NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

SYSTEMS ENGINEERING CAPSTONE REPORT

DISTRIBUTED MARITIME OPERATIONS AND UNMANNED SYSTEMS TACTICAL EMPLOYMENT

by

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June 2018

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2018	**3. REPORT TYPE AND DATES COVERED** Systems Engineering Capstone Report

4. TITLE AND SUBTITLE
DISTRIBUTED MARITIME OPERATIONS AND UNMANNED SYSTEMS TACTICAL EMPLOYMENT

5. FUNDING NUMBERS

6. AUTHOR(S) Christopher H. Popa, Sydney P. Stone, Ee Hong Aw, Choon Pei Jeremy Teo, Licun Edwin Cai, Wai Hoe Chong, Rachel Cline, Jiesheng Jackson Hong, Chong Khai Roger Koh, Wee Leong Lee, Jun Jie Lim, Xinhong Lin, Shay Paz Liraz, Kai Boon Eugene Mok, Alex W. Ryan, Boon Hong Aaron Teow, Andrew R. Whitmer, Peter J. Winstead, and Yong Jie Chia

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
OPNAV N9I

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT (maximum 200 words)

The concept of Distributed Maritime Operations intends to enable a force that is capable of winning a fleet-on-fleet engagement through the integration of manned and unmanned systems, execution of deceptive tactics, and emboldening of units to conduct offensive strikes. This report contributes to the concept of DMO in the 2030-2035 timeframe through the development of an operational simulation that examines the ability for various compositions of multi-domain fleet assets to perform tactical operations in a naval combat environment. This project studies the impact of the friendly force employment of deception and tactics against an enemy force, and the resulting impact on the adversary's ability to progress through the various stages of a kill chain. Through the development and analysis of a discrete event simulation, this research investigates the ability for naval forces in the air, surface, and electromagnetic warfare domains to contribute to DMO through the performance of tactical offensive operations and employment of deceptive tactics. The analysis resulted in two major findings. In terms of force composition, an increased number of missile carrying assets had the largest impact on operational effectiveness and survivability. Tactically, the utilization of electronic jamming, coupled with the utilization of unmanned deceptive swarms, provided a significant improvement in the survivability of friendly force assets as well as the attrition of enemy forces.

14. SUBJECT TERMS
Distributed Maritime Operations, DMO, Tactical Employment of Unmanned Systems

15. NUMBER OF PAGES 199

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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Submitted in partial fulfillment of the
requirements for the degrees of

MASTER OF SCIENCE IN COMPUTER SCIENCE

and

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 2018

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ABSTRACT

The concept of Distributed Maritime Operations intends to enable a force that is capable of winning a fleet-on-fleet engagement through the integration of manned and unmanned systems, execution of deceptive tactics, and emboldening of units to conduct offensive strikes. This report contributes to the concept of DMO in the 2030–2035 timeframe through the development of an operational simulation that examines the ability for various compositions of multi-domain fleet assets to perform tactical operations in a naval combat environment. This project studies the impact of the friendly force employment of deception and tactics against an enemy force, and the resulting impact on the adversary's ability to progress through the various stages of a kill chain. Through the development and analysis of a discrete event simulation, this research investigates the ability for naval forces in the air, surface, and electromagnetic warfare domains to contribute to DMO through the performance of tactical offensive operations and employment of deceptive tactics. The analysis resulted in two major findings. In terms of force composition, an increased number of missile carrying assets had the largest impact on operational effectiveness and survivability. Tactically, the utilization of electronic jamming, coupled with the utilization of unmanned deceptive swarms, provided a significant improvement in the survivability of friendly force assets as well as the attrition of enemy forces.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACE	Aviation Combat Element
AESA	Active Electronically Scanned Array
AIS	Automatic Identification System
AMRAAM	Advanced Medium Range Air to Air Missile
AOR	Area of Responsibility
AOU	Area of Uncertainty
ARG	Amphibious Readiness Group
ARM	Anti-Radiation Missile
ASBM	Anti-Ship Ballistic Missile
ASCM	Anti-Ship Cruise Missile
BIC	Bayesian Information Criterion
CG	Guided Missile Cruiser
CONUS	Continental United States
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research
CSG	Carrier Strike Group
CVN	Nuclear Powered Aircraft Carrier
CVW	Carrier Air Wing
DDG	Guided Missile Destroyer
DES	Discrete Event Simulation
DL	Distributed Lethality
DMO	Distributed Maritime Operations
DoD	Department of Defense
DOE	Design of Experiments
DRFM	Digital Radio Frequency Memory
DTE	Detect to Engage
EMW	Electromagnetic Warfare
EPF	Expeditionary Fast Transport

EMCON	Emissions Control
ESG	Expeditionary Strike Group
ESM	Electronic Support Measures
ESSM	Evolved Sea Sparrow Missile
EW	Electronic Warfare
F2T2EA	Find, Fix, Track, Target, Engage, Assess
FTE	Find, Target, Engage
GPS	Global Positioning System
HARM	High Speed Anti-Radiation Missile
ICOM	Inputs, Control, Outputs, Mechanisms
IR	Infrared
ISR	Intelligence, Surveillance, Reconnaissance
JCA	Joint Campaign Analysis
JCS	Joint Chiefs of Staff
LCS	Littoral Combat Ship
LHA/LHD	Amphibious Assault Ship
LPD	Landing Platform Dock
LRASM	Long Range Anti-Ship Missile
MANPAD	Man Portable Air Defense
MDUSV	Medium Displacement Unmanned Surface Vessel
MOE	Measure of Effectiveness
MOP	Measure of Performance
MST	Maritime Strike Tomahawk
NMI	Nautical Miles
NOB	Nearly Orthogonal Balanced
NPS	Naval Postgraduate School
NWDC	Naval Warfare Development Command
OOB	Order of Battle
OPNAV	Office of the Chief of Naval Operations
PACOM	Pacific Command

PLAAF	People's Liberation Army Air Force
PLAN	People's Liberation Army Navy
PRC	People's Republic of China
SCS	South China Sea
SAG	Surface Action Group
SAM	Surface to Air Missile
SEA	Systems Engineering Analysis
SM	Standard Missile
TERN	Tactical Exploited Reconnaissance Node
UAV	Unmanned Aerial Vehicle
VLRAAM	Very Long Range Air to Air Missile

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EXECUTIVE SUMMARY

In a dynamic and uncertain global environment with regular challenges between major military forces, the expectation of a sea domain predominantly controlled by the maritime forces of the United States cannot be assumed. The contested environments in the maritime sphere of influence demand continued innovation with respect to current and projected future weapons systems and network capabilities. The challenges in the sea, air, subsurface, electromagnetic and cyber domains serve as the impetus for the United States to continue developing innovative employment concepts and doctrine in an effort to remain at the forefront as the world's prominent naval power. The Distributed Maritime Operations (DMO) concept is proposed to enhance the U.S. naval force offensive capabilities by creating a distributed network of collaborative, integrated platforms across all operational domains.

The objective of the Systems Engineering Analysis Cohort 27 Capstone group, as provided by the OPNAV project sponsor, is to develop a system of systems, comprised of both manned and unmanned systems, for employment within the Distributed Maritime Operations construct in the 2030-2035 timeframe. The team will analyze and evaluate the ability for various compositions of dissimilar platforms to perform tactical offensive operations in contested environments. The team's effort will not be focused towards the design and acquisition of new platforms, but will instead focus on the execution of deceptive tactics, integration of manned and unmanned assets, and the application of tactical offensive capabilities against a capable adversary force in an effort to develop a more lethal and survivable naval force.

A. DISTRIBUTED MARITIME OPERATIONS

In order for the team to develop a system of systems that contributes to the ability to perform Distributed Maritime Operations, the construct for DMO requires bounding and defining in further detail. For the scope of this Capstone project, DMO is considered as an employment concept in which multi-domain platforms and technologies are integrated and leveraged with the objective of increasing overall lethality, while also decreasing susceptibility to attack from an adversary. A system of systems that performs DMO is capable of projecting offensive firepower and executing collective defense over a large geographical area from a unified set of naval forces across all operating domains. The primary principle that separates DMO as an innovative concept from current naval force operations is the empowering of operators and commanders to exploit available technologies and take offensive action in an engagement when capable, to strike first in an effort to win in combat against a capable adversary.

The DMO concept considers not only offensive strikes as the primary tactic for winning in battle, but also identifies the ability to deceive and confuse the enemy as a critical task to achieve success in a contested environment. For this study, the employment of DMO is decomposed into three primary functions; counter-measures, counter-targeting, and counter-engagements. Each serves a different purpose with respect to an engagement between opposing forces, and results in different intended outcomes. Counter-measures are defensive in nature, as the aim is to divert enemy resources once a weapons engagement from an enemy threat has occurred. The objective in employing counter-measures is to distract or impair the enemy systems in an effort to protect against an enemy action that has already occurred. Conversely, counter-targeting assumes a more offensive stance within the confines of an engagement between adversary forces. Counter-targeting is considered as actions that are taken pre-emptively by friendly forces in an effort to prevent an enemy weapon's launch from being directed towards an actual blue force asset. This counter-targeting objective can be achieved through the employment of deceptive tactics and operational maneuvers that divert or prevent an enemy from targeting an independent unit or group of friendly forces. The study's final element of DMO is counter-engaging, which describes actions taken by friendly forces to neutralize a threat to preclude any potential weapons launch from an enemy platform. Each of the aforementioned principles of DMO are considered in the project as a requisite function in order to contribute to the ability to conduct distributed operations in a challenged maritime environment.

As described with the counter-engagements, counter-targeting, and counter-measure components of the DMO concept, the primary focus for the Capstone project is the employment of various deception methods and tactics in an effort to influence the success of friendly forces in combat. The SEA-27 team categorizes these deceptive tactics into four major groupings; swarms of unmanned assets, mechanical and physical counter-measures, electronic jamming, and the limiting of electromagnetic radiation, or emissions control (EMCON). Each of these tactics are examined to determine the operational impact of these counter-targeting actions and defensive counter-measures on the ability for friendly forces to remain operational and combat capable throughout the duration of an engagement.

B. DMO MODEL AND SIMULATION

In order to analyze and evaluate the utility of various force architectures comprised of multi-domain platforms, the team constructed an event-based model using a discrete event simulation program called ExtendSim, to represent a fleet-on-fleet engagement against a near peer adversary. The ExtendSim engagement simulation developed by the SEA-27 team considers both friendly and enemy orders of battle in terms of the major platforms, sensors, and weapons systems projected to be operational in the prescribed 2030-2035 timeframe. Additionally, the employment of the previously described tactics are modeled in an effort to gain insights into the potential value of employing the deceptive measures with respect to various survivability and lethality performance metrics.

In order to conduct a detailed analysis of the effectiveness of friendly counter-measure, counter-targeting, and counter-engagement tactics, the Capstone team built a simulation model focused on execution of an enemy kill chain. The model represents an enemy threat in the surface, air, and missile domains as it proceeds through the various stages of a kill chain, with an objective of prosecuting an assigned blue force platform. The kill chain sequence incorporates the major functions that an enemy threat must perform including finding, targeting, and ultimately engaging an assigned friendly force asset, as depicted in Figure 1. The relative performance parameters of both the enemy threat and the friendly force asset are considered when determining the outcome of a particular engagement, to include the potential employment of various tactics and counter-measures at the various stages of the kill chain for friendly forces. This implementation of the deception and diversion methods at the various stages of an enemy threat progressing through the kill chain allows the friendly force to degrade or disrupt the enemy's ability to conduct the finding, targeting, and engagement functions. The application of various logic statements and settings within the simulation facilitate the ability to examine the impact of a DMO-centric, forward-leaning friendly force on the overall measures of success.

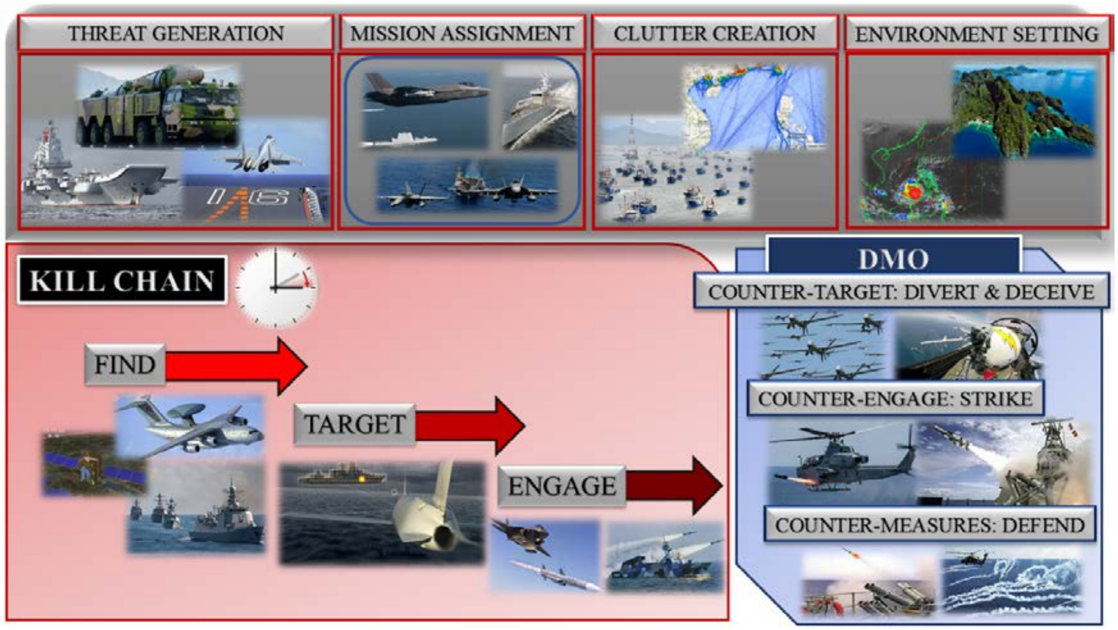

Figure 1. Functionality of the DMO Event-Based Model

The ExtendSim model data outputs and the application of multiple regression analyses allows for the evaluation of both a baseline fixed force and variable force structure. The baseline force structure consists of a fixed set of friendly force ships and aircraft arranged into traditional action groups including a Carrier Strike Group, Expeditionary Strike Group, Surface Action Group, and various independent deployable units. The independent variables examined for the fixed force structure include the various tactics such as the employment of jamming, quantities of available physical counter-measures, EMCON assignments, and deployment of swarm assets. The variable DMO force structure is comprised of any potential combination of surface, air, and unmanned assets and the associated employable tactics and counter-measures. The input variables considered for analysis of the variable force structure include both the tactics previously described, as well as the variable quantities of platforms in the surface and air domains.

From the analysis of these 2 major categories of force structures, the team determines the statistically significant factors or tactics and platforms that contribute to friendly force mission success, as well as the operational impact of employing the various groupings of platforms and the associated tactics and deceptive measures.

C. CONCLUSIONS

From the analysis of the fixed and variable force structures, several factors are deemed statistically and operationally significant with respect to the ability for various force compositions to perform DMO. With respect to friendly force survivability, the employment of jamming and deceptive swarms demonstrate a larger impact on operational effectiveness than any of the mechanical or physical counter-measures or any of the EMCON techniques analyzed. The application of jamming against enemy threats serves to disrupt the finding and targeting phases of the kill chain, resulting in a delay to find and/or engage the assigned blue force asset. The time delay for the enemy threat in the targeting phase results in an increased number of opportunities for the friendly forces to conduct counter-engagements to neutralize or destroy the threat prior to a missile or weapons engagement. Additionally, the presence of a swarm creates additional contacts and clutter that require the enemy to dedicate additional time and resources in order to identify and classify each of the swarm vehicles as hostile or friendly. Again, this delay imposed upon the threat is advantageous to friendly forces in terms of conducting offensive strikes and employing layered defense against an inbound threat.

The primary missile carrying surface platforms, specifically the cruisers and destroyers, have the greatest statistical and operational impact when empowered to take an offensive stance in an engagement scenario. The success of friendly forces with respect to survivability and lethality is influenced by the significant contributions of the missile carriers in terms of both offensive and defensive weapons, as well as the capability to contribute to a common operating and fire control network. The missile carriers provide long-range offensive strike capability and serve as the primary foundation for the collective defense of the force across a large geographical area. Additionally, with respect to the integration of unmanned assets, the missile carriers can serve as a parent platform for the deployment and control of unmanned assets.

The SEA-27 team provides these recommendations based on the analysis of the statistical and operational significance of the factors that contribute to the ability to perform DMO against a capable adversary. With respect to jamming, it is critical to not only examine the methods of employing the application of electromagnetic radiation against an adversary, but to also consider the ability to defend against a similar attack. With the heavy reliance on networks to communicate and share a common operational picture, the susceptibility to jamming must be mitigated to prevent being incapacitated due to the inability to freely use the electromagnetic spectrum. Unmanned assets and technologies, while modeled primarily as clutter in the engagement simulation, can serve as a significant factor for the combat capabilities of friendly forces in terms of ISR capability as well as increased lethality. The presence of armed unmanned assets changes the dynamics of a battlespace, with the advantage given to the operators that are able to effectively employ the multi-domain unmanned vehicles. Lastly, if the unmanned assets are able to successfully emulate another vessel in the order of battle that is frequently targeted by enemy threats, the aircraft carrier for example, all other friendly force platforms reap the benefits of a reduction in being targeted and engaged by enemy threats.

