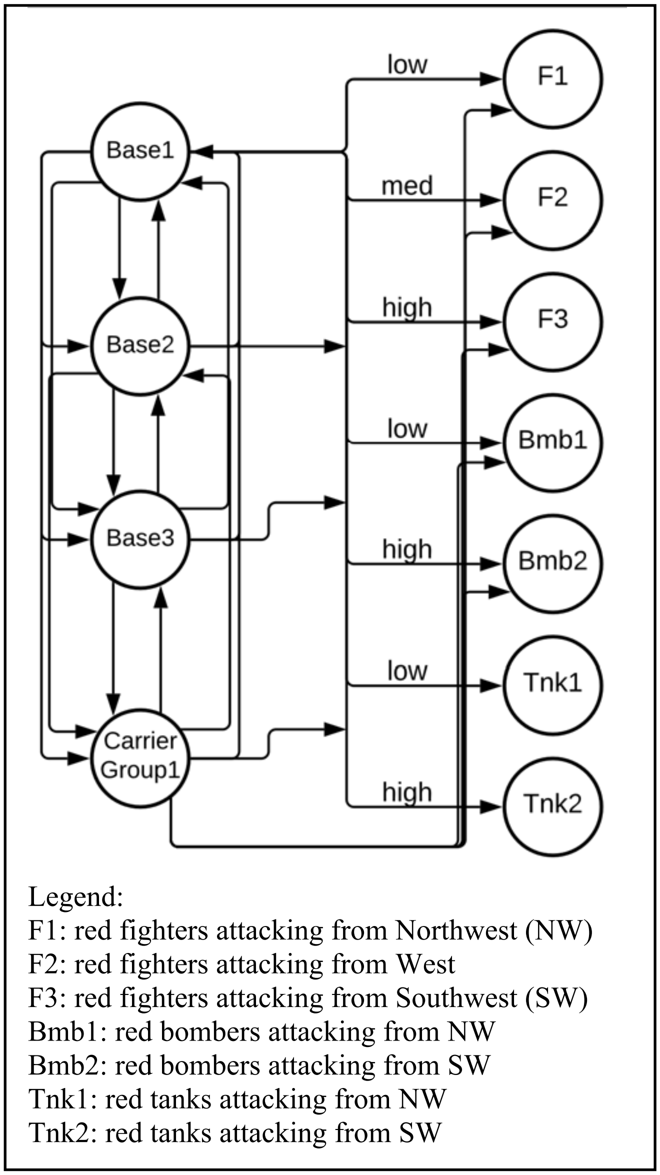
Red COA 1 is the approach taken for the AFSIM simulation. For the blue response, a generic COA that does not use WCCAAM step 8 establishes a baseline response. In this generic blue COA, all three blue bases have defending units, and cargo planes take direct paths between supply and demand bases. After simulating the scenario with the generic blue COA in AFSIM, the outcome read: *Lost 1 Base, Lost 1 Cargo Plane, 1 Red Fighter Survived, 4/7 Blue Fighters Survived, 2/5 TOs Met, and 0/2 SOs Met*.

After following WCCAAM steps 1-7, figure 5 shows the resulting weighted directed graph form of the wargame scenario. Figure 5 only displays the nodes, edges, and edge costs from Base 1 to each red threat for readability. Figure 5 does not display commodities, supplies, demands, and resulting flow amounts. WCCAAM step 8 then simulates a blue COA for this scenario, and the final output is displayed in figure 4.



```
Optimal flows for Fighters:
Base1 -> RedBomber1: 2
Base1 -> RedFighter1: 2
CG1 -> RedFighter1: 3
Base2 -> CG1: 1
Base3 -> CG1: 1
CG1 -> Base1: 3
Optimal flows for Bombers:
Base1 -> RedArmor1: 2
Base2 -> Base1: 2
Optimal flows for Cargo:
Base1 -> Base2: 3
Base2 -> Base3: 2
Tactical Objectives:
TO 1 Achieved: Defend Base 1
TO 1 risk:  4.0
TO 2 Achieved: Defend Base 2
TO 2 risk:  19.0
TO 3 Not Attacked: Defend Base 3
TO 3 risk:  0.0
TO 4 Achieved: Red Fighters
TO 4 risk:  10.0
TO 5 Achieved: Deliver Cargo
TO 5 risk:  5.0
Strategic Objectives:
SO 1 Achieved: Defend Bases
SO 1 risk:  23.0
SO 2 Achieved: Air Superiority
SO 2 risk:  15.0
```