ACKNOWLEDGMENTS

The SEA-27 team sincerely thanks our advisors, Dr. Paul Beery and Dr. Michael Atkinson, for their guidance and direction throughout the duration of the project. To say that we couldn't have completed the project without the dedication of their time and support is truly an understatement. We also thank Captain Jeff Kline for his mentorship and sage advice throughout our time at NPS: thank you for providing us the opportunity to shine on camera and promote the Systems Engineering Analysis Curriculum in the SEA promotional video!

The SEA 27 team also credits the faculty and professors of the Systems Engineering and Operations Research departments with providing the requisite knowledge and instruction needed to complete the capstone project. The ability for the lecturers to present the necessary material from both the academic fields of study as well as from an operational standpoint proved to be vital in our research and analysis. Thank you all for always being available and keeping your doors open for questions and guidance.

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I. INTRODUCTION

The United States Navy has conducted integrated maritime operations since its days of inception nearly 250 years ago, thus the idea of ships and their associated aircraft operating as unified groups is hardly a new concept. Force packages of surface combatants and aircraft organized into Carrier Strike Groups, Amphibious Readiness Groups, and Surface Action Groups have traditionally operated collectively to project power, maintain freedom of the seas, and further U.S. interests in military and foreign policy. Tactics and doctrine have been established and practiced over time with respect to the construct of distributed forces that function as a cohesive fighting force, but continuous improvement in emerging adversary technologies and platforms challenge this ability to conduct operations in littoral environments.

A. BACKGROUND

As described in the National Defense Strategy, the U.S. has become accustomed to "dominant superiority in every operating domain. We could generally deploy our forces when we wanted, assemble them where we wanted, and operate how we wanted. Today, every domain is contested-air, land, sea, space, and cyberspace" (Mattis 2018, 3). In the current strategic environment, the assumption that the attainment of sea control is easily achievable by the world's most powerful Navy is now regularly questioned by capable adversaries. Sea control in this sense is defined as "winning fleet battles in blue water against a first class-opponent" (Hughes 1999, 10). The U.S. has not engaged in major naval fleet combat since World War II; therefore, it is difficult to discern if the current and future U.S. Navy is capable of achieving this description of control of the sea in any specific region.

A report produced by the Center for Strategic and Budgetary Studies titled *Maritime Competition in a Mature Precision-Strike Regime* supports this idea, which concludes that since the last major naval engagement for the U.S. "advances in maritime capabilities have been dramatic. Yet the data on the relative value of these new capabilities are meager, culled from minor conflicts that may stimulate as many false conclusions as useful insights" (Krepinevich 2014, 3). Without tangible data from modern engagements between present-day and projected future naval powers, the research and modeling of these capabilities becomes exceedingly valuable in forecasting the potential outcomes of battles against increasingly capable opponents.

With respect to gaining sea control, challenges from competitors are prevalent and widespread, especially when attempting to access specific global regions via the maritime domain. U.S. forces conducting operations in open seas are regularly tested by major regional powers such as the Chinese forces in the Western Pacific, Iranian presence in the Middle East region, and Russian forces in the Baltic and Mediterranean. Additionally, the proliferation of progressive combat technologies exacerbates the threat faced by U.S. operational forces. Potential state and non-state adversaries now have access to increasingly precise and lethal munitions, and modern surveillance technology enables enemy assets to locate and engage targets more proficiently and effectively.

Maritime operations, particularly in the littorals, will continue to be contested and dangerous, compelling U.S. forces to operate in an increasingly dispersed and forward leaning manner. Distributed Maritime Operations (DMO) aims to address these concerns of conducting operations that support national and strategic objectives in contested environments. U.S. forces employing DMO intend to project greater offensive combat capability from a unified, yet independent system of naval platforms that provide robust capabilities across all maritime domains: sea, air, land, subsurface, and cyber in order to gain control of the sea, especially when faced with the challenge of opposition by a near-peer adversary.

B. TASKING STATEMENT

The Chair of the Systems Engineering Analysis (SEA) curriculum details the project assignment for the SEA Cohort 27 Capstone via a tasking letter. The memorandum describing the tasking of the integrated project was provided to the SEA-27 team under the guidance of the Office of the Chief of Naval Operations Director of Warfare Integration, OPNAV N9I.

> Design a cost effective and resilient unmanned and manned system of systems capable of contributing to Distributed Maritime Operations concept in the 2030-2035 timeframe. Focus your design's contributions on counter-targeting, decoys, deception, electromagnetic warfare and the manned-unmanned tactics associated with them to achieve desired effects in supporting tactical offensive operations in the air, surface, undersea and cyber domains. Consider employment requirements, power requirements, operating areas, bandwidth and connectivity, interoperability, sensor data processing, transfer and accessibility, logistics, forward arming and refueling (FARPS) basing support in forward areas from CONUS bases. Where possible, include joint contributions in the systems of systems. Generate system requirements for platforms, sensors, active decoy packages, manning, communication and network connectivity, and their operational employment concepts. Address the costs and effectiveness of your alternatives in mission areas like at-sea strike and electromagnetic warfare. (Kline 2017, Tab A)

C. PROBLEM STATEMENT

Further direction on research topic areas is provided via the supplementary problem statement, derived from the SEA-26 and SEA-27 teams' involvement in the 2017 Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Warfare Innovation Continuum Workshop. Members of the SEA teams contributed to the DMO concept research with respect to combined, joint, and coalition warfare at-sea by leveraging operational military experience and current scientific advancements from civilian engineers across the defense and technology industries. The CRUSER Warfare Innovation Continuum Workshop was motivated by the following problem statement:

> Emerging technologies in unmanned systems; autonomy; missile systems; undersea systems; long-range, netted and multi-domain sensors; and networks create a new environment for operations in the littorals, on and over the sea. This changing technology environment both challenges traditional fleet operations and provides opportunities for innovative tactics, techniques, and procedures to achieve maritime domain objectives in sea control, power projection and distributed maritime operations. The Warfare Innovation Continuum (WIC) is a series of independent, but coordinated cross-campus educational and research activities to provide insight into the opportunities for warfighting in the complex and electromagnetically contested environment at sea and littorals. Unmanned systems technologies; joint, combined and coalition forces contributions; and multi-domain C2 provide opportunities to support integrated fires and tactically offensive operations, and further develop the concept of distributed maritime

> operations. The larger research question is: "How might emerging technologies; concepts; joint, combined and coalition forces contribute to distributed maritime and cross-domain operations?" (Kline 2017, Tab B)

D. OBJECTIVE

This report details the efforts to apply DMO with the goal of improving the ability of naval forces to function in an integrated manner when conducting operations in a challenged, littoral environment. The Capstone team focuses efforts not on designing new platforms or force compositions, but instead, on the employment of manned and unmanned systems to increase combat power, specifically the use of deceptive strategies and tactics for improved counter-targeting and tactical offensive operations. A significant area of focus for current and future naval forces is the ability to promptly strike effectively, which is critical to overall mission success. The ability to counter-target, or take action prior to an adversary missile launch to prevent friendly forces from being targeted or engaged, is also required for mission success, but is largely an evolving practice with current, advanced technologies and demands further study. The SEA-27 group leverages academic backgrounds and operational experience to examine the technologies and resources that will improve the Navy's ability to conduct integrated engagements and counter-targeting through the employment of tactics and counter-measures. The objective of the SEA-27 team is to perform an evaluation and provide actionable recommendations regarding the ability to perform DMO in a contested maritime setting, in support of the development of a more lethal and survivable naval force.

E. OUTLINE

This report details the SEA-27 Capstone team's research, modeling, and evaluation of various systems and their respective contributions to the performance of DMO. The organization of the report follows the sequence of events and activities the group performed to define the tasking, identify the problem and solution spaces, develop a representative model, and analyze the alternative force compositions in terms of the ability to perform the fundamental principles of DMO.

The first major section of the report consists of Chapters II through V, and details the foundational theories related to DMO. Chapter II defines DMO and the supporting concepts and terminology, as well as the structure for the problem in terms of boundaries and areas of focus. Chapter III details the context for the project with a description of the operational scenario, environment, and order of battle for the friendly and enemy forces engaged in a fleet-on-fleet battle. Chapter IV specifies the kill chain sequence that provides the foundation for an operational simulation, as well as the tactics and counter-measures considered for inclusion in the DMO construct. Chapter V details the measures and metrics applied to the model to evaluate of the alternative force compositions and their respective impact to DMO.

The latter half of the report describes the development and implementation of an operational simulation to facilitate a structured analysis of varying combinations of friendly force assets and tactics. Chapter VI describes the functionality and limitations of the simulation, as well as the intended outputs as a function of the input variables and associated experimental design. The discussion in Chapter VII provides the results and analysis of the DMO force structures in terms of the previously identified measures of effectiveness and performance. The analysis is summarized and applied in Chapter VIII, which provides the team's conclusions and recommendations based on the analysis of the integrated forces' ability to perform DMO in a contested environment.

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II. DISTRIBUTED MARITIME OPERATIONS

Distributed Maritime Operations (DMO) is an emerging idea in modern naval warfare, in which publications and doctrines are still in the process of being established. The U.S. Naval Warfare Development Command (NWDC) is developing the DMO concept to put into effect a more offensively inclined Navy across all domains, as well as identify and mitigate the risks of combat power capability gaps. NWDC's current efforts are focused on integration of existing platforms and systems with the DMO concept to achieve maritime strategic and operational objectives. NWDC defines DMO as the "warfighting capabilities necessary to gain and maintain sea-control through the employment of combat power that may be distributed over vast distances, multiple domains, and a wide array of platforms" (Coffman 2017). The primary doctrinal emergence with the employment of DMO is the emboldening of units and action groups to conduct offensive targeting when capable, and reduce susceptibility to attack from adversary forces.

A. DEFINING DISTRIBUTED MARITIME OPERATIONS

The development of DMO as a concept for the operational employment of maritime assets stems from the Distributed Lethality (DL) model of achieving sea control, specifically in the surface domain. The DL concept is comprised of three pillars: the ability to increase the offensive power of individual warships through networked firing capability; distribution of the offensive capability over a wide geographic area; and the allocation of sufficient resources to the surface platforms in order to enable the enhanced combat capability (Rowden 2017). DL not only emphasizes expanding the offensive firepower of surface ships, but also stresses the need for more resilient and sustainable surface platforms that are resistant to adversary targeting and able to withstand damage in the event of an attack. The concept of DMO adopts an extended viewpoint of DL, with similar key tenets, but expands upon these surface warfare principles to consider all domains including air, subsurface, and cyber warfare.

NWDC describes the desired end state of employing DMO as "fleet-centric fighting power, enabled by integration, distribution and maneuver that allows simultaneous employment of synchronized kinetic/non-kinetic mission execution across multiple domains in order to fight, and win in complex contested environments" (Canfield 2017). This view of DMO ensures the consideration of not only traditional tactics such as integrated air and missile defense and at-sea strike, but also the incorporation of non-kinetic tactics such as ISR, deception, and the use of unmanned systems particularly for enhanced capabilities in offensive tactical operations.

A primary goal of employing DMO is to allow operational commanders the ability to distribute their fleet assets of varying capabilities as a single, united weapon system capable of providing unit protection and collective defense, as well as the previously discussed ability to conduct offensive strikes and fleet engagements. By leveraging different combinations of platforms, sensors, weapons, and technologies, the combat power of a diverse, yet unified force package can be amplified, with increased capability of neutralizing and counter-engaging multi-dimensional threats across all maritime domains.

In order to comprehend the intended employment of DMO, several major concepts and terms must be defined as they relate to integrated operations in a contested environment. The following terms are extracted from the tasking and require further delineation in order to effectively apply the respective concepts to DMO.

Resilient: "System that is trusted and effective out of the box, can be used in a wide range of contexts, is easily adapted to many others through reconfiguration and/or replacement, and has a graceful and detectable degradation of function" (Goerger 2014, 871).

Counter-Measures: "Employment of devices and/or techniques with the objective of the impairment of the operational effectiveness of enemy activity. Counter-measures can be active or passive, and can be deployed either preemptively or reactively" (*Department of Defense [DoD] Dictionary of Military and Associated Terms* 2018, 56).

Counter-Targeting: "Actions that friendly forces take prior to enemy missile launch that will divert enemy resources (missiles, ISR assets, etc.) away from real targets. Counter-targeting can include operational deceptions and decoys as well as tactics" (Kline 2017).

Decoy: "An imitation in any sense of a person, object, or phenomenon that is intended to deceive enemy surveillance devices or mislead enemy evaluation" (*DoD Dictionary of Military and Associated Terms* 2018, 63).

Deception: "Actions executed to deliberately mislead adversary military, causing the adversary to take actions that will contribute to the accomplishment of the friendly mission. Deception is confusing or misleading an adversary by using some combination of human produced, mechanical, or electronic means" (Joint Chiefs of Staff [JCS] 2017, *vii*).

Electromagnetic Deception: "The deliberate radiation, re-radiation, alteration, suppression, absorption, denial, enhancement, or reflection of electromagnetic energy intended to convey misleading information to an enemy or to enemy electromagnetic-dependent weapons, thereby degrading or neutralizing the enemy's combat capability" (*DoD Dictionary of Military and Associated Terms* 2018, 75).

B. SCOPING THE DMO CONCEPT TO THE PROJECT

Considering the continuous advancement in technologies and the design of major fleet platforms, designing a system of systems relevant to the DMO concept has the potential to expand to infinitely large problem and solution spaces. To aid in organization and to facilitate a focused operational analysis, this report establishes boundaries regarding the domains, focus areas, platforms, technologies, and tactics associated with DMO.

1. Domains and Focus Areas

The project tasking emphasizes four key domains for supporting tactical distributed operations: air, surface, undersea and cyber. Due to the subject matter expertise and operational familiarity of land operations for several group members, the land domain is added as a separate entity from the surface (sea) domain. In addition to the operational domains, five focus areas are specified for consideration in the system of systems design; counter-targeting, decoys, deception, electromagnetic warfare, and manned–unmanned tactics.

2. Platforms

To employ the concept of DMO, fleet assets or platforms are required to project offensive capability to meet strategic and operational objectives. The specific order of battle for friendly and enemy forces is discussed in detail in Chapter III, but in terms of bounding the project scope for platforms that are active in the timeframe of the U.S. Navy of 2030 to 2035, platforms in various stages of maturity are considered. The major operational units of the Navy inventory to be incorporated into the team's research for the employment of DMO include aircraft carriers, surface combatants, fixed and rotary wing manned aircraft, and legacy missile systems, as their intended service life extends into the project timeframe. Additionally, several capabilities that are still in development or early in maturation stages are also considered, especially in the realm of unmanned surface and air assets. The new technologies and advances that are incorporated for study in the DMO concept include not only physical surface and air platforms or missile systems, but also planned future networking capability and tactics that have an impact on the ability to conduct distributed offensive operations.

3. Technologies

In the effort to advance the Navy's DMO concept, several developing and emerging technologies are incorporated into the team's research. While the development of new technologies is not the focus for the SEA-27 team, it is imperative that the advancements are considered for inclusion when developing a system that contributes to the innovative DMO concept. This idea is emphasized (Curley 2012, 79) "new technology is not tactics, but it may have a decisive effect in both altering the face of battle and affecting its outcome."

Evolving technologies are being developed for improvements in the performance of sensors, weapons, surveillance, and networks. For each of these respective areas, the technological capabilities advance at a rapid rate, and therefore it is difficult to predict the technological maturation of technologies in the 2030 to 2035 timeframe. For this project, the team will consider technologies that have been physically tested, but may not be fully indoctrinated into the Navy's repertoire of tactics and doctrine. For example, the ability to develop an integrated fire control network that incorporates all platforms and domains is a technological necessity to employ the DMO concept, but this ability currently remains in the stages of testing and evaluation.

4. Tactics

As noted in (Hughes 1999) technology and tactics are inherently linked. Tactics continue to mature and improve drastically with advances in technology, especially related to military deception, decoy counter-measures, and counter-targeting. For the scope of this project, the SEA-27 team is considering the inclusion of tactics that utilize the most recently developed deception platforms to include active and passive unmanned surface and aerial systems. The following chapters will detail the tactics and counter-measures considered, as well as their employment and integration within the currently employed and future DMO force compositions.

C. BOUNDING DISTRIBUTED MARITIME OPERATIONS

To ensure that the team's proposed DMO system of systems meets intended strategic and operational objectives, architectures are constructed to determine what functions the platforms and assets must be able to perform. The formulation of architectures that describe the intended functionality of the DMO concept reinforces the boundaries previously described with respect to domains, platforms, technologies, and tactics.

With DMO applying to all domains, warfare areas, and environments, it is necessary to delineate the primary functions that must be performed to support integrated operations in a challenged setting. The functional architecture in Figure 1 serves to create a "functional description of the system to serve as a basis for identification of the resources necessary for the system to accomplish its mission" (Blanchard and Fabrycky 2011, 106). The primary function that the team aims to achieve with the system of systems is to perform Distributed Maritime Operations. This overarching function is then decomposed to consider DMO in each of the aforementioned operational domains to include air, surface, subsurface, land, and cyber, as well as the tactics associated with each domain.

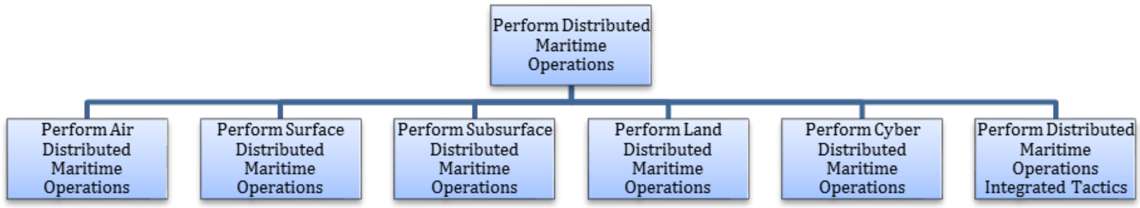

Figure 1. DMO Top Level Functional Architecture

With the project focus dedicated to the employment of tactics within the DMO concept, an additional functional decomposition is constructed to identify and categorize the various classes of tactics that can be performed by existing and proposed future platforms. The primary tactics considered for DMO across all domains are collected into the following groupings: swarms of unmanned vehicles, mechanical or physical decoys and counter-measures, management of electromagnetic emissions, and electronic jamming. These tactics categories are further decomposed, as shown in Figure 2. These tactics and their specific integration in to the DMO construct will be further detailed in Chapter IV of this report.

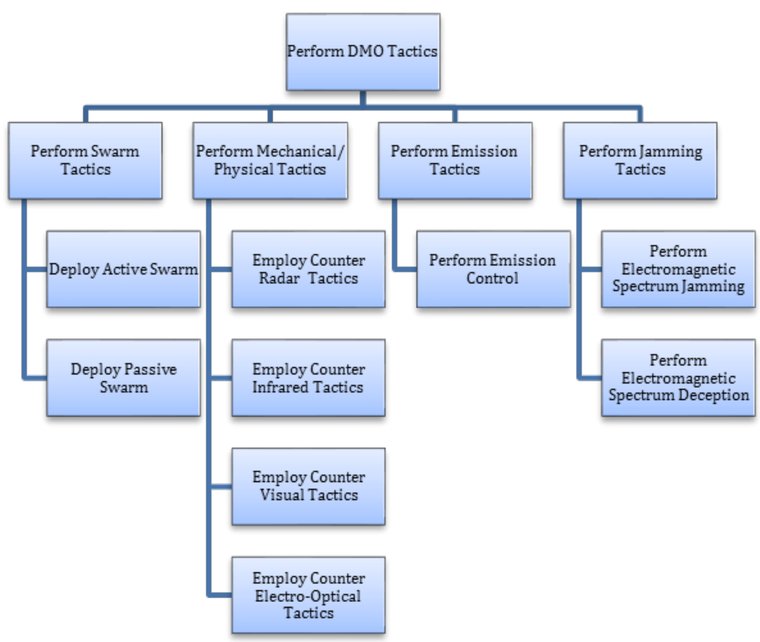

Figure 2. DMO Tactics Functional Architecture

In addition to the architectures described in the previous figures, supplementary diagrams are detailed in Appendix B, constructed by the team to further define the boundaries and separations between the systems included in the project focus, and those external to the scope of this research. The domain specific functions and tactics described in the architectures serve as the requirements and expected performance characteristics for the DMO systems. The determination of the capabilities required to perform DMO ensures that the team's proposed system of systems meets the minimum standard in terms of functionality. Additionally, when referenced throughout the iterative systems engineering process, the architectures facilitate traceability to the critical domains and tactics that must be considered in the development of the DMO system. These functions are required to be incorporated into the DMO system in order to contribute effectively to the desired distribution and integration of the fleet centric fighting power needed to project lethality to gain and maintain sea control.

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III. CONCEPT OF OPERATIONS

DMO is a concept that must be applicable to a multitude of strategic scenarios and operational environments. For the purpose of this project, the SEA-27 team defines a particular setting and scenario with the intention of providing an underlying operational situation for the forces and tactics incorporated into the DMO structure. The setting described in the following sections is used to provide an area of operations and order of battle with respect to platforms, sensors, and weapons systems, as well as a baseline for the employment of tactics.

A. SCENARIO

The scenario provides context and describes the setting for the massing of friendly and enemy military forces in preparation for conflict in the prescribed area of operations. The SEA-27 team utilizes an adapted version of the narrative described in the "Maritime War of 2030" framework as described in Appendix A (Kline 2018). The geo-political situation in the year 2030 is characterized by continued tension between the United States and the People's Republic of China (PRC) in the South China Sea region, with PRC continuing to construct military basing on contested islands. With the increased threat of PRC expansionism and potential conflict, the United States maintains its routine patrols through the region, and maintains its defense treaties with established regional partners.

The maritime war at sea in the 2030 to 2035 timeframe progresses from escalating aggression and unlawful PRC activities in the region, to harassment of neighboring nations' fishing vessels and the massing of PRC maritime forces in the South China Sea. The United States acquires intelligence of the PRC objective to capture the Philippine island nation of Palawan. The U.S. "blue" forces anticipate imminent engagement with PRC "red" forces and are consequently conducting preparations for combat at sea, with immediate mobilization of regional friendly assets to the South China Sea (SCS), specifically to the northwestern edge of Palawan.

B. OPERATIONAL ENVIRONMENT AND TASKING

The operational tasking for the U.S. maritime forces includes the establishment of a defensive perimeter on the western coastline of Palawan, the creation and continuous use of a distributed tactical common operational picture and weapon system network, and the integration of unmanned assets to enhance defensive and offensive capabilities. In order to effectively defend friendly forces and the allied island from imminent attack, U.S. maritime assets must apply the DMO concept through the employment of traditional warfare areas including air and missile defense, surface warfare, and at-sea strike, as well as manned–unmanned tactics, counter-targeting, deception operations, and electromagnetic warfare. While the blue forces are executing a largely defensive operation in the protection of an island from an imminent attack, the ships and aircraft are emboldened to be forward leaning to an offensive posture, and to conduct strikes once able, as prescribed by the DMO doctrine.

C. AREA OF OPERATIONS

As described in the scenario, the friendly assets in the western Pacific region will deploy to the northern coastline of Palawan to provide a presence and defensive fortification for the island. Figure 3 depicts the potential SCS area of operations for both friendly and enemy units, which spans approximately 700,000 square miles of international waters and territorial seas. The white outline represents the potential operating locations for friendly and enemy maritime forces, while the yellow box outline denotes the location of Palawan, the primary objective and location for U.S. forces.

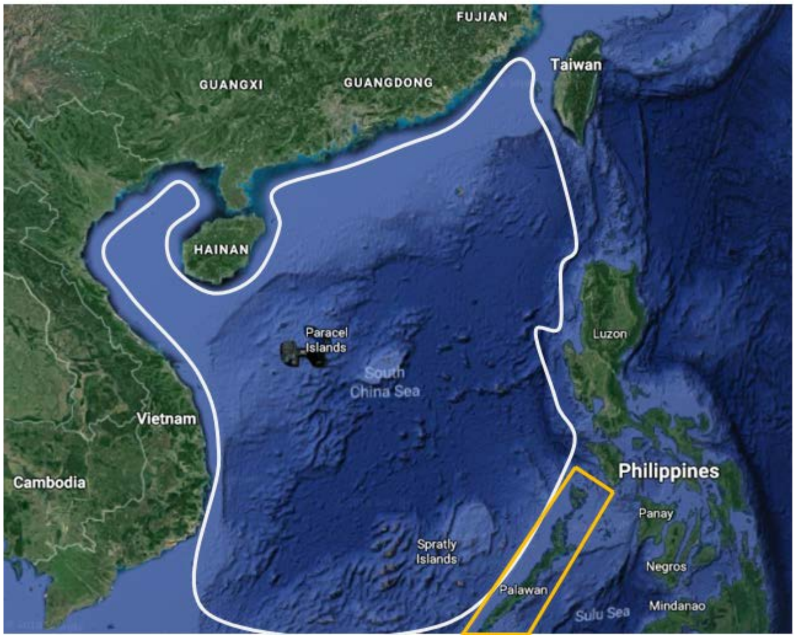

Figure 3. Projected Operating Area. Adapted from Google Maps (2018).

1. Environmental Considerations

The environment in the vicinity of Palawan and throughout the SCS has the potential to impact the ability to perform DMO, specifically with respect to weather conditions and sea states. World Weather describes the atmosphere for the western coast of Palawan, which for one half of the year is dry and experiences a mild climate, while the remaining six months of the year are impacted by seasonal rains and storms. The average wind speed and visibility vary with these seasonal climates, and can degrade the performance of the sensors employed on the maritime platforms, as well as limit the ability for friendly forces to conduct flight operations. The typical visibility is approximately five miles in the immediate island region, while the dryer months (March through May and September through November) allow for ideal operating conditions, with increased visibility to ten miles and fewer extreme wind gusts. Additionally, in these dryer seasons, the sea state is often more calm and predictable, which promotes an environment of increased commercial and military maritime operations in the region (World Weather 2018).

2. Regional Considerations

In addition to the environmental considerations, the South China Sea is a complex area that provides several unique challenges for friendly forces to conduct DMO. The primary factor of concern in the region is the heavy presence of neutral commercial air and sea traffic that cause significant congestion in sea lanes and air passages. The United Nations evaluates that one-third of all global shipping passes through the South China Sea as it is the one of the most used sea transit lanes in the world (Hoffmann et al. 2016). This factor of considerable clutter and congestion impacts the forces' ability to differentiate between enemy and neutral contacts, but can also be leveraged as an advantage for deception and decoy operations. Another challenge for the U.S. forces is the PRC maritime militia fishing fleets that serve as non-militarized ISR platforms. Additional regional concerns for the friendly forces include general lack of geographical familiarity with the region, as well as considerations for the attempted control and management of the electromagnetic spectrum.

D. ORDER OF BATTLE

The defined scenario and concept of operations not only provides the SEA-27 team with a regional area and tasking to consider, but also allows for the development of an order of battle (OOB) that incorporates maritime platforms. The OOB is comprised of surface ships, aircraft, weapons systems and sensors, for both friendly and enemy forces. The information considered regarding the capabilities of each platform and asset is compiled from open source databases. From the orders of battle, the team will examine various configurations of individual and integrated platforms for inclusion in the concept of employing DMO in the contested SCS environment. Although any actual conflict will certainly involve joint and coalition forces, the SEA-27 team focuses specifically on the maritime force contribution to better analyze naval tactics in this environment.

1. Friendly Order of Battle

The U.S. maritime forces order of battle was derived from the U.S. assets available within the Pacific Command (PACOM) area of responsibility (AOR). The U.S. forces incorporated into the friendly order of battle include those on rotational deployment, as well as those stationed in major force concentration bases such as Japan, Guam, Hawaii, and San Diego. In an effort to constrain the total types and quantities of the various platforms engaged in the conflict against adversary forces, only U.S. assets were considered in the friendly OOB.

a. Friendly Platforms

The primary driver for the determination of friendly forces in the region is the surface vessels, as the area of operations is a substantial distance from any major homeports for the U.S. Navy. By defining the number and type of available surface vessels, the team can begin to determine the associated air platforms and weapon systems that each vessel provides. Additionally, in today's typical force compositions, the surface vessels can be viewed as independent deployable units, or they can be organized and assembled into various action groups. Examples of such action groups include a Carrier Strike Group (CSG) which consists of an aircraft carrier, air wing, and several smaller surface combatants that provide defense and additional strike capabilities, an Expeditionary Strike Group (ESG) or Amphibious Readiness Group (ARG) that is comprised of an amphibious assault ship and several amphibious transports, or a Surface Action Group (SAG) that provides multi-mission capabilities from guided missile and littoral combat platforms. These various force compositions of CSGs, ESGs, SAGs, and additional independent units will be available to blue force commanders for DMO in order to meet the desired operational objectives.

(1) Surface Platforms

As previously mentioned, the foremost influence for the determination of all blue forces available for inclusion in DMO is the surface ships available in the region. Table 1 details the various ship types that are considered based on their projected service lives into the 2030 timeframe, as well as their respective proximity to the intended area of operations in the vicinity of Palawan. The vessels described below may already be deployed to the SCS, or may be reassigned to the SCS from their previously given tasking in adjacent areas or homeports in the Seventh and Third Fleets.

Table 1. Friendly Order of Battle—Surface Vessels

Ship Type	Ship Class	Designator	Manning
Aircraft Carrier	Nimitz/Gerald R. Ford	CVN	Manned
Amphibious Assault	America/Wasp	LHA/LHD	Manned
Amphibious Transport Dock	San Antonio	LPD	Manned
Guided Missile Cruiser	Ticonderoga	CG	Manned
Guided Missile Destroyer	Arleigh Burke	DDG-51	Manned
Guided Missile Destroyer	Zumwalt	DDG-1000	Manned
Littoral Combat Ship	Freedom/Independence	LCS	Manned
Expeditionary Fast Transport	Spearhead	EPF	Manned
Medium Displacement Unmanned Surface Vessel	Sea Hunter	MDUSV	Unmanned

(2) Air Platforms

The aircraft available in the region are then determined as a function of their parent surface vessel. The fixed wing aircraft are assigned to squadrons in either the Carrier Air Wing (CVW) stationed on the CVN aircraft carrier, or the Aviation Combat Element (ACE) located on the LHA/LHD class amphibious assault ships. The rotary wing and unmanned aircraft are deployed in squadrons or detachments to the aircraft carriers as well as the smaller surface combatants that possess flight deck and aircraft hangar storage capabilities. Table 2 specifies the comprehensive list of all aerial platforms to be included in the friendly forces OOB.

Table 2. Friendly Order of Battle—Aircraft

Aircraft Role	Aircraft Type	Designator	Nomenclature	Manning
Stealth Multi-role Fighter	Fixed Wing	F-35	Lightning	Manned
Multi-role Combat	Fixed Wing	F/A-18	Super-Hornet	Manned
Electronic Warfare	Fixed Wing	EA-18	Growler	Manned
Airborne Early Warning	Fixed Wing	E-2	Hawkeye	Manned
Maritime Patrol	Fixed Wing	P-8	Poseidon	Manned
Multi-role Maritime Helicopter	Rotary Wing	MH-60	Seahawk	Manned
Attack Helicopter	Rotary Wing	AH-1	Super Cobra/Viper	Manned
Autonomous Surveillance	Fixed Wing	MQ-4	Triton	Unmanned
Autonomous Helicopter	Rotary Wing	MQ-8	Fire Scout	Unmanned
Autonomous High Altitude Long Endurance	Fixed Wing	MQ-9	Reaper	Unmanned
Tactical Exploited Reconnaissance Node	Rotary Wing		TERN	Unmanned

b. Friendly Unmanned Systems

As presented in the surface ship and aircraft orders of battle, several unmanned autonomous vessels are incorporated for DMO consideration. With the timeframe set to 2030 through 2035, the various unmanned aerial and surface vessels are expected to be utilized in a wide variety of mission assignments, and can therefore be evaluated for their impact on the DMO construct in terms of sensor performance, weapons employment, and tactical relevance in their use as deceptive platforms or decoys.

c. Friendly Sensors

Another consideration for the order of battle in addition to the platforms that operate in the various domains, is the sensors that enable the asset to perform the functions of

DMO. The sensors carried onboard a weapon system allow a surface combatant, aircraft, or unmanned system to detect contacts in the operating area, identify and classify the contacts in terms of mission or intent, and target hostile contacts that pose a threat to the operations and survivability of friendly forces. Table 3 lists the primary sensors and their parent platform from the U.S. order of battle. The use of the sensor data in the model of the DMO concept will be discussed in further detail in later chapters of the report.

Table 3. Friendly Order of Battle—Sensors

Sensor	**Parent Platforms**
Visual	All Surface, All Air, All Unmanned
Infrared	CVN, LHD/LHA, CG, DDG-51, DDG-1000, LCS, LPD, F-35, F/A-18, EA-18, E-2, P-8, MH-60, AH-1, MQ-8 Fire Scout, MQ-4 Triton, TERN
Electronic Support Measures (ESM)	CVN, LHD/LHA, CG, DDG-51, DDG-1000, LCS, LPD, F-35, F/A-18, EA-18, E-2, P-8, MH-60, AH-1, MQ-8 Fire Scout, MQ-4 Triton
Air Search Radar	CVN, LHA/LHD, CG, DDG-51, DDG-1000, LCS, LPD, MH-60, AH-1, TERN
Surface Search Radar	All Surface Platforms, MH-60, AH-1, TERN
Fire Control Radar	CVN, LHD/LHA, CG, DDG-51, DDG-1000, LCS, LPD, MH-60, AH-1, MQ-8 Fire Scout
Navigation Radar	All Surface Platforms
Phased Array Radar	CVN, CG, DDG-51, DDG-1000
AESA (Active Electronic Scanned Array Radar)	F-35, F/A-18, EA-18, E-2, P-8, MQ-4 Triton
Airborne Early Warning Radar	E-2, P-8
Synthetic Aperture Radar—Maritime	MH-60, MQ-8 Fire Scout, MQ-4 Triton

d. Friendly Weapons Systems

In addition to the major platforms and autonomous resources, weapons systems are also incorporated into the friendly order of battle, with the intention of demonstrating the offensive and defensive combat power of performing DMO. While many other weapons and missiles exist and are in development for future use, the systems detailed in Table 4 are the principal assets that are employed in various mission sets, to include air and missile defense, at-sea strike, and air to air combat.