Figure 4. WCCAAM Output



Legend:
F1: red fighters attacking from Northwest (NW)
F2: red fighters attacking from West
F3: red fighters attacking from Southwest (SW)
Bmb1: red bombers attacking from NW
Bmb2: red bombers attacking from SW
Tnk1: red tanks attacking from NW
Tnk2: red tanks attacking from SW

Figure 5. Wargame Weighted Directed Graph

WCCAAM output in figure 4 reads like a unique COA that assigns blue units as commodities to counter red threats. For the first blue unit type, blue fighters, WCCAAM pre-positions four at Base 1 and the remaining three at Carrier Group 1. At turn initiation, these fighters neutralize the red threats of fighters (RedFighter1) and bombers (RedBomber1) attacking from the north. For the second blue unit type, blue bombers, WCCAAM pre-positions two from Base 2 to Base 1 and orders them to attack the northern red tank threat (RedArmor1). For the third blue unit type, the cargo planes, no pre-positioning can take place. At turn initiation, the WCCAAM COA sends all three cargo planes to Base 2. Then the two cargo planes needed at Base 3 continue to their destination. Finally, WCCAAM lists all mission objectives and their risk totals. AFSIM simulates the wargame scenario using the WCCAAM COA. The results read: *Lost 0 Bases, Lost 0 Cargo Planes, No Red Fighters Survived, 3/7 Blue Fighters Survived, 5/5 TOs met, and 2/2 SOs Met*.

Table 4. AFSIM Results of Generic COA vs. WCCAAM COA

Generic COA Result:	**WCCAAM COA Result:**
1/3 Blue Bases Lost	0/3 Bases Lost
1/3 Blue Cargo Planes Lost	0/3 Blue Cargo Planes Lost
4/5 Red Fighters Destroyed	5/5 Red Fighters Destroyed
4/7 Blue Fighters Survived	3/7 Blue Fighters Survived
2/5 TOs Met	5/5 TOs Met
0/2 SOs Met	2/2 SOs Met

As Table 4 displays, there is a clear upgrade in performance between the generic COA and the WCCAAM COA. The WCCAAM COA loses one less blue base and one less cargo plane, destroys one additional red fighter, and meets five additional objectives. The only negative result is the loss of one additional blue fighter. This result shows evidence that WCCAAM correctly models a wargame and produces a viable COA.

4.3 Statistical Tests

Step two of the verification and validation process performs fraction factorial DOE statistical tests. For these tests, WCCAAM again models the Gulf War scenario. However, the unit numbers increase for this test to give results closer to the original Wargaming 101 scenario, increasing the statistical relevance. The changes add infantry and tanks to the blue commodities and infantry and Scud missile launchers to the red commodities. The last change removes cargo planes and bombers from the scenario.

The DOE test matrix's eleven factors denote the number of each type of blue unit assigned to each base and the red COA. Each factor's levels vary with the distribution of 450 blue infantry units, twenty-five blue tank units, six blue fighter units, and three red COAs. The response variables denote the risk totals for each of the five TOs and two SOs.

The DOE test matrix defines 50 runs per each of the three red COAs. The fundamental DOE principle of testing each of the 36 edge points determines this number's minimum value. The additional 14 center points ensure model accuracy and data fit. The DOE matrix tests WCCAAM twice, resulting in 300 total tests (150 runs for each of the two tests).

Test 1 applies the DOE matrix to evaluate WCCAAM in a locked, no unit pre-assignment wargame scenario. Test 1 shows the correlation between initial unit placement and objective risk reduction. Figures 6 and 7 show the risk response to each of the three red COAs for Test 1.

Test 2 applies the DOE matrix to evaluate WCCAAM in an unlocked, unit pre-assignment allowed wargame scenario. Test 2 shows that WCCAAM produces the lowest possible risk COA achieved by any random unit pre-placements in DOE test one. Figures 8 and 9 show the risk response to each of the three red COAs for Test two.