Table 4. Friendly Order of Battle—Missiles

Missile	Designator	Type	Launching Platform(s)
Standard Missile-2	RIM-66	Medium Range Surface to Air	CG, DDG-51, DDG-1000
Standard Missile-3	RIM-161	Ballistic Missile Defense	CG, DDG-51, DDG-1000
Standard Missile-6	RIM-174	Extended Range Surface to Air, Anti-Ship Cruise Missile (ASCM)	CG, DDG-51, DDG-1000
LRASM	AGM-158C	Long Range Anti-Ship Missile	CG, DDG-51, DDG-1000 F-35, F/A-18
Maritime Strike Tomahawk	MST	Long Range Anti-Ship Cruise Missile	CG, DDG-51, DDG-1000
Harpoon	AGM/RGM-84	Over the Horizon Anti-Ship Missile	CG, DDG-51, LCS, F-35, F/A-18
ESSM	RIM-162	Evolved Sea Sparrow - Medium Range Surface to Air Missile	CVN, LHA/D, LPD, CG, DDG-51, DDG-1000, LCS
Sidewinder	AIM-9	Short Range Air to Air	F-35, F/A-18, EA-18, AH-1
Hellfire	AGM-114	Short Range Air to Surface	F-35, F/A-18, MH-60, AH-1, MQ-8, TERN
AMRAAM	AIM-120	Advanced Medium Range Air to Air	F-35, F/A-18
HARM	AGM-88	High Speed Anti-Radiation	F-35, F/A-18

2. Enemy Order of Battle

While the friendly force order of battle is assembled as a function of the surface vessels present in the region, the enemy has the “home field” advantage with respect to the forces they are capable of providing in order to meet their objective of establishing a military presence on Palawan. The PRC forces can be deployed from both the naval surface vessels underway in the SCS, as well as the sea and air bases located on the mainland and the forward operating bases on the contested reefs and island chains. Similar to the projections used in the friendly order of battle, the enemy forces predicted to be operational in the 2030 timeframe include those currently in use with service lives extending into the 2030s, as well as technology advances and platforms in development that are expected to fulfill an operational role in the China Navy of 2030-2035.

a. Enemy Platforms

The enemy platforms presented are mobilized both from land and sea, with several major PRC homeports on mainland China positioned approximately seven hundred to one thousand nautical miles from the western coast of Palawan. Additionally, the PRC possesses forward basing and “lily pad” capability with the construction and buildup of military infrastructure on the contested reefs within the Spratly and Paracel island chains, located at a range of just over 100 and 400 nautical miles from Palawan, respectively. The mainland and island chain bases are projected to possess the capabilities to support both surface ships and aircraft of all types, so nearly all of the planned 2030 operational PRC naval forces are considered in the enemy order of battle.

(1) Surface Platforms

Table 5 details the various PRC surface ship types that are considered in the opponent order of battle. Many of the vessels listed are currently in development as the People’s Liberation Army Navy (PLAN) undergoes a fleet buildup period, but are projected to be in an operational status in the 2030 through 2035 time horizon. This is supported by a statement extracted from China’s Military strategy, “the PLAN is accelerating the modernisation of its forces for comprehensive offshore operations; developing advanced submarines, destroyers, and frigates; creating an aircraft carrier fleet;

and improving integrated electronic and information systems” (State Council Information Office of the People's Republic of China, 2015).

Table 5. Enemy Order of Battle—Surface Vessels

Ship Type	Ship Class	Designator	Manning
Aircraft Carrier	Kuznetsov/ *Liaoning*, CV03	Type 001A/002/003	Manned
Guided Missile Cruiser/Destroyer	Renhai	Type 055	Manned
Guided Missile Destroyer	Luyang III	Type 052D	Manned
Multi-role Frigate	Jiangkai II	Type 054	Manned
Multi-role Corvette	Jiangdao	Type 056	Manned
Stealth/Missile Boat	Houbei	Type 022	Manned
Amphibious Assault - Landing Helicopter Dock	Not Yet Determined	Type 075	Manned
Amphibious Transport Dock	Yuzhao	Type 071	Manned
Landing Ship—Tank	Yuting II	Type 072A	Manned

(2) Air Platforms

Not only is the PRC constructing new capabilities in the surface warfare domain, but air warfare is also a major focus of development and modernization for the PLAN and People’s Liberation Army Air Force (PLAAF). With the ability to provide land based aircraft, the enemy order of battle is much larger in terms of types of air assets available. Additionally, the aircraft carrier fleet and associated air wing is still in the development stages for the PRC, but is expected to expand drastically over the next ten to fifteen years, and is considered as a factor in the enemy order of battle.

Table 6. Enemy Order of Battle—Aircraft

Aircraft Role	Aircraft Type	Designator	Nomenclature	Manning
Air Superiority Fighter	Fixed Wing	J-11	Flanker B+	Manned
Carrier Based Fighter	Fixed Wing	J-15	Flying Shark	Manned
Multi-role Strike Fighter	Fixed Wing	J-16	Shenyang	Manned
Electronic Warfare Fighter	Fixed Wing	J-16D	Shenyang	Manned
Multi-role Stealth Fighter	Fixed Wing	J-20	Chengdu	Manned
Attack & Close Air Support	Fixed Wing	Q-5	Nanchang—Fantan	Manned
Strategic Bomber	Fixed Wing	H-6K	Xian	Manned
Airborne Early Warning	Fixed Wing	KJ-3000	Mainring	Manned
Maritime Patrol	Fixed Wing	Y-8FQ	Shaanxi	Manned
Utility/ASW Helicopter	Rotary Wing	Z-18	Changhe	Manned
Airborne Early Warning Helicopter	Rotary Wing	Z-8AEW	Super Frelon	Manned
High Altitude Long Endurance UAV	Fixed Wing		Soaring Dragon	Unmanned
Medium Altitude Long Endurance UAV	Fixed Wing		Pterodactyl	Unmanned
Stealth Supersonic UAV	Fixed Wing	AVIC 601	Dark Sword	Unmanned

b. Enemy Unmanned Systems

Similar to the friendly order of battle, various unmanned aerial systems are incorporated into the platforms available for employment in the scenario. The PRC has an extensive list of unmanned aerial vehicles (UAVs) currently in development, so for the purposes of this project, the primary asset in each major autonomous aircraft category was considered. These unmanned aircraft are capable of providing intelligence collection, surveillance, information sharing, and strike capabilities.

c. Enemy Sensors

An additional consideration for the enemy order of battle is the various sensors inherent to each surface and air platform. The sensors employed on the ships and aircraft are used for a wide range of purposes to include ISR, maneuvering, establishing a tactical operating picture, and weapons deployment. The use of the sensor data in the simulation of the fleet-on-fleet engagement will be described in additional detail in Chapter IV of this report, but Table 7 lists the primary sensors and their parent platform from the red order of battle.

Table 7. Enemy Order of Battle—Sensors

Sensor	Parent Platforms
Visual	All Surface, All Air, All Unmanned
Infrared	Aircraft Carrier, Renhai, Luyang, Jiangkai, Houbei, J-11, J-15, J-16, J-20, Z-18, Z-8AEW
ESM (Electronic Support Measures)	Aircraft Carrier, Renhai, Luyang, Jiangkai, Helicopter Dock, Landing Dock, J-15, J-16, J-16D, J-20, KJ-3000
Air Search Radar	Aircraft Carrier, Renhai, Luyang, Jiangkai, Helicopter Dock, Landing Dock, All Manned Aircraft
Surface Search Radar	Aircraft Carrier, All Amphibious Assault, Renhai, Luyang, Jiangkai, Houbei J-15, J-16, Q-5, H-6K, KJ-3000, Z-18, Z-8AEW
Fire Control Radar	All Surface, J-11, J-15, J-16, J-16D, Q-5, H-6K, Z-18, Z-8AEW
Navigation Radar	All Surface
Phased Array Radar	Aircraft Carrier, Renhai, Luyang, Jiangkai, Jiangdao
AESA (Active Electronic Scanned Array Radar)	Renhai, J-15, J-16, J-16D, J-20, All Unmanned Air
Over the Horizon Radar	Renhai, Luyang, Jiangkai
Synthetic Aperture Radar—Maritime	Aircraft Carrier, Renhai, Luyang, KJ-3000, Y-8FQ, All Land-Based Missiles & Unmanned Air
Synthetic Aperture Radar—Space	Yaogan Satellite

d. *Enemy Weapons Systems*

The final element in the enemy order of battle are the weapons systems carried by the surface ships and aircraft, as well as the land based missile sites that have the potential to strike friendly forces in the area of operations. The various armaments listed in Table 8 are capable of both offensive strike in the air and surface warfare domains, and defense from incoming aircraft and missile threats.

Table 8. Enemy Order of Battle—Missiles

Missile	Designator	Type	Launching Platform
Dong-Feng 21	DF-21D	Anti-Ship Ballistic Missile (ASBM)	Land—Mobile Launcher
Dong-Feng 26	DF-26	Anti-Ship Ballistic Missile (ASBM)	Land—Mobile Launcher
Silkworm	HY-2	Anti-Ship Cruise Missile (ASCM)	Land—Mobile Launcher
Eagle Strike-12	YJ-12	Anti-Ship Cruise Missile (ASCM)	Aircraft Carrier, H-6K, Q-5
Eagle Strike-18	YJ-18	Anti-Ship Cruise Missile (ASCM)	Renhai, Luyang, J-15, J-16
Eagle Strike-62	YJ-62	Anti-Ship Cruise Missile (ASCM)	Luyang
Eagle Strike-83	YJ-83	Anti-Ship Cruise Missile (ASCM)	Lyuang, Jiangkai, Jiangdao, Houbei, J-15, J-16, Z-18
Eagle Strike-100	YJ-100	Anti-Ship Cruise Missile (ASCM)	Renhai, Luyang, H-6K
Flying Crossbow	FN-16	Man Portable Air Defense (MANPAD) Surface to Air	Jiangdao, Houbei, All Amphibious Assault
Hongqi-16	HQ-10	Surface to Air	Aircraft Carrier, Luyang, Jiangkai, Jiangdao
Hongqi-16	HQ-16	Medium Range Surface to Air	Renhai, Luyang
	CM-102	Anti-Radiation/Anti-Ship	J-16D
Thunderbolt-9	PL-9	Short Range Air to Air Missile	J-11, J-15, J-16, J-16D, J-20
Thunderbolt-12	PL-12	Medium Range Air to Air Missile	J-11, J-15, J-16, J-20
	VLRAAM	Very Long Range Air to Air Missile	J-16

With the orders of battle determined for the friendly and enemy forces, comprised of surface vessels, aircraft, sensors, and weapons systems, the DMO concept can be evaluated with respect to the capabilities these platforms provide in the operational scenario.

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IV. KILL CHAIN AND TACTICS

In an effort to model and simulate the influence of various platforms, sensors, weapons systems, and tactics within the DMO construct, the process or structure used for the employment for those systems must be determined. Given that the goal of this research is to assess the utility of various countermeasures in the DMO context, the definition of a kill chain is useful to identify the times at which those counter measures could be introduced. While there are dissimilarities in the engagement processes employed by different ships and aircraft based on the sensors and weapons systems available to them, as well as the doctrine in effect, the underlying structure for the kill chain process is analogous, and is therefore be assumed to apply to all elements in both the friendly and enemy orders of battle.

A. TRADITIONAL ENGAGEMENT PROCESS

There are many different types of procedures or action chains used to conduct a detect-to-engage (DTE) series of events for armed platforms. A targeting sequence is typically broken down into the sub-tasks that must occur for a weapons system to effectively engage an enemy platform or location. The primary required tasks include detecting or finding the target, establishing a track on the targets location and movement, communication of targeting data between the sensor and weapon system, conducting the engagement with either kinetic or non-kinetic weapons, and evaluating the engagement to determine follow-on actions.

The most commonly used kill chain for military applications is the F2T2EA model, which is decomposed into the following subtasks: find, fix, track, target, engage, assess, as detailed in Figure 4. The first half of the F2T2EA kill chain describes the role that sensors play in the DTE process. The find task involves the initial detection of the target, fix refers to the determination of the physical target location, and tracking ensures a consistent ability to fix the target as it maneuvers. The second half of the kill chain then uses the information provided by the sensors in order to conduct an engagement. Once a stable track has been established, the sequence can progress to targeting, where calculations can be performed to determine if a weapon has the capability to intercept or engage. Once an adversary platform has been targeted, the operator may then move on to the process of engaging, where a weapon has been selected and fired from the targeting platform or other friendly platforms in the integrated targeting system. The final stage of the kill chain is to perform an assessment, where results of the engagement are calculated to determine if the employment of the kill chain and weapon was successful.

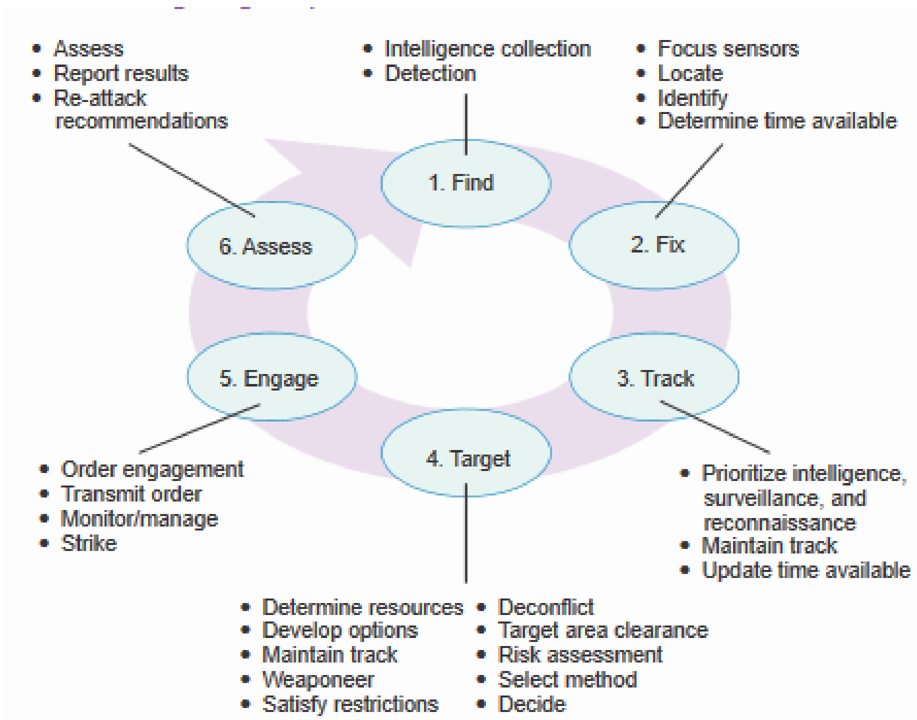

Figure 4. F2T2EA Kill Chain. Source: Joint Publication 3-60 (2013).

B. KILL CHAIN WITH IMPROVEMENTS IN WEAPONS SYSTEM TECHNOLOGY

With advancements in the technological capabilities of current and future weapons systems, some of the processes detailed in the F2T2EA kill chain can be combined due to the rapid transition from one phase of the kill chain to another. The F2T2EA sequence was developed in the early 1990s, and while the framework is still valid and used by many of today’s air and surface platforms, the ability for sensors and weapons to nearly simultaneously find, fix, track and target an enemy platform is almost routine in practice.

Additionally, many systems do perform these exact functions, but not necessarily in a linear or series fashion where one stage directly precedes the next. For example, with the tracking of electromagnetic signals, the ability exists where a platform may be able to find and establish a track based on the presence of electromagnetic radiation, prior to being able to identify the exact location of the electromagnetic source. Furthermore, with the extended range of some weapons currently in use and planned for future employment, a missile may be able to be re-routed in flight to a different target location after the targeting and engagement steps have been completed.

These advancements in weapon capabilities allow for a compressed or simplified version of the kill chain to be incorporated into an operational model representative of detect to engage sequences in the context of DMO. The SEA-27 team has deemed the critical functions of the F2T2EA kill chain in the context of DMO to be find, target, and engage (FTE). Figure 5 describes how these functions are adjusted into the abridged version of the traditional kill chain. Find, fix, and track are collapsed into a distinct activity, target remains a singular event in the kill chain, and engage is incorporated with the task of assessing the success or failure of the engagement. These fundamental functions will be incorporated into the team's model of the DMO concept, and the implementation will be discussed in further detail in later sections of the report.

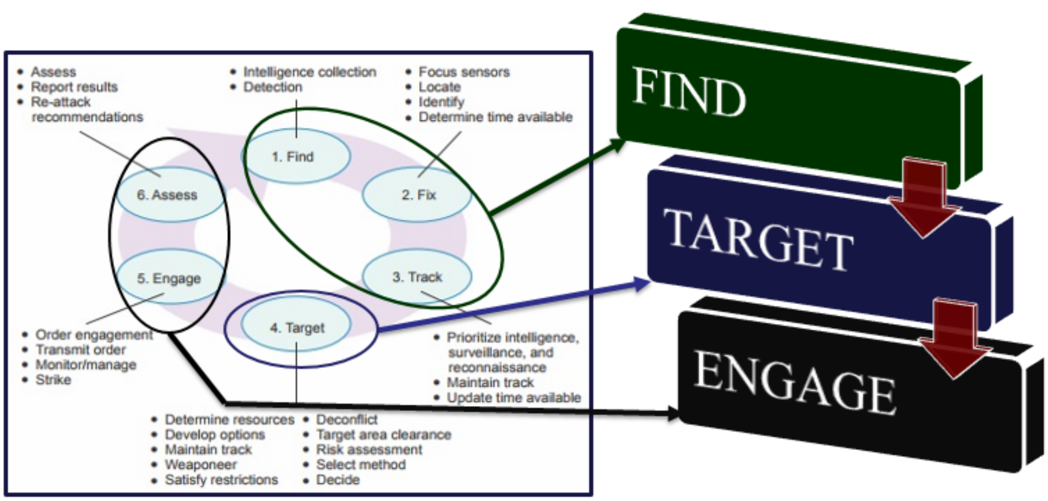

Figure 5. Simplification of F2T2EA Kill Chain to FTE Process. Adapted from Joint Publication 3-60 (2013).

For a platform to prevent the targeting or engagement from an adversary weapon system, typically only one phase in the kill chain must be disrupted. The application of the FTE kill chain in DMO allows for an examination of how certain tactics and counter-measures can cause this disruption and allow for friendly forces to perform counter-targeting and counter-engagements. Additionally, if an adversary platform is required to dedicate extended time to locating and targeting friendly platforms, blue assets have the increased capability to conduct offensive strikes, with the goal of targeting adversary systems once within range of blue weapons systems, as advocated in the forward-leaning DMO concept.

C. TACTICS AND COUNTER-MEASURES

Hughes (1999, 7) states “the traditional definition of tactics is the art or science of disposing of or maneuvering forces in relation to each other and the enemy, and of employing them in battle.” The primary focus for the SEA-27 team with respect to the DMO construct is the employment of various tactics and counter-measures that enable the disruption of the enemy kill chain to either prevent, or lower the probability of a successful enemy engagement of friendly forces. While many types of tactics and counter-measures exist for the purpose of confusing adversary sensors and targeting systems, as previously identified in the tactics architecture, the team determined several predominant categories of deceptive methods to examine with respect to the platforms detailed in the orders of battle. These categories include swarms of unmanned assets, mechanical and physical decoys, controlled emission of electromagnetic radiation, and electronic jamming. Each of these categories are further described to consider the functionality and employment of each tactic type, as well as the intended impact on the FTE kill chain.

1. Swarm

The continual advancement and employment of swarm technologies and capabilities is both an advantage and concern for friendly forces operating in a contested environment. As stated by (Chung 2015, 2341), with the “increasing availability and proliferation of unmanned system technologies, such as unmanned aerial vehicles (UAVs) in civilian and military applications, both opportunities and challenges arise in addressing large numbers of robots capable of collective interactions." While detailed study has only begun into the potential for these unmanned swarm systems and development of integrated tactics in defense, the SEA-27 team will examine and model the capability for a swarm to act as a decoy or counter-measure to prevent or disrupt enemy targeting systems from engaging friendly forces.

Although employing swarms of unmanned aerial platforms is an emerging tactic that has yet to be demonstrated in major combat, considering autonomous vehicle technology is critical, as supported by the Director of the Technology and National Security Program who states, "militaries that figure out how best to employ swarms, along with the doctrine, training, command-and-control structures, and other key enablers needed to support them, will have a significant advantage over those who do not" (Scharre 2014). These collaborative autonomous systems, both active and passive, have the potential to impact the outcome of a fleet engagement, even between two powers that possess advanced systems capable of tracking and classifying hundreds of targets simultaneously.

a. Employment of Swarm as a Tactic for Deception

For the purposes of this project, a swarm is described as a cooperative system comprised of numerous unmanned vehicles that function with limited operator involvement (Lachow 2017). The swarm systems are characteristically classified in terms of their size, range, and capability. These unmanned aerial systems range from small hand-held, short-range micro-UAVs to high-altitude long endurance aircraft that provide ISR and strike capabilities out to distances exceeding thousands of miles. These systems can be used in support of military deception in numerous ways: including saturation of radar and detection systems by deploying a large number of remotely piloted vehicles, as well as the ability to emulate a larger vessel such as a surface combatant or manned aircraft by radiating active emissions from the unmanned systems.

The primary difference between using swarms for saturation of enemy radar and radiating active emissions is the use of the vehicle as an active or passive asset. In order to imitate a larger vessel or aircraft, the drone is required to broadcast electromagnetic emissions with the intent of misleading adversary sensors. The same is true to produce a deceitful radar cross section that provides a false surface, air, or missile contact for the enemy to differentiate from a real blue platform. The active swarm requires larger unmanned platforms and greater power generation in order to propagate the energy needed to effectively mimic a surface combatant or aircraft. The passive swarm predominantly serves as clutter for the adversary sensors, with the effectiveness of the swarm directly proportional to the quantity of vehicles that aim to cause disorder and confusion for the red radars and weapons systems.

b. Impact of Swarm on the Kill Chain

For both types of swarms, active and passive, the purpose of the collective system of unmanned vehicles in the DMO concept is to hamper the adversary's ability to find and target blue platforms. Whether or not the drones radiate electromagnetic energy, the aim of deploying the vehicles is to gain the tactical advantage by overwhelming the enemy sensors searching for and targeting friendly forces. A greater quantity of autonomous vehicles deployed by blue platforms results in an increased number of radar and sensor contacts that the enemy sensors must sort through and classify when conducting the find and targeting sequence of the kill chain. The additional time required for the adversary to detect all radar contacts and distinguish the unmanned vehicles from the larger blue platforms may allow for blue to conduct the first strike in the engagement, or counter the red platform earlier in the FTE sequence, increasing overall blue survivability. Additionally, if the red platforms misidentify the autonomous vehicle as a legitimate target, the enemy may misappropriate targeting and engagement resources on the illusory contact.

2. Mechanical and Physical Counter-measures

When compared with the technologically advanced swarm tactics, mechanical and physical counter-measures are rather rudimentary and archaic as they have been employed for decades with few notable groundbreaking improvements. That being said, mechanical jamming, through the deployment of decoy devices can be exceptionally effective when confusing or deceiving adversary systems. The definition of counter-measure encompasses a wide variety of mechanisms that facilitate military deception against an enemy, and is defined as the "form of military science that, by the employment of devices and/or techniques, has as its objective the impairment of the operational effectiveness of enemy activity" (*DoD Dictionary of Military and Associated Terms* 2018, 56).

With respect to physical or mechanical counter-measures, this concept is typically synonymous with decoys, or objects that deceive sensors and ISR assets for the intention of disseminating misleading information. Numerous types of physical counter-measures are currently employed to generate misrepresentative information for the enemy. The categories of decoys and tactics that are further detailed and considered for this project of analyzing the concept of DMO include visual, radar, and infrared counter-measures.

a. Employment of Mechanical and Physical Counter-measures for Deception

Within DMO, the decoys and counter-measures serve to either create a false image of contacts, deceive sensors by creating saturation or clutter tracks, and/or distract surveillance and tracking systems from detecting, targeting, and engaging a friendly asset. The counter-measures are classified in terms of their respective objectives or the sensor in which they are intended to deceive. Mechanical and physical decoys are typically categorized as defensive tactics or soft-kill options that reduce the probability of intercept for a weapon in the terminal phases of guidance.

(1) Visual Counter-measures

The first category of physical decoys and tactics that are employed to obscure or confuse visual systems and the personnel that operate the imaging systems are visual counter-measures. Examples of the decoys or tactics that prevent the detection and targeting capability from visual instruments include deploying smokescreens; the setup of inflatables or passive decoys that emulate the size, shape, and general appearance of an actual friendly platform; and the tactical maneuver of vessels, aircraft, and personnel to deceive enemy forces. Visual smoke can be deployed from any vessel, aircraft, or even unmanned vehicles, and creates a barrier between enemy sensors or ISR platforms and the assets in the vicinity of the deployed smoke screen. The obscurant serves as a cloak to mask movements of forces, and prevent the enemy equipped with visual and imagery systems from detecting or targeting a friendly platform. Inflatables and passive decoys can also be launched or dispensed from any platform, with the objective of deceiving enemy scouting systems through the misidentification of a decoy as the actual opponent platform. Additionally, a substantial quantity of passive decoys can saturate and create excessive clutter for enemy systems.

(2) Radar Counter-measures

The primary sensor for detection and targeting for the majority of combat capable platforms is radar. There are a number of radar counter-measures available that are typically employed by units for close-in self-defense. One of the most common radar counter-measures is chaff, or clusters of metal strips that are projected away from a targeted platform in an effort to seduce or distract an inbound missile. The metal pieces are dispersed into a cloud of radar clutter from a canister that is deployed from a launcher on the parent vessel, and serve as the soft-kill option for preventing a radar-guided missile from striking the friendly ship or aircraft. Another type of counter-measure that has the objective of deceiving radars and radar-guided missiles are active decoys such as Nulka, or similar devices that imitate the radar cross section of the targeted platform. These counter-measures can currently be deployed from surface ship platforms, but may also be developed for integration onto aircraft and unmanned platforms.

(3) Infrared Counter-measures

The final category of counter-measures considered for inclusion in the DMO construct are intended to deceive infrared (IR) or heat-seeking sensors and weapons. Similar to a visual smoke screen, IR Smoke is employed to create a barrier between the parent platform and IR seeking threat. For major heat producing platforms such as ships and aircraft, IR-guided missiles pose a significant threat, especially during prolonged combat operations in which the reduction of the heat signature becomes increasingly difficult. An additional decoy to counter the threat of IR-seeking weapons are flares. Aircraft serve as the primary launch platform for flares, as a single canister can hold several dozen flare targets, providing additional target for the threat missile to acquire instead of the friendly platform. For aircraft especially, a tradeoff is apparent as the ability to carry offensive strike weapons is diminished if any pylons or hard points are dedicated to these defensive counter-measures.

b. Impact of Mechanical and Physical Decoys on the Kill Chain

The employment of visual, radar, and IR counter-measures influence all phases of the FTE kill chain. The use of passive and active decoys create clutter for adversary ISR systems, making it harder to differentiate between false and real contacts. The presence of additional contacts creates a time delay for the red threat to effectively detect and classify its assigned blue platform for targeting and engagement. Chaff, flares, and smoke are more geared towards interrupting the targeting and engagement phases, as these decoys primarily serve as close-in defense once all other hard-kill options have been expended. The value of each of the physical and mechanical counter-measures can be determined within the DMO construct as a function of the surviving blue and red forces upon completion of the fleet on fleet engagement simulation.

3. Electronic Jamming

A critical component of conducting military deception within the DMO framework is electronic warfare (EW), especially in relation to the FTE kill chain for platforms that rely on the transmission and receipt of electromagnetic signals to detect, target, and engage an enemy. Electronic jamming is a function within the EW subcomponent of electronic attack, and serves to overwhelm or deceive a sensor through the controlled and directed propagation of electromagnetic signals. The practical application of jamming is defined as "the deliberate radiation, re-radiation, or reflection of electromagnetic energy for the purpose of preventing or reducing an enemy's effective use of the electromagnetic spectrum, and with the intent of degrading or neutralizing the enemy's combat capability" (*DoD Dictionary of Military and Associated Terms* 2018, 75).

The objective of jamming is to obstruct the open transmission and absorption of electromagnetic energy for an adversary system. Electronic jamming with the intent of incapacitating or degrading a sensor is effective if the signal generated either replicates the operating parameters of the system and overpowers the enemy signal, or exploits a specific vulnerability such as the reliance on a single frequency. For example, if a sensor is known to only operate at a single frequency on the electromagnetic spectrum, spot or barrage jamming may be executed to transmit signals that block or saturate the exact frequency required for operation. If a system functions via the use of multiple frequencies, barrage jamming is more effective as the interfering signals are produced for the intended impediment of several different frequencies. This project will detail these and several other specific types of jamming that aim to target or degrade various enemy sensors and targeting systems.

a. Employment of Electronic Jamming as a Tactic

Electronic jamming is accomplished by transmitting a radio frequency or electromagnetic signal that interferes with the regular operation or attacks a susceptible element in the enemy's communications or sensing systems (Pardhasaradhi et al. 2013). The outgoing jamming signal can simply overpower or saturate the adversary's antenna or receiver, or the signal can be a targeted energy that is intended to impede a particular function or portion of the electromagnetic spectrum. There are numerous categories of electronic jamming, classified either by the method of employment or desired impact on an adversary system. For this project, five particular types of jamming were considered as individual and combined tactics for friendly forces employing DMO to defend maritime and land assets from imminent attack.

(1) Spot Jamming

The first and simplest form of electronic attack is spot jamming, in which a system that outputs the jamming signal generates power to propagate a signal of a distinct, singular frequency. Spot jamming is a form of noise jamming, which is designed to increase the noise or inherent signal clutter created by the transmitting system (air combat command training support squadron *Electronic Warfare Fundamentals* 2000). By contributing additional noise to the system, the radar is less able to distinguish actual contacts in the noise prominent environment, therefore allowing actual contacts to go undetected. This spot jamming technique is effective against communication systems or radars that emit energy of a single frequency, so long as the jammer signal and associated noise is stronger in terms of power and bandwidth, than the victim radar output and received signals.

(2) Barrage Jamming

Another form of electronic attack that is considered for employment in DMO is barrage jamming, which also falls under the larger classification of noise jamming. While spot jamming focuses the generated energy on a narrow band or single frequency, the same method of signal generation is used, but applied to a wider band or frequency range. Greater power is needed from the source platform in order to conduct barrage jamming of an enemy system, but it allows the friendly forces to hinder the performance of frequency-agile radars or systems that use multiple frequency ranges for operation.

(3) Sweep Jamming

The final form of noise jamming is sweep jamming, which is essentially a combination of the two previously addressed types of electronic attack. In order for a jamming signal to be effective at interfering with the adversary system, enough power must be generated to block or inhibit the radar from transmitting or receiving its electromagnetic signals. Spot jamming provides the power along a single beam, so the power generation is typically sufficient, but limited to only one frequency. On the other hand, barrage allows for simultaneous disruption of multiple frequencies, but with reduced output power. Sweep jamming is conducted to focus all of the energy produced on a single beam that shifts frequencies, which allows for jamming of various frequencies at greater power. While this method of electronic attack is advantageous when applied to systems that function on various frequencies, if the timing of the jamming signal frequency shifts are not aligned with the adversary system, the jamming has the potential to lag behind the victim system and be rendered completely ineffective.

(4) DRFM Jamming

Digital Radio Frequency Memory (DRFM) jamming is not classified as noise jamming, instead this type falls under the category of a repeater technique, in which the jamming system receives the electromagnetic energy from the adversary radar or communications system, and retransmits the same signal to create a deceitful or fraudulent return. The advantage to deception or DRFM jamming over the previously described EW attack types is that the power required to absorb and retransmit a false contact signal is much less than a jammer that is trying to overpower output signals. Additionally, DRFM jammers are less prone to detection by the adversary, as the returned signal is what is expected to be received by the radar or communications system, as opposed to noise jamming which operators are typically able to detect due to the noticeable change in interference. Additionally, due to the reduced power requirements, DRFM jammers are able to deceive multiple adversary sensors simultaneously, as opposed to noise jamming which requires a precise, directed path of electromagnetic energy towards a single enemy platform (Pardhasaradhi et al. 2013).

(5) GPS Jamming

The final EW tactic considered is GPS jamming, which intends to disrupt the operation of navigation and targeting systems that rely on the satellite based GPS radio-frequency network for location and tracking services. GPS operates on two primary frequencies, and can therefore be blocked or jammed using instruments that produce radio waves that create substantial interference for these operating bands. While GPS is rarely used as a sole source for targeting information, missile guidance often times requires inputs from a GPS system, and therefore the interference with these signals has the potential to reduce the probability of hit for an enemy weapon system.

b. Impact of Electronic Jamming on the Kill Chain

Depending on the friendly forces' timing for executing the jamming of adversary radar and communications systems, the electronic attack tactics have the potential to degrade the adversary sensors and weapons during any phase of the FTE kill chain. By jamming enemy air and surface search radars, the blue aircraft may be able to conduct scouting at longer ranges, and ships may be able to maneuver undetected to avoid targeting from enemy systems. The electromagnetic interference caused by jamming has the potential to reduce susceptibility to attack from enemy threats, and enhance the ability to project combat power at farther ranges as friendly assets conduct offensive strike operations rather than focusing on unit protection and collective self-defense of the entire operating group.