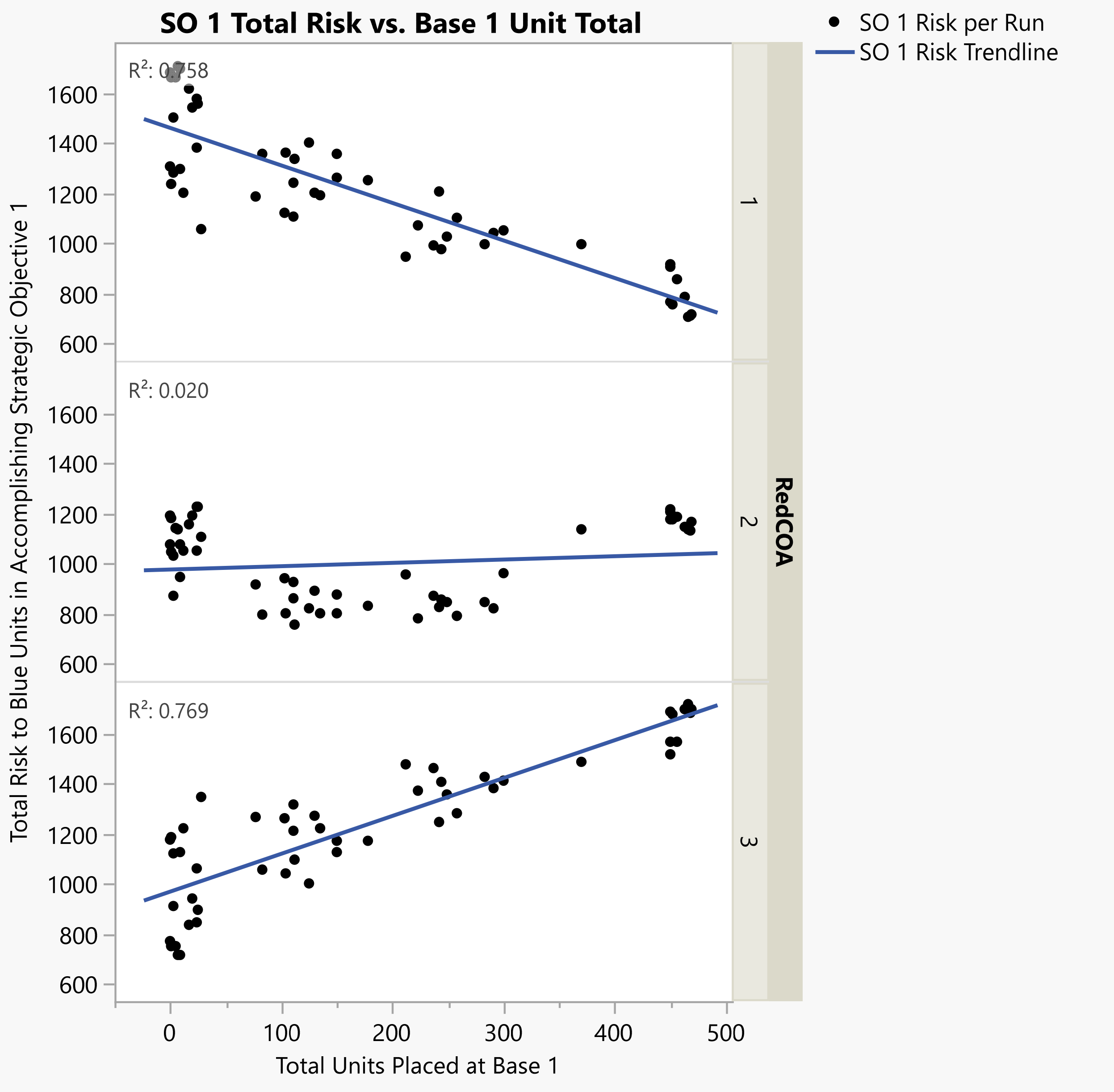


Figure 6. Blue Risk Required to Achieve SO 1 vs. Total Units Placed at Base 1

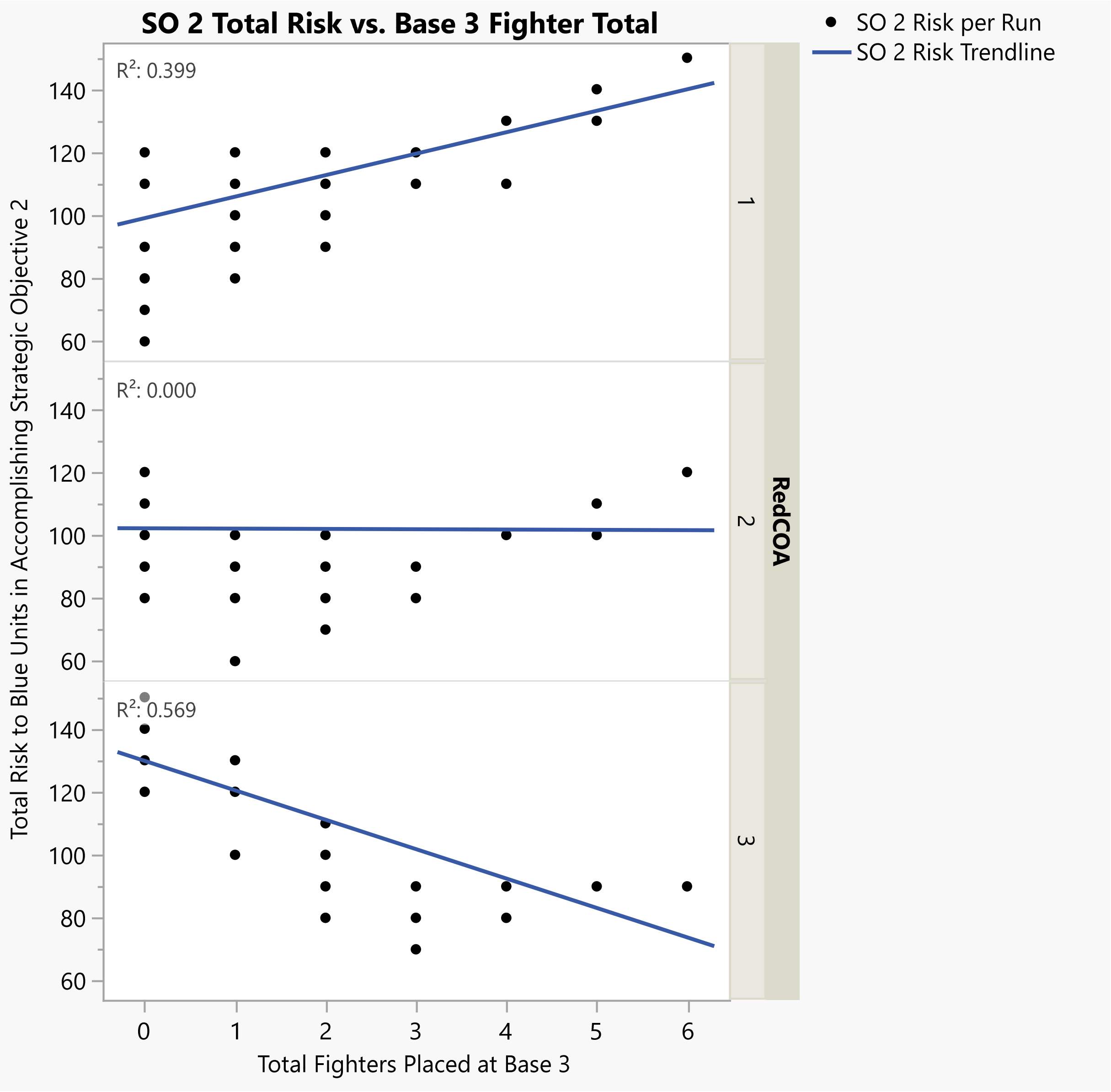


Figure 7. Blue Risk Required to Achieve SO 2 vs. Fighters Placed at Base 3

Figure 6 reveals that as the number of units placed at base one increases, the risk of SO 1 (defending blue bases) decreases when red employs COA 1 (red attacking from the north). The R^2 value, 0.758, shows a strong correlation. This strong correlation means that the variation in the factor, SO 1 risk, can be attributed to unit numbers' response.

Figure 6 also shows no correlation, R^2 of 0, for red COA2 (balanced attack from North and South), and a strong correlation, R^2 of 0.769, for red COA 3 (red attacking from the south). The positive correlation for red COA 3 indicates that a high number of units placed at base one (B1Total) raises the total risk of defending blue bases when red attacks from the south. Figure 7 shows in a similar layout that there is moderate correlation, R^2 of ~0.5, between the placement of fighters at base three, the red COA chosen, and the reduction in risk of SO2 (achieving air-superiority).

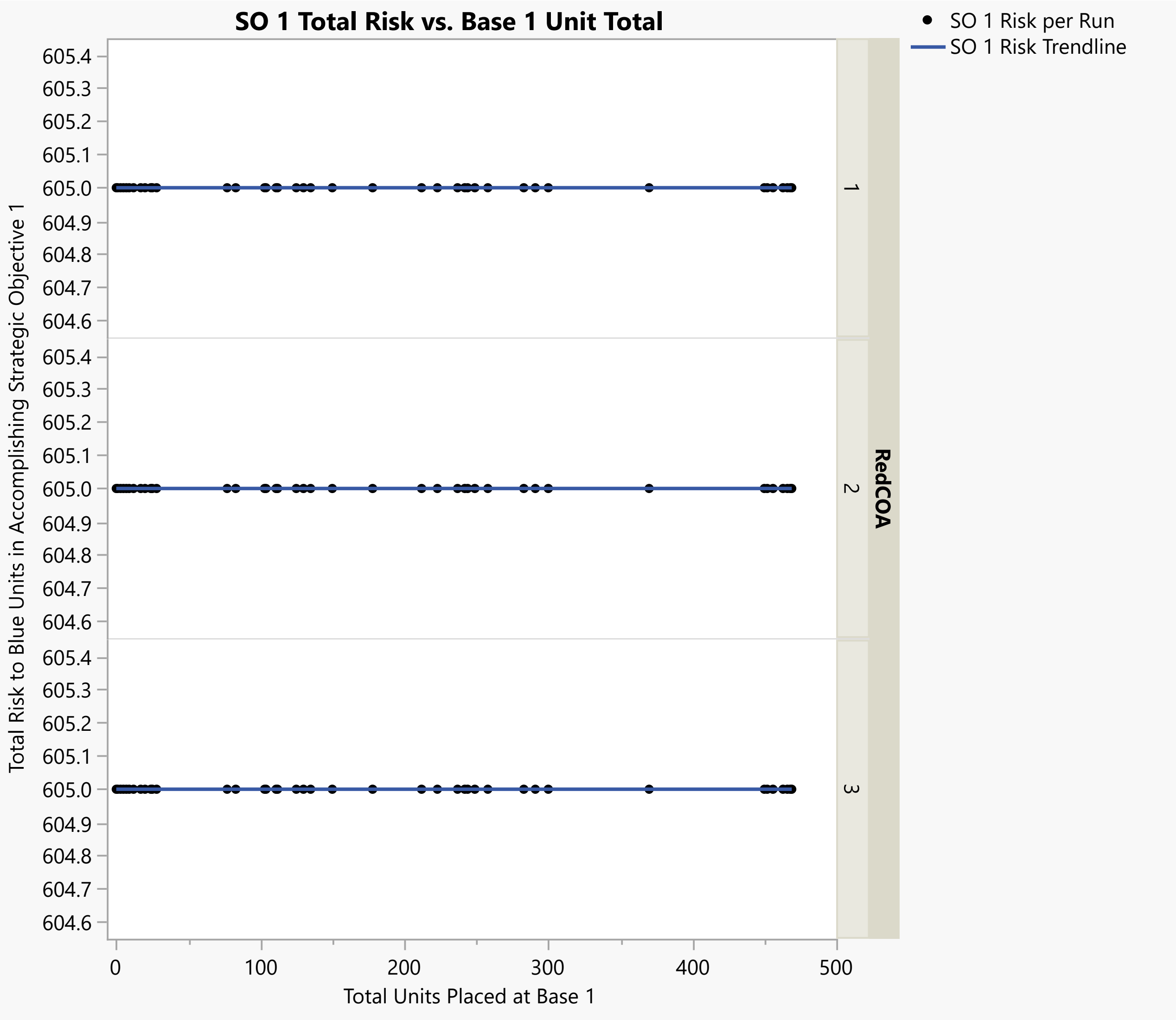