4. Emissions Control

The final tactic considered is emissions control, or EMCON, which is defined as "controlled use of electromagnetic, acoustic, or other emitters to optimize command and control capabilities while minimizing, for operations security, detection by enemy sensors, mutual interference among friendly systems, and/or enemy interference with the ability to execute a military deception plan" (*DoD Dictionary of Military and Associated Terms* 2018, 79). EMCON is another form of electronic warfare that is employed primarily to prevent adversary forces from determining the precise location of ships and action groups. EMCON encompasses not only the limiting of radiation propagated from the ship radar systems, but also entails the reduction of radar cross section by external physical means, and altering the internal ship equipment configurations to reduce the platforms acoustic signature.

a. Employment of EMCON as a Tactic

With the intent of deceiving enemy sensors or preventing the adversary from ascertaining the exact location of friendly forces, various levels of EMCON are employed. EMCON Delta is the level associated with routine operations, in which all available sensors and equipment are in their standard configuration. There is no limitation on transmitting radio or electromagnetic energy, and no additional measures in place to restrict acoustic and infrared signatures or radar cross section. The most extreme level of EMCON, known as EMCON Alpha, employs measures to reduce the electromagnetic, acoustic, heat, and radar cross section signatures from the platform. Essentially, the ship or aircraft limits nearly all navigation, communications, propulsion, and weapons systems to nominal levels of external signals in order to reduce the probability of being detected. EMCON Alpha describes the maximum level of stealth that an asset can achieve. Intermediate levels of EMCON are employed to cause confusion by a warship or aircraft reconfiguring its systems and physical presence to imitate a commercial or fishing vessel.

EMCON is employed primarily as a defensive measure to prevent the enemy ISR and combat capable platforms from locating and targeting friendly platforms. While the intent is to reduce the adversary's probability of finding and targeting, therefore increasing blue survivability, this limitation of blue capabilities also hinders friendly forces. With instruments and equipment reconfigured to reduce susceptibility of being attacked, the friendly platform is also unable to fully employ its sensors and weapons systems that are restricted in operation. For example, a surface ship set in EMCON Alpha is required to restrict the performance of its air search and fire control radar, making it difficult to detect and classify any inbound enemy aircraft and missile threats. In order to conduct an offensive strike or counter-engage any enemy threat, the ship must revert to EMCON Delta, which may take several seconds, reducing the available time to engage as a function of sensor and weapon system range and capability.

b. Impact of EMCON on the Kill Chain

A platform that employs EMCON aims to avoid detection and classification as an enemy target by converting to a stealth condition that worsens the adversary's ability to find, target, and engage. The altering of equipment arrangements that reduce acoustic and infrared signatures, changing of external features and lighting configurations, and restriction of electromagnetic transmissions all contribute to the intended degradation of a wide variety of sensors. For example, a large majority of missiles utilize radar or radiation seeking terminal guidance, if a platform is in an EMCON setting that restricts radar transmissions, the probability of hit for that specific missile may be reduced. Similarly, for a platform that only inherently retains the capability to search and target via an ESM sensor, the ability for that specific platform to detect and engage a platform in EMCON is diminished.

While there are obvious advantages to employing EMCON on friendly vessels with the objective of increasing survivability, these restrictive settings also incur a tradeoff with reduced offensive and counter-engagement capabilities. The limiting of the propagation of electromagnetic energy hinders the friendly forces' ability to sense, communicate, target and engage. A restrictive EMCON setting makes the conducting of flight operations for surface vessels challenging, impedes usual communications and networking capacities between friendly platforms, and causes a delay or increased time required to conduct synchronized command and control operations. For purposes specific to DMO, the inability to radiate while in an EMCON condition impedes the detection and engagement of threats via active means, which is essential to obtain a targeting solution and launch guided missiles to intercept the threat.

The tactics and counter-measures described are incorporated into the simulation and analysis of DMO as applied to a fleet on fleet engagement. The following section will describe how the implementation of the tactics impact the kill chain, and relate to the performance of DMO. Measures of performance and effectiveness are determined for the DMO construct, with consideration to the friendly and enemy forces that survive the conflict, as well as the effect of the various swarm, decoys, jamming, and EMCON techniques to degrade the ability for red threats to execute the phases of the kill chain to target and prosecute friendly assets.

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V. MEASURES OF EFFECTIVENESS AND PERFORMANCE

To evaluate the proposed system that aims to contribute to the friendly forces' ability to perform DMO, an assessment can be conducted with respect to the performance of the platforms and efficacy of the tactics within the DMO construct. The metrics established to determine the level of successful DMO employment are the Measures of Effectiveness (MOEs) and Measures of Performance (MOPs). These quantifiable measures allow the team to conduct an analysis of the numerous systems and force compositions, and determine which of the alternatives best achieves the defined goals and requirements.

A. MEASURES OF EFFECTIVENESS

MOEs serve to measure the extent to which a system accomplishes the overall mission. For this project, the MOEs are reflective of the ability to perform distributed, tactical offensive operations in a contested environment. The SEA-27 team has established four principal MOEs that are used to evaluate the ability for a configuration of friendly platforms to accomplish the task of employing tactics across all domains in support of conducting offensive and defensive engagements of attacking adversary threats.

1. MOE 1: Surviving Blue Forces

The first and most fundamental measure for assessing overall mission success is the ability for friendly forces to survive the war-at-sea. In order to be able to employ tactics and counter-engage the inbound red threats, the friendly order of battle needs to remain present throughout the simulation. As described in *Fleet Tactics and Coastal Combat*, "success is measured in ship casualties and a comparison of the numbers put out of action on both sides" (Hughes 1999, 8). This metric is described mathematically as the ratio of remaining blue forces upon conclusion of the engagement to the quantity of friendly platforms that entered the simulation.

$$\text{Percentage}_{\text{Surviving Blue Forces}} = \frac{\text{Quantity of Blue assets surviving at end of simulation}}{\text{Quantity of initial Blue assets}}$$

2. MOE 2: Remaining Red Threats

An additional simple, yet essential measure of success for friendly forces is the percentage of adversary threats that are eliminated during the engagement. In naval warfare when considering the operational objectives, ships and aircraft eliminated from the fight typically serve as the primary metric for success or failure, as supported by the statement from Hughes (1999, 9), "When fleets meet in battle it is force-on-force, and enemy warships incapacitated are the aim and satisfactory measure of effectiveness." The method of calculating this measure is the proportion of red threats that survive the conflict to the total quantity of red platforms that are generated in each model run.

$$\text{Percentage}_{\text{Remaining Red Forces}} = \frac{\text{Quantity of Red platforms remaining at end of simulation}}{\text{Quantity of total Red platforms}}$$

3. MOE 3: Red Threats that Successfully Complete the Find Sequence of the Kill Chain

In addition to the metrics that evaluate the number of forces that survive the projected engagement between friendly and enemy forces, the SEA-27 team evaluates the percentage of enemy platforms that complete the various stages of the kill chain. The simulation of the war-at-sea scenario generates a red threat which is assigned a specific blue platform type to find, target, and engage. With the various tactics employed by blue assets that aim to diminish sensor performance to reduce the probability of enemy detection and engagement, metrics can be used to gauge the value of the deceptive strategies and counter-measures. The expression used to calculate the red threats that are successful in their search to find their assigned blue platform is the ratio of red assets that complete the find sequence in the simulation to the total number of red assets generated in the model.

$$\text{Percentage}_{\text{Red find Blue}} = \frac{\text{Quantity of Red threats successfully find assigned Blue platform}}{\text{Quantity of total Red threats}}$$

The requirement for the red threat to successfully complete the find sequence of the model is to successfully determine the location of the assigned blue platform via the various sensors carried by the red threat. For example, a red surface ship may be able to detect and find its assigned target at greater distances by employing its electronic support measures

(ESM) sensor and numerous onboard radars, or at shorter ranges, the surface ship personnel may be able to exploit line-of-sight visual and electro-optical capabilities to acquire the target.

4. MOE 4: Red Threats that Successfully Execute the Target and Engage Sequences of the Kill Chain

The final MOE to evaluate the success or failure of a set of blue platforms and their associated tactics is the number of enemy threats that successfully execute the complete kill chain sequence, including the obtaining of a targeting solution and weapons engagement against its assigned target. This metric is calculated by determining the quantity of red threats that are able to complete the targeting and engagement stages of the sequence as a function of either the total quantity of threats that were simulated in the run, or the number of enemy threats that successfully found their assigned target. While many of the tactics available to blue forces support the objective of reducing the threats' capability to detect and find a friendly asset, there are also several counter-measures that serve to create confusion and disruption in the targeting and engaging phases, including active electronic jamming as well as the limiting of electromagnetic radiation from the targeted blue platform.

$$\text{Percentage}_{\text{Red target Blue - Total}} = \frac{\text{Quantity of Red threats that target/engage assigned Blue platform}}{\text{Quantity of total Red threats}}$$

$$\text{Percentage}_{\text{Red target Blue}} = \frac{\text{Quantity of Red threats that target/engage assigned Blue platform}}{\text{Quantity Red threats that successfully find their assigned Blue}}$$

For a red threat to be considered as a platform that completes the targeting stage and conducts an engagement, a fire control solution must be established and a weapon must be capable of reaching the assigned friendly platform at a specified range. For example, while an adversary surface ship may be able to detect a blue aircraft at an extended range, if the enemy warship does not have the capability to engage the friendly aircraft due to fire control radar limitations or an inadequate weapon engagement range, the red threat has not successfully completed the targeting sequence. Conversely, even if the enemy platform is within firing solution range of the assigned blue asset, but has not adequately detected and located the target during the find phase, then the red threat again has not reached the completion of the targeting phase of the kill chain.

In the engagement phase of the kill chain, the blue assets do not possess any counter-measures or the ability to employ tactics that specifically interrupt the engagement phase once a firing solution has been obtained by the adversary threat, but instead are able to conduct counter-engagements to neutralize the adversary prior to a weapons launch. The counter-measures and deceptive tactics are instead employed only after a weapon is launched from the red platform. Additionally, this metric does not consider whether or not the enemy missile actually intercepts or mission kills the blue asset, as that data is considered in MOE #1, or the number of surviving blue forces.

B. MEASURES OF PERFORMANCE

The effectiveness measures serve to measure overall mission success, and measures of performance (MOPs) assess the sub-tasks of the tactical DMO mission. The MOPs provide supporting data to evaluate the effectiveness measures for the scenario of performing distributed operations in a contested environment. For the team’s model, the following data can be captured and assessed to support the evaluation of the primary metrics for the friendly assets’ ability to perform DMO against the multi-domain capable adversary forces.

1. Area of Uncertainty

The first MOP calculated from the simulation is the area of uncertainty, or AOU. This metric is associated with the red threats’ ability to search and detect its assigned blue asset. The AOU is calculated as an expanding area of increasing radius from the platform’s actual location based on the blue platforms average speed and the tactics employed. The blue forces’ objective is to create as large of an AOU as possible by increasing the time for the enemy threat to find the friendly platform.

Various tactics can be activated by blue forces to degrade the adversary’s ability to detect and ascertain the location of the blue force platform. Emissions control, electronic jamming, physical decoys, and unmanned swarms are the primary tactics that impact the

AOU size. By creating additional clutter or contacts for the red threat to differentiate the actual assigned target from the neutral traffic and additional platforms that serve as distractions, the AOU grows larger with the increased time the red threat consumes attempting to find its assigned blue platform. Additionally, the limiting of radiation emissions from a blue platform reduces the probability of being detected by an ESM sensor at extended ranges, and electronic jamming of the threat radars aims to prevent the red threat from obtaining a clear radar fix on the blue asset. The goal for employing any of the counter-measures or tactics is to increase the AOU, which may ultimately have an impact on the MOEs of surviving friendly forces and/or the reduction of the quantity of red platforms that successfully execute various stages of the FTE kill chain

2. Counter-engagement of Enemy Missiles

In support of the MOEs detailing the number of surviving friendly forces and the red threats that complete the engagement sequence, a potentially insightful MOP is the ability for the blue platforms to counter-engage or divert the incoming missiles from the red threats. The blue assets possess various hard-kill and soft-kill options to prevent an inbound missile from striking the blue assets as a function of the range from the friendly asset to the inbound missile. Traditional anti-air and missile defense methods can be employed such as defensive missile intercepts, as well as counter-measures and tactics including mechanical and physical decoys. The team aims to capture the quantity of soft-kill decoys employed including chaff and smoke in an effort to determine which counter-engagement methods are most effective at preventing an inbound missile from collision with a friendly asset.

Additionally, with the primary focus of DMO geared towards the ability to conduct tactical offensive operations, the team will determine the percentage of missiles and counter-measures that friendly forces employed in a defensive manner as opposed to an offensive strike. The missiles employed in a defensive manner are those categorized by counter-engaging an enemy inbound missile, while the weapons used in an offensive posture are those that are used to target the platforms that serve as the source of the missile. For example, if a red threat aircraft enters the targeting sequence, a blue asset is capable of conducting an offensive strike if the threat is within weapons engagement range. If the friendly platform conducts an engagement to neutralize the red aircraft prior to enemy missile launch, the missiles are employed offensively. If the enemy aircraft obtains a targeting solution and fires missiles at the assigned blue platform, then the counter-engaging missiles are employed in a defensive capacity. The comparison of the two metrics will provide insight into the ability for the friendly force to enforce a more forward leaning DMO doctrine.

3. Threat Time in Find Sequence

Similar to the AOU performance measure with relation to the probability of the red threats ability to locate the friendly forces is the evaluation of the time that each red threat devotes to the detection and find activities in the kill chain. The metric is calculated as a function of the start time of the simulation and the starting position of the red platform. As time elapses, the enemy threat maneuvers and searches for the blue asset it has been assigned. With the blue employment of DMO and the associated tactics that aim to degrade sensor performance, the red threat may take an extensive amount of time to locate and classify the assigned ship or aircraft.

The additional time in the find portion of the kill chain allows the closure distance to decrease between friendly and enemy systems, potentially giving the advantage to blue forces who can conduct a counter-engagement when a red threat is within the engagement zone of friendly weapons systems. The team also hopes to address the question, "is additional time spent in the find sequence advantageous to blue forces in actuality, or does it allow for the red threat to close the distance to the assigned blue platform before engaging, providing friendly forces with less time to conduct a counter-engagement?"

4. Threat Time in Target Sequence

Another time delay based MOP details the time that a red air or surface threat spends in the targeting sequence. The adversary land-based missiles do not progress through the targeting sequence, as once a missile finds its assigned target, it transitions to the engagement phase where it advances to its inherent terminal guidance mode. Once the adversary platform is able to successfully locate the blue surface vessel or aircraft that it has been assigned, the threat transitions to the targeting phase. In the targeting portion of the kill chain, the red platform must employ its fire control systems to prepare to conduct an engagement. The primary method of delaying a red platform in the sequence of targeting activities is to prevent or diminish the ability to obtain the fire control solution through the application of electronic jamming, reduction of the platforms heat signature, and governing the emanation of electromagnetic radiation.

The output data and associated MOEs and MOPs provide a method of quantitatively examining the impact of employing tactics and counter-measures associated with the objective of performing DMO. The friendly force assets are capable of employing emissions control, electronic jamming, swarms, and/or mechanical-physical decoys in an effort to establish a forward-leaning offensive posture, and prevent the adversary forces from conducting an engagement against significant elements in the blue force order of battle. In Chapter VII of this report, various data analysis and statistical techniques are applied to determine the effectiveness of individual tactics and combinations of counter-measures with respect to the survivability of friendly forces, as well as the desired increase in offensive firepower and lethality.

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VI. DMO MODEL AND SIMULATION

To evaluate the alternative force combinations in terms of the established metrics for DMO, the SEA-27 team represents the events of the engagement through the creation of a model. By constructing a model, the team is able to examine the ability for arrangements of multi-domain assets to employ DMO and the associated tactics, while simulating the engagement between the competing fleets. The objective of developing the model is to facilitate an analysis of alternatives, and determine the force compositions that demonstrate the DMO principles of an effective shared network of resources and a forward leaning posture through increased lethality and offensive firepower. The following sections of this chapter describe the structure and framework for the model, as well as the variable inputs with the implementation of a design of experiments.

A. MODELING DISTRIBUTED MARITIME OPERATIONS

Simulating the fleet-on-fleet engagement to perform an analysis of DMO is accomplished through the use of a discrete event simulation, or DES. "A DES models queuing systems as they progress through time. In doing so it represents the world as entities that flow through a network of queues and activities" (Brailsford et al. 2014, 17). In the case of a battle between opposing military forces, the items or entities in the simulation are the ships, aircraft and missiles. These items progress through a sequence of activities or events, which for an engagement between armed forces, are the primary phases of the kill chain; find, target, and engage.

In a DES, time is event based as opposed to specified intervals or time steps, meaning that the simulation runs as a function of distinctive points in time when the system changes, such as when an item performs an activity. In a time-step simulation, the model records the state of the system at predetermined equal time steps, but for an event-based simulation, the model progresses through time intervals of varying lengths, and records the state of the system whenever a change or event occurs. For a model that represents hundreds of ships, aircraft, and missiles, the event driven simulation ensures the capture of activities that result in a change in the system, such as the loss of an aircraft or an engagement of an enemy ship. The DES employed by the SEA-27 team aims to facilitate the analysis of tactical offensive and defensive capabilities projected from either a baseline traditional force structure or an innovative DMO force composition, as well as the associated deceptive tactics and counter-measures.