Figure 8. Blue Risk Required to Achieve SO 1 vs. Total Units Placed at Base 1

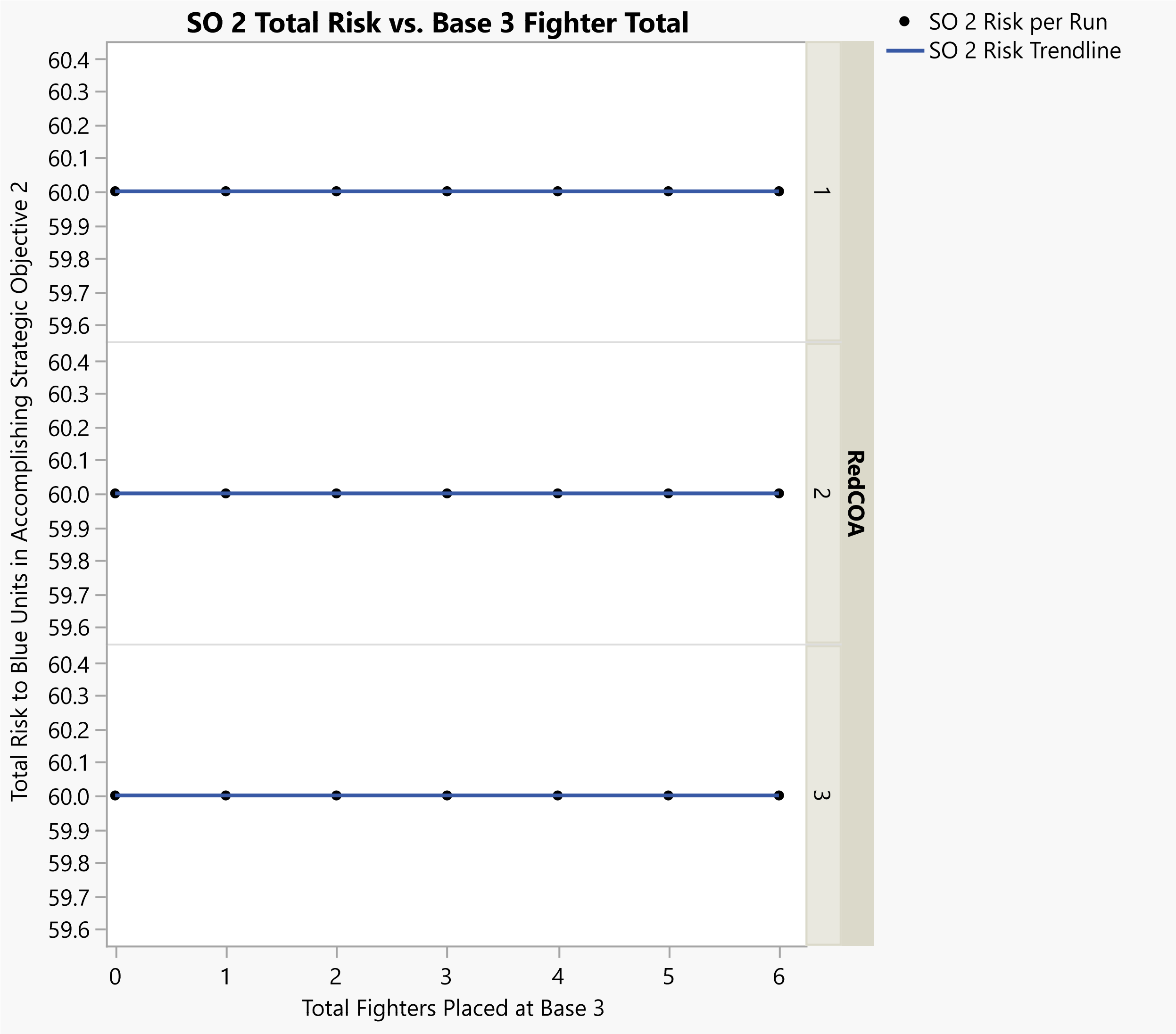


Figure 9. Blue Risk Required to Achieve SO 2 vs. Fighters Placed at Base 3

In figures 8 and 9, test 2 results show that with unit pre-placement allowed, WCCAAM achieves the lowest possible risk response for each red COAs. The lowest SO1 risk achieved in Test 1 was 605, and the lowest risk for SO2 was 60. These two risk numbers were achieved every time over the 150 runs in Test 2. This result is significant because it shows a consistent lowest SO risk level achievement for each of the test matrix's varying unit locations.