1. Model Structure

The structure of the model is governed by the process or sequence of activities that the items must progress through, from the initialization of the model to the conclusion of a given run within the simulation. Each run within the simulation represents a new replication of the battle between friendly and enemy forces. At the initialization of every run, each red threat is assigned a friendly force asset to target and engage. In order to do so, the series of events that the enemy threats execute are the primary functions of the detect-to-engage kill chain. The items that conduct this sequence of activities are the enemy order of battle platforms, including the PLAN surface vessels, aircraft, and land-based missile systems. The adversary threats are simulated to progress through the find, target, and engage phases of the kill chain against an assigned friendly asset. The red threats aim to complete the entirety of the sequence to engage and destroy the blue forces, while the friendly assets employ offensive and defensive measures to prevent potential losses. The model explores the ability for various arrangements of U.S. forces to employ offensive tactics and deceptive counter-measures to divert or prevent the enemy from completing the kill chain sequence.

a. Threat Generation

The initial stage of the simulation is the generation of the adversary aircraft, surface vessels, and land-based missile systems. The types and quantities of the enemy platforms in the model remain constant throughout all runs of the simulation, and are further detailed in Appendix D. While the fundamental red order of battle is essentially constant with respect to the platforms generated, several attributes or characteristics of each of the threats vary upon the creation of the platform within the model. Once an enemy threat is generated, it is attributed with a set of sensors and weapons systems along with the associated operating and engagement ranges, as well as the speed of advance. These attributes contribute to the performance of the enemy threat in later stages of the model.

Additionally, a threat generated in the model is assigned a starting range as a function of the distance from the location of friendly forces on the western coast of Palawan. The type of threat dictates the values of the starting range which it can be assigned. For example, PLAN surface vessels and aircraft conducting routine operations in the South China Sea could have a uniformly distributed starting position ranging anywhere from forty to eight-hundred nautical miles from friendly forces. The land-based missile systems are more restricted in their potential starting ranges. Rather than a random, continuous value ranging from forty to eight-hundred, the possible locations of the land-based missile sites are limited to three discrete values, as determined by the location of the forward operating bases on the Spratly and Paracel island chains, or on the primary mainland bases. Figure 6 depicts the distinct values for the potential land-based missile ranges. The missile boats are also limited in starting distance, as they are assumed to be staged at the forward operating bases, and are tethered by a maximum operating range of one hundred and fifty nautical miles.

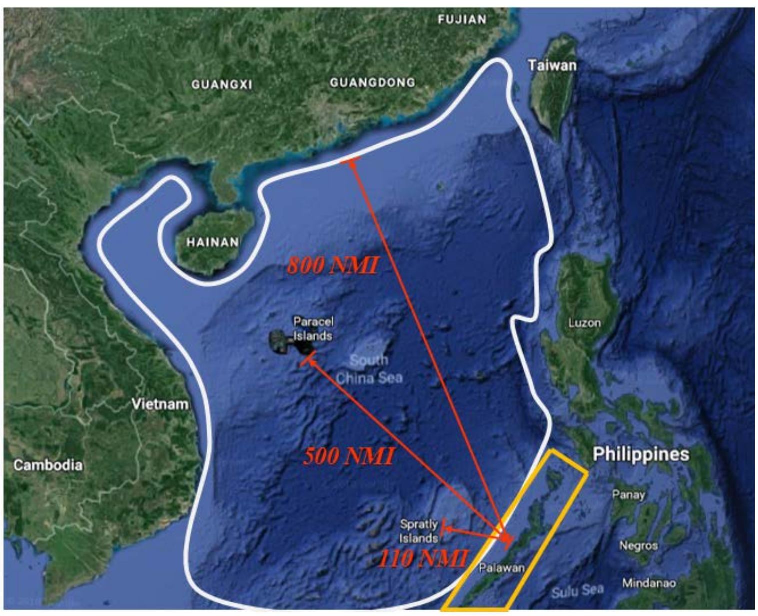

Figure 6. Starting Ranges of Enemy Platforms and Land-Based Missiles. Adapted from Google Maps (2018).

At this stage in the model, the enemy platforms and missiles are created as individual entities, with each threat assigned its own performance characteristics as a function of its inherent sensors and weapons, as well as the geographical and physical features of starting distance and speed of advance. The speed of each threat is based on the specific platform type, but the starting position varies for each individual threat. For example, with multiple Renhai destroyers generated in the run, all have the same speed of advance of twenty-five knots, but the individual surface combatants are given various starting separation distances from the location of the friendly forces. The next stage in the initialization of the enemy order of battle is the engagement mission assignment, or pairing of a friendly platform type to the enemy threat.

b. Mission Assignment and Pairing

In order for the adversary aircraft, surface combatant, or land-based missile to progress through the various stages of the kill chain, the threat is first assigned a type of friendly asset to find, target, and engage. The mission assignment is determined based on the quantities and types of friendly forces available for targeting in the model, which vary from run to run, unlike the enemy order of battle that is fixed and constant for all runs of the engagement. In the model, the threats are paired against a friendly asset to target prior to initialization of the kill chain. This eliminates the potential for a threat to engage a friendly platform that has not been assigned, even if the non-assigned friendly asset is a more practical or valuable target than the assigned platform. For example, an adversary fighter may be tasked with targeting a friendly LPD surface ship. The enemy fighter aircraft may encounter a more valuable friendly asset such as the amphibious assault LHA, but will not deviate from its mission assignment to find, target, and engage the LPD.

Mission assignment probabilities are calculated and implemented to ensure that only feasible engagement options are allowed for enemy threats within the model. For example, the U.S. aircraft carrier is the high value unit that is typically the highest targeting priority for an enemy fleet. The majority of the adversary's combat capable platforms will have a non-zero probability of being assigned the CVN for targeting and engagement, but an aircraft carrying only air-to-air missiles or an unmanned vehicle with only ISR capabilities cannot possibly engage the CVN, so these platforms will have a probability of zero for a targeting assignment to the friendly force aircraft carrier.

The probabilities of viable mission assignments are determined via a multi-criteria scoring model. The weighting and scoring of representative criteria for each friendly asset ensures a systematic determination of the engagement priorities for an enemy threat. This consistent method of scoring is accomplished by identifying the levels of combat power and sensor reach for each U.S. platform type, and assigning higher enemy prioritization to the friendly assets that have greater influence as a function of the platforms' weapon and sensor capabilities. The first criterion is the combat power of a friendly platform in terms of ordnance inherent to the platform, as well as the organic assets attached to the platform. For example, an amphibious assault ship (LHD/LHA) does not carry a substantial quantity of missiles for offensive strike, but the platform provides an aviation combat element of attack aircraft. Therefore, the priority for enemy engagement of the LHD/LHA is higher than the amphibious transport dock (LPD) ship, even though the LPD has a greater inventory of shipboard missiles.

The second criterion evaluated is the level of reach, which considers both operational range, as well as the maximum range of sensors, network capability, and weapons. An example of a high value unit according to this criteria is the E-2 Airborne Early Warning (AEW) aircraft, which has no intrinsic strike capability and a limited operational range, but much more robust network and sensor integration capability. Appendix F details the criteria intervals for both combat power and level of reach, and the resulting scores for each of the blue assets. With the primary mission of DMO being the ability to amplify offensive firepower, a higher weighting for the prioritization of enemy targeting is given to combat power at 65%, while level of reach contributes to 35% of the overall score.

As described in the example of the aircraft carrying only air-to-air missiles, an enemy threat generated in the model may only be capable of targeting a specific platform type. This scenario is considered in the mission assignment calculations, as the probabilities for targeting the blue platforms are redistributed among the platforms that the threat is capable of engaging. For the aircraft carrying only air-to-air missiles, the probabilities that the red aircraft could be assigned a blue surface platform to engage are decreased to zero, and the percentages for the surface vessels are evenly redistributed to the friendly air platforms that can be targeted. Additionally, the primary multi-role platforms such as a blue F-35 or red J-20, were separated in the model into air engaging and surface engaging platforms as a function of the missiles carried onboard. This ensured that a PLAN J-20 (Air) carrying only air-to-air missiles could not be assigned to target and engage a surface ship. This simplification is applied to both friendly and enemy forces, as to not give the advantage to one fleet over another.

Additionally, the enemy platform is solely assigned a blue asset category for engagement rather than one specific platform. For example, a single PLAN J-15 fighter aircraft may receive the assignment to find, target, and engage a U.S. guided-missile cruiser, or CG. This assignment does not correspond to a specific cruiser in the model, but instead applies to any CG. There may be anywhere from zero to five cruisers in the friendly forces order of battle as a function of the quantity generated, so the J-15 fighter can attack any CG in the simulation. Additionally, the J-15 may be assigned the CG, along with an enemy surface combatant who is also assigned to prosecute the friendly CGs. The enemy surface combatant could potentially target and destroy the CG prior to the arrival of the J-15, but the J-15 in the model is not capable of determining if the CG has been successfully mission killed, so it will still continue to target and engage the already damaged friendly cruiser. In the event that there are no cruisers generated for friendly forces, the J-15 reenters the pairing sequence to receive a new assignment to a different platform type. The mission assignment sequence allows for dissimilar categorical pairings, (enemy surface ship to friendly aircraft, enemy missile to friendly surface ship, etc.) as well as unequal quantities such as a single J-15 fighter having to find and target a single cruiser out of the three cruisers in the vicinity of Palawan.

The final scenario in which an adversary platform may require a new targeting objective is the frustration reassignment, or when an enemy threat is unsuccessful in finding the assigned friendly platform due to sensor incompatibility or failure. The targeting assignment for an adversary to locate the friendly forces assigned aircraft, warship, or land-based missile is provided at the start of the simulation, but the threat can potentially be reassigned during the run if a platform allocates greater than 75 percent of its allowable time to find the assigned asset and is unsuccessful. This maximum allowable time is a function of the starting separation distance between the threat and the assigned blue force asset, as well as the speed of advance for the enemy platform or missile. An example of this reassignment is a PLAN Z-18 helicopter with an operating speed of 120 knots assigned to target a friendly force MDUSV at a range of one hundred and eighty miles. The maximum allowable time for the Z-18 to find and target the MDUSV is one-and-a-half hours based on the range separation and speed. If the Z-18 dedicates greater than approximately an hour and ten minutes or transits more than 100 and 35 miles towards the asset without finding the MDUSV, the Z-18 can request a reassignment to a different friendly force asset. In this case, the threat is essentially requesting a new assignment which may be denied, or could result in a new assignment to a different targetable asset.

c. Environmental Considerations

The concluding element of the initialization sequence for the group of enemy threats is the determination of environmental factors including weather and clutter. These attributes influence the threats sensor performance, resulting in either an enhanced or degraded capability of finding and targeting the assigned friendly platform. The first component of the environmental factors is weather. For the model, the various meteorological conditions are simplified to 3 conditions and given a probability of occurrence. For the majority of the simulation runs in which weather is not a factor, the cloud cover and rains are negligible, and therefore there is no degradation to sensor performance for both friendly and enemy forces. In the occasional event of storms or reduced visibility, a degradation factor of 10 percent is applied to detection systems including radars, as well as infrared, visual, and electronic support measure sensors. The final, and least frequent, weather condition considered in the vicinity of Palawan is severe weather that degrades sensor performance by 30 percent. Appendix C details the probability of each weather condition as well as the associated degradation to the systems used for detection of the assigned friendly platforms. The weather condition and degradation factors simultaneously impact all platforms in the simulation, and remain constant throughout the duration of the run.

The generation of clutter in the model contributes to the overall quantity of air and surface contacts in the simulation. Clutter includes neutral commercial and shipping traffic through the air and sea lanes in the region. The presence of the neutral vessels provides additional contacts for the enemy platforms to differentiate from targetable threats when conducting the find and targeting phases of the kill chain. The model represents clutter through the creation of approximately 55 to 75 additional contacts in the operating area, determined as a function of typical congestion of merchant vessels and aircraft in the local region. The average quantity of sea and air traffic in the vicinity of Palawan is determined from the annual average of Automatic Identification System (AIS) tracks that travel through the prescribed area of operations during a 3-hour time interval (Marine Vessel Traffic 2018).

d. Kill Chain Sequence

Upon generating the complete enemy order of battle, assigning all enemy threats to friendly platforms for targeting, and setting the environmental conditions, the engagement simulation begins with each threat at the start of the kill chain. The model clock now progresses forward from time 0, as each adversary aircraft, surface ship, and land-based missile proceeds toward the location of the U.S. forces at its attributed speed. Each individual threat attempts to find its assigned target by employing its onboard sensors. If a threat is able to find its assigned friendly platform, the enemy combatant or missile advances to the targeting phase, and with the acquisition of a firing solution, ultimately the threat is able to engage the blue asset. Each phase of the enemy's kill chain consists of a variety of activities or events that dictate the platform's performance with respect to the ability to find, target, and engage. Additionally, the modeled activities within each phase incorporate the ability for friendly forces to employ DMO offensive counter-engagements as well as counter-targeting and tactics to divert or prevent the adversary from conducting a successful engagement. Figure 7 depicts the fundamental functionality and sequence of the model, with further detail and annotations of the ExtendSim event based simulation shown in Appendix H.

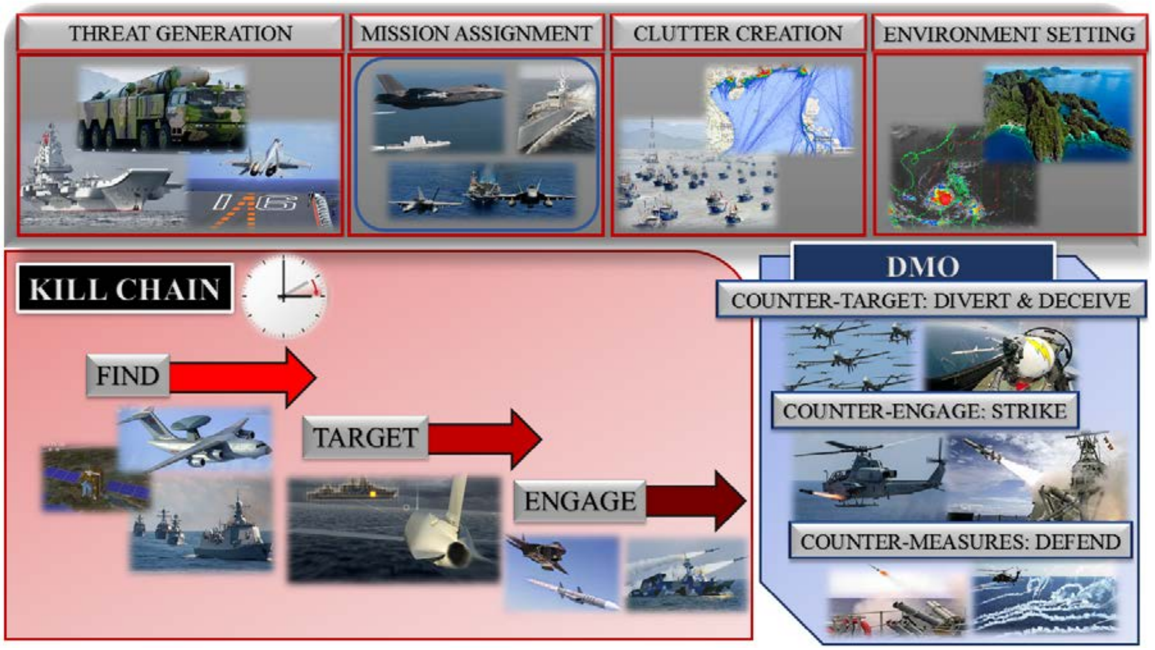

Figure 7. Primary Functions of the DMO Model

(1) Finding

The initial phase of the kill chain consists of a sequence of activities for an enemy threat to detect and locate the friendly force target that it has been assigned. The ability for the adversary to find the assigned platform type is a function of the sensors carried by the searching platform, the maximum range of the sensors, and the relative performance of that sensor in finding the blue asset. The probability of find values represent the single-look chance of successful detection specific to an individual enemy sensor and the friendly platform the sensor is attempting to locate. The enemy platform employs its appropriate sensors to conduct a single-look scan of the operational area in an attempt to find the assigned friendly force asset. This process of sensor single-look, independent scans to find the assigned blue target is iterated many times as the enemy platform progresses inbound toward the friendly forces' location.

With each sensor scan, clutter is also considered as the need to differentiate neutral and friendly traffic from a targetable rival platform. The ability to reduce clutter by a certain quantity for each scan is dependent on the performance of a specific sensor. An advanced radar may be able to instantaneously categorize a large group of contacts as neutral traffic with each look, resulting in a significant reduction in clutter and a higher probability of find, while an optical or infrared sensor requires several seconds per an individual contact to distinguish the platform as a legitimate target or neutral traffic. An adversary surface combatant equipped with advanced high power radars can perform rapid scans of the operating area, so even with high clutter saturation and a full friendly order of battle to include swarm and decoys, the enemy ship can typically perform enough independent scans to decipher and classify all contacts, resulting in an overall high probability of finding the assigned friendly force platform.

The range gates implemented for each sensor type ensure that a friendly asset located at a distance greater than the operational range of a radar or other available detection methods cannot be found successfully. For example, a small missile boat with only a short-range surface search radar cannot locate a friendly force aircraft at a range of several hundred miles because the associated probability of finding an aircraft with the surface search radar at this range is 0. There may also be instances where a targetable platform is within range of an enemy sensor, but due to weather conditions or clutter or employed counter-measures, the probability of find may be reduced to a level in which the enemy is unable to detect the assigned friendly asset on a single look.

Additionally, sensor fusion, or the ability for a platform to use multiple onboard sensors to find is accomplished by applying a calculation that considers the probability of find for all sensors that are able to be employed for a certain range. An example of the sensor fusion can be explained as an adversary fighter J-16 aircraft assigned to target a friendly force littoral combat ship (LCS). The J-16 may be able achieve an initial detection at a range of eighty miles using the AESA radar, but due to clutter or other contacts in the area, the J-16 has not successfully identified all targets and determined the exact location of the LCS target. As the J-16 continues to progress inbound towards the location of the LCS, in addition to the AESA radar, the aircraft's surface search radar can also be employed to assist in the finding of the blue force surface combatant. With multiple sensors in range of the assigned target, the probability of find for both independent radars are considered, increasing the overall probability of the J-16 finding the friendly LCS.

Throughout the simulation, an adversary platform only attempts to detect and locate the friendly force platform type that it has been assigned. There is no benefit or penalty applied to either force for an enemy combatant detecting an asset of a different platform type. A PLAN aircraft, such as the bomber H-6K, could be assigned to target the LHA amphibious ship, and in its efforts to locate the LHD/LHA(s), the H-6K conducts an overflight of an entire carrier strike group without conducting an engagement because the threat aircraft is not assigned any element of the strike group. By not allowing the enemy platforms to engage friendly targets of opportunity, this artificially skews the attrition rates to benefit blue forces. However, the relative impact of the employment of tactics remain unaffected by the modeling limitations of preventing enemy threats from targeting and firing upon the first available blue asset. Furthermore, it is assumed that each enemy platform is independent in its kill chain efforts, meaning that the H-6K that overflew the strike group does not communicate the information to any other platforms in the simulation. Each aircraft, warship, or missile threat continues its attempts to find the assigned friendly asset until either the run time expires, the threat is unable to reach the assigned platform due to range and speed, or the friendly asset is successfully found by the enemy, resulting in the transition to the targeting stage of the kill chain.

An example of an enemy platform conducting the activities of the find phase is a PLAN surface ship that has been assigned the mission of neutralizing the Zumwalt DDG-1000(s). The surface threat can employ a variety of sensors including ESM, surface search radar, and visual sensors to locate the DDG-1000(s). The ability for the threat surface combatant to detect and locate the DDG-1000 is dependent on the operational ranges of these sensors, and a probability of find associated with each of the sensors. In the case that the DDG-1000 is operating in an EMCON condition, the ability for the PLAN surface ship to detect using ESM is reduced to 0. If the adversary ship is located over 300 miles from the nearest DDG-1000 platform, the surface search radar is unable to be employed due to operating range restrictions. Additionally, due to the reduced radar cross section of DDG-1000, the probability of finding the Zumwalt class using the surface search radar is much lower than the probability of locating a much larger vessel such as an aircraft carrier or amphibious assault ship. In each of these cases related to the ability for a threat to detect a friendly force platform, the DDG-1000 platform has the advantage due to separation distance and employment of deceptive tactics. The opposite may be also true for a given run, in which the separation distance is not nearly as great and the enemy has several sensors within range to successfully locate the stealth destroyer. With the PRC warship's successful find of the assigned DDG-1000, the enemy combatant can advance to the targeting stage of the kill chain.

(2) Targeting

Only an adversary aircraft, surface ship, or land-based missile that has successfully found the friendly force platform it was assigned can advance to the targeting stage. In the targeting phase, there are additional conditions that an enemy platform must meet in order to obtain a firing solution and conduct an engagement. Each platform that advances to the targeting stage essentially has to conduct similar activities to those encountered in the find stage. This is described as the enemy threat starts the targeting phase without any feasible targeting data or a firing solution, and has to use the platform's employable sensors with associated probabilities of targeting in order to build up to obtaining a target solution through numerous scans of the operating area. Additionally, even if a radar that is able to generate a firing solution is employed to successfully find a targetable platform, a new probability of target value is applied in this phase, which considers not only the radar's sensor capability, but also the ability of the weapon system to obtain a feasible firing solution. Several red force threats employ sensors that can be used to find the assigned blue platform, but cannot be applied to generate a firing solution. The systems that may assist in finding a friendly force asset but require a secondary targeting capability include ESM, navigational radar, and visual sensors. An example of this restriction may be a small surface combatant that can detect and classify a target using a surface search radar, but requires the integration of a fire control radar to successfully complete the targeting phase of the sequence.

An enemy platform progresses through the activities of the targeting phase to achieve the ability to engage until either the simulation expires due to run time constraints, the combatant is unable to obtain the targeting solution by the time the adversary platform passes the assigned blue asset, or until the threat is counter-engaged by friendly forces. Only a threat that successfully obtains a viable targeting solution can proceed to the final phase of the kill chain to conduct an engagement. Success in the targeting stage only considers the platform's capability for achieving a firing solution from the onboard sensors and fire control systems, and does not reflect the available weapon engagement range. For example, a J-16 aircraft may employ the AESA radar to obtain a firing solution against a blue threat at a range of over one hundred miles, but the aircraft is restricted by only carrying short-range missiles onboard to conduct a physical engagement. The J-16 platform will advance to the engagement phase due to the success in obtaining a targeting solution, even though an engagement will not be effective until the separation distance is reduced to the maximum weapon range.

An example of a red threat that may reach the targeting phase is the DF-26 anti-ship ballistic missile which has been assigned to neutralize the friendly forces aircraft carrier. Using the launcher's radar capability and guidance communications linked to the in-flight missile, the DF-26 may have successfully located a CVN, and transitioned to the target phase. Based on the operating condition of the CVN and/or counter-measures employed by the targeted platform and supporting friendly assets, the DF-26's probability of target may or may not be degraded for each scan, resulting in either an engagement of the CVN, or a diversion of the inbound ballistic missile threat through kinetic or non-kinetic means.

(3) Engaging

The final phase of the kill chain is the series of events that represent an engagement from an enemy platform against its assigned blue force asset. Once an adversary obtains a firing solution, the platform is advanced to the engagement phase where an ordnance launch occurs or the land-based missiles reach their terminal guidance phase against the assigned friendly force asset. In this phase of the FTE chain, the enemy surface and air platform-based missiles launched from the parent threat enter the simulation as separate entities. The starting range of the enemy platform-launched missiles is the launch point from the parent aircraft or surface vessel, and is assigned the same target as the launching platform. The missiles launched are generated and prescribed similar attributes as the parent platforms, to include an independent speed of advance, terminal guidance type, and probability of hit against a specific friendly platform. The threat missiles can be counter-targeted in this phase by the counter-measures and tactics available to friendly forces. For example, a YJ-83 anti-ship cruise missile launched from an enemy surface or air platform is terminally guided by active radar homing, and therefore could potentially be countered by hard-kill methods as well as diverted through the use of active decoys, electronic jamming, or physical counter-measures such as chaff. The parent platform that conducted the engagement with the launch of missiles towards a friendly asset, then turns outbound to increase the separation distance to attempt to prevent being counter-engaged by friendly forces. The parent platform or land-based missile remains in the engagement phase until the entirety of available weapons is expended, the combatant or missile passes the assigned targeted platform, the run expires due to time, or the threat is counter-engaged by friendly forces.

e. Counter-engagements and Counter-targeting

While the operational scenario describes the U.S. forces' objective as defending an allied nation from friendly attack, and the model is created from the viewpoint of adversary forces conducting an attack on the U.S. assets, DMO focuses primarily on the shared projection of offensive firepower. Therefore, incorporating the ability for blue forces to conduct strikes from a forward leaning posture is critical to the evaluation of the DMO capability. The portrayal of an offensive stance is accomplished through the ability to conduct engagements of threats prior to the establishing of a targeting solution. Once an enemy surface or air platform successfully finds its assigned blue asset and reaches the targeting phase of the kill chain, any of the platforms in the friendly order of battle with combat capability can conduct a strike to engage the red combatants.

In addition to the strike or counter-engagement capabilities, the friendly forces can also employ counter-targeting tactics, meaning actions taken by U.S. assets to prevent an enemy from conducting an engagement, or divert enemy resources away from actual friendly forces. These counter-targeting methods enable an offensive posture due to employment prior to enemy missile launch, and can include the various types of electronic jamming, deployment of a swarm or decoys, and operating in a limited emission condition.

(1) Resource Pool

For both offensive engagements (prior to an enemy missile launch), and defensive purposes (post enemy missile launch), the missile inventory available to friendly forces are maintained within a collective resource pool. This contrasts the red order of battle in which the missiles generated are tethered to the parent platform and are not collaboratively shared between threats. The model represents DMO as a united network of offensive lethality and firepower, and therefore all missiles are shared for cooperative engagements from all launch platforms. The missiles available for friendly forces in the shared resource pool for a given run of the model are determined as a function of the generated friendly order of battle. For example, a single run in which a CG and several F-35 aircraft are generated will have a greater quantity and variety of missiles in the resource pool than a run which only contains an LCS and a P-8 patrol aircraft.

The selection of the missile to perform an engagement is based on range gates and logic statements implemented in the model. An example scenario of this model functionality can be explained as an enemy surface combatant that successfully finds its assigned target, and consequently becomes a targetable platform for a friendly force engagement due to the adversary platform switching to a targeting system to complete the engagement. This adversary warship is located at a range of 90 miles from the location of friendly forces, so the counter-engagement range gates in the model can be applied. The most capable friendly force anti-ship missile at the range of ninety miles is the LRASM. The resource pool is checked to see if any LRASMs are available for employment based on friendly force platforms generated in the run. If there are no LRASM assets available, the next most capable missile at the given range will be checked for quantities available. In this scenario, the next blue force missile for employment is the SM-6 in surface mode, which is available due to the presence of a DDG-51 in the simulation. For this specific missile, an additional check is done for an extended range capability if an E-2 is present. As the enemy platform continues inbound towards friendly forces, more missile types become available for employment as the range gates open. If a suitable friendly missile is available based on the platform needed to launch the attack weapon, an engagement of an adversary threat can occur. In any event, if a friendly force platform launches a missile to engage an adversary threat, the targeted enemy platform's inbound progression and ability to conduct the various stages of the kill chain is unaffected.

(2) Elimination of Missiles from Mission Killed Platforms

In the event an enemy threat is able to damage or mission kill a friendly force asset that contributes to the shared missile inventory, the ordnance contribution of the degraded U.S. ship, aircraft, or unmanned asset is potentially reduced. This decrease in weapons inventory is accomplished by considering the types and quantities of missiles carried by the affected platform, and applying a random percentage to remove a portion of the platforms missile capacity, potentially ranging from zero missiles to the full inventory carried by the battle damaged asset. For example, a DDG-51 class destroyer may be engaged by an adversary aircraft and struck by an anti-ship cruise missile. If the model registers the DDG-51 as hit, the contributions of the ship to the missile resource pool are multiplied by a percentage factor ranging from 0 to 1, and the missiles remaining in the pool from the damaged ship becomes the initial total minus the quantity lost due to the percentage calculation. An example to better illustrate this case is the DDG-51 that contributes 83 missiles to the resource pool. If the DDG-51 is struck by an enemy missile, and the random percentage factor generated is 0.4, which corresponds to 33 missiles, the DDG-51 now contributes only 50 missiles to the resource pool after the missile strike (83 minus 33). The random percentage factor is justified by the potential impact of a threat missile, which may completely mission kill the destroyer, resulting in a full reduction of the ship's missile contributions to the friendly resource pool, or the enemy missile may only damage the aft missile cells, resulting in a partial reduction of counter-engagement capability.

f. Inclusion of ISR Platforms and Area of Uncertainty

With the fundamental principles of DMO aimed towards the enhancement of operational lethality, the model primarily focuses on the simulation of attack capable platforms and engagements using both kinetic and non-kinetic means. An additional facet of the DMO concept is the ability for an action group to share a common tactical operating picture that allows for cooperative engagements between multi-domain platforms. In both the friendly and enemy orders of battle, there are several platforms that enable this link or network capability, such as the airborne early warning aircraft and unmanned ISR assets. While these resources do not contribute any missiles to the shared resource pool, they contribute to the fleet's ability to perform the finding stage of the kill chain.

The area of uncertainty only applies to the adversary in the finding phase who is actively attempting to find its assigned target, and represents a geographical area around the targeted asset that increases as a function of the friendly platforms speed as well as the time that the blue asset goes undetected. For each unsuccessful find scan from the adversary threat sensors, the AOU grows larger around the targeted friendly platform. The presence of the enemy ISR platforms in a particular run directly correlates to a change in the area of uncertainty calculations for a friendly asset. The various adversary airborne early warning rotary and fixed wing aircraft, maritime patrol aircraft, and reconnaissance satellite are advantageous to the enemy as the AOU for any targetable blue platform is decreased. By diminishing the AOU, an adversary system is able to devote more detection resources to a smaller geographical area, resulting in either a higher probability of finding the assigned blue platform, or less time spent in the find phase of the kill chain sequence. Additionally, for both friendly and enemy forces, the presence of the ISR platforms creates additional clutter, or contacts that the strike assets must dedicate time and resources to detect and classify. These ISR assets also serve as a mission assignable or targetable platform for both forces, and contribute to the overall fleet survivability metrics.

g. Employment of Tactics

The final major component of the model's functionality is the incorporation of the counter-measures and tactics employable by the friendly forces. Each of the 4 major categories of counter-targeting and deceptive tactics identified for inclusion in the DMO evaluation are considered in the model. The tactics are implemented separately as a function of the intended impact of applying the tactic, and where the counter-measure influences the adversary's kill chain.

(1) Swarm

The first of the DMO tactics available for employment by friendly forces is the use of swarms of unmanned assets. Swarms serve as a counter-targeting measure, as it can be employed prior to an enemy threat launching a missile in an effort to divert threats or prevent the ability to target friendly forces. The primary objective of deploying a cooperative group of remotely piloted or controlled vehicles is to create clutter for enemy sensors, or emulate a targetable friendly forces asset. If the swarm is able to effectively imitate a blue vessel or aircraft, the enemy resources used to perform the functions of the kill chain are diverted from the actual targetable friendly assets, and are then dedicated to pursuing a false contact.

The swarm capability is incorporated into the model in terms of an input variable as well as the adversary's mission assignment calculations. The swarm random input provides a continuous value ranging from 0 to 1, corresponding to the effectiveness of the swarm, or the ability to emulate a high value unit. If the swarm is present in the model, then the mission assignment calculation is considered, in which the swarm probability of assignment is a random value that ranges from 0 to the percentage equal to the high value unit. The greatest level of effectiveness for a swarm of vehicles is to successfully emulate the high value units, either the aircraft carrier in the surface domain, or the E-2 airborne early warning aircraft in the air domain. If the swarm mission assignment probability is set to the value of the critical friendly assets, this results in the enemy resources being equally distributed between the actual, manned high value asset, and the false high value unit that is comprised of numerous remotely controlled vehicles.

Tables 9, 10, and 11 detail sample calculations for the employment of swarm in the model, in which the initial mission assignment values are considered, normalized, and redistributed among the platforms and swarm asset. Table 9 defines the example mission assignment probabilities with no change due to swarm not being active for a particular run of the simulation. The following example shown in Table 10 is the other extreme, in which a swarm is present and is determined to be extremely effective in imitating the carrier via either radar cross section or electromagnetic emissions. For this case, the probability of an enemy threat being assigned the swarm is equal to the value of the mission assignment probability for the aircraft carrier, and the remaining percentage of assignment probabilities are redistributed among the other targetable platforms in the simulation. The final example depicted in Table 11 demonstrates the case in which a swarm is partially effective, or may be successful at emulating a vessel or aircraft other than the aircraft carrier or E-2 high value units. The aircraft carrier accounts for nearly half (45 percent) of the mission assignment probability, and swarm is generated to represent a partial effectiveness of emulating the carrier. The probability of mission assignment for swarm is generated relative to the CVN, as 23 percent of possible assignment in the sample simulation, which reduces the targeting probabilities for the other friendly force assets in the simulation due to the normalization and redistribution of the probabilities upon consideration of the addition of the swarm vehicles.

Table 9. Mission Assignment Sample Probabilities—No Swarm

	CVN	**LPD**	**DDG-51**	**F-35**	**SWARM**	**TOTAL**
SWARM INACTIVE	45%	30%	20%	5%	0%	**100%**

Table 10. Mission Assignment Sample Probabilities—Effective Swarm

SWARM ACTIVE 100% EFFECTIVE -NESS		***CVN***	***LPD***	***DDG-51***	***F-35***	***SWARM***	**TOTAL**
	INITIAL	45%	30%	20%	5%	0%	**100%**
	REDISTRIBUTED	31%	21%	14%	3%	31%	**100%**

Table 11. Mission Assignment Sample Probabilities—Partially Effective Swarm

SWARM ACTIVE 65% EFFECTIVE -NESS		***CVN***	***LPD***	***DDG-51***	***F-35***	***SWARM***	**TOTAL**
	INITIAL	45%	30%	20%	5%	0%	**100%**
	REDISTRIBUTED	35%	23%	15%	4%	23%	**100%**

(2) Mechanical and Physical Counter-measures

For the various types of mechanical and physical decoys and tactics, each device is considered independently, and incorporated into the specific phase of the model that is impacted by the counter-measure. Passive and active decoys serve as counter-targeting measures as they are employed preemptively at the start of the simulation to hinder or prevent enemy finding and targeting of friendly forces. The decoys serve as additional contacts or clutter for the enemy forces to have to allocate resources to classify and identify. Chaff, flares, and the various types of smoke