4.4 Verification and Validation Summary

The results from this section show WCCAAM effectively models, analyzes, and develops COAs. The AFSIM test shows a 71% increase in WCCAAM objective completion than a generic user-developed COA. Statistical testing reveals two things: that wargames in WCCAAM graph form model scenarios correctly and that WCCAAM generates COAs with minimal risk to blue units. The following section provides a conclusion and lists possible future works.

5 Conclusion and Future Work

Wargame commanders no longer need to choose between the Military Decision Making Process (MDMP) paper matrices or full battlefield wargame Modeling and Simulation (M&S) solutions. The Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM) provides a novel solution to the problems posed by current Course of Action (COA) development and analysis methods. The two-step WCCAAM validation and verification process demonstrates that WCCAAM produces effective and consistent COAs. The advantages of WCCAAM include a decrease in workforce requirements when compared to manual methods and a reduction of computational resource requirements when compared to full battlefield M&S solutions through automating three steps of MDMP.

There are several possibilities when it comes to future work associated with this research. One future work could introduce artificial intelligence machine learning methods to replace the mission analysis phase of MDMP to reduce further workforce requirements. The production of staff estimates could be completed by parsing the intelligence reports and eventually producing near-real-time results. Calculation of the remaining fighting strength of units by simulating combat adjudication outcomes could be another future work. These estimates could give predictions on future turn blue COAs. Final future work could link each single turn COA produced by WCCAAM into a multi-turn wargame. With these future works completed, the WCCAAM could completely replace the MDMP steps.

IV. Conclusions and Final Thoughts

4.1 Conclusions

Chapter four considers the conclusion reached from the scholarly article presented in chapter three in the context of the over-arching and subsidiary research questions presented in chapter one. The over-arching investigative question was: 'Can we improve current United States Department of Defense (DOD) Course of Action (COA) wargaming techniques through the development of a novel method that leverages technology?'

Chapter three presents a novel solution called the Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM). WCCAAM breaks the problems presented by COA wargaming and the Military Decision Making Process (MDMP) into identifiable and achievable steps. WCCAAM turns wargames into weighted directed graphs that are computational and analytical models. These models are processed by a multicommodity flow algorithm and output a COA. The Advanced Framework for Simulation, Integration, and Modeling (AFSIM) simulations and statistical tests demonstrate a 71% objective completion improvement with the WCCAAM COA versus a human-generated COA. The statistical analysis reveals that over a 300 run test matrix, WCCAAM produces the optimal, minimal risk COA.

From these results, we assess that WCCAAM demonstrably answers the research question. WCCAAM improves DOD COA wargaming techniques by filling the gap between paper and high-fidelity simulation methods for COA development and analysis. WCCAAM minimizes operator overhead and reduces computational resources usually required when completing the steps outlined in the MDMP.

4.2 Final Thoughts and Future Works

4.2 Final Thoughts and Future Works

Potential future demonstrations of WCCAAM's application are currently under development. These future demonstrations include wargame scenario simulations of the Battle of Midway, a Korean Peninsula campaign, a stress testing scenario, and a time-study of WCCAAM's effectivity.

The Battle of Midway is commonly known as one of the most significant victories of the US Navy, proving aircraft carriers' value [35]. In this battle, the allied commander used aircraft carriers to carefully distribute planes and resources in such a way to achieve victory. In the WCCAAM weighted directed graph model, the nodes represent the aircraft carriers, the commodities would represent the different types of fighters available to the allied commander, and the commodity demands represent the force amounts needed to counter Japan. The effectiveness of WCCAAM in simulating the distribution of many assets to neutralize enemy threats makes this an ideal scenario.

The Korean peninsula is currently an Area of Responsibility (AOR) of great interest to the US DOD and the world [36]. In this wargame scenario, the simulation of the defense against long-range missile attacks, conventional warfare, and the complex logistical plans would test the abilities of WCCAAM over a broad spectrum of domains. A simulation through WCCAAM would help the US DOD gain insights on needed resource distribution and perform COA analysis should military action ever become needed in this AOR.

A stress test scenario could demonstrate WCCAAM's limitations. A stress test scenario would show the maximum limits of WCCAAM application by incrementally increasing the number of nodes and commodities. As the number of nodal and commodity interactions increase, WCCAAM output time will increase until the results become impracticable. Identifying the point at which time delays become exponential and output COAs become untrustworthy is vital in understanding WCCAAM's potential applications.

A final test of WCCAAM could include a time-study. Future researchers should incorporate a time-study to prove face-validity of WCCAAM effectiveness versus current COA wargaming methods. This study would monitor the time required for a sample USAF population to create COAs from a wargame using current DOD methods and WCCAAM. The goal of this study is to show that the time commitment of WCCAAM is smaller than that of the toolset currently available to the US DOD.

There are also several possible future works associated with WCCAAM. These potential future associated projects include introducing artificial intelligence machine learning (AIML) methods, adjudication calculations of unit remaining fighting strengths, future wargame turn COA projections, and incorporation of WCCAAM into the USAF environment. After completion of these future works, WCCAAM could replace all steps of the MDMP.

One of the most time-consuming parts of MDMP is reading wargame intelligence reports and their translation into staff estimates. In MDMP, this represents the mission analysis phase. The output of this phase is the starting point of WCCAAM. The introduction of AIML could replace the mission analysis phase of MDMP, reducing workforce requirements. Using AIML, staff estimates' production could be completed through automated parsing of intelligence reports and eventually produce real-time results.

A common feature of most wargame and battlefield COA analysis tools is the calculation of unit remaining fighting strength. The unit fighting strengths are calculated by performing a combat calculation and developing estimated attrition rates. In WCCAAM, the unit commodity counts could decrease to follow these attrition rates to show a more accurate representation of unit abilities after a complete battle adjudication.

If a team added a remaining unit strength calculator to WCCAAM, these estimates could predict future turn blue COAs. These predicted future blue COAs could connect the current single-turn COAs produced by WCCAAM into multi-turn wargame COA projections. Since many wargames are reliant upon multiple turns, this addition could become invaluable for continued WCCAAM application.

A final future work associated with WCCAAM is the effort to transport this open research project to the working USAF environment. The work involved in turning WCCAAM into a usable USAF tool involves transforming the current method of manually building the weighted direct graph in code to a simpler interface and its incorporation into a currently used service tool. Since WCCAAM already takes input from spreadsheets, the simplest way to remove the operator from coding is to build up the graph from columns of the wargame's commodities, nodes, edges, etc. Another step in getting WCCAAM available for USAF use is its incorporation into a currently used tool such as the Integrated Sustainment Wargaming Analysis Toolkit (ISWAT). ISWAT is currently a visualization tool for logistical wargames, but AFMC has shown interest in absorbing some of WCCAAM's COA development and analysis capabilities. Working with ISWAT's development team to create a new capability may be the best way forward to ensure these capabilities get into the hands of airmen.

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14. ABSTRACT

This research presents the Wargaming Commodity Course of Action Automated Analysis Method (WCCAAM), a novel approach to assist wargame commanders in developing and analyzing courses of action (COAs) through semi-automation of the Military Decision Making Process (MDMP). MDMP is a seven-step iterative method that commanders and mission partners follow to build an operational course of action to achieve strategic objectives. MDMP requires time, resources, and coordination – all competing items the commander weighs to make the optimal decision. WCCAAM receives the MDMP's Mission Analysis phase as input, converts the wargame into a directed graph, processes a multi-commodity flow algorithm on the nodes and edges, where the commodities represent units, and the nodes represent blue bases and red threats, and then programmatically processes the MDMP steps to output the recommended COA. To demonstrate its use, a military scenario developed in the Advanced Framework for Simulation, Integration, and Modeling (AFSIM) processes the various factors through WCCAAM and produces an optimal, minimal risk COA.

15. SUBJECT TERMS
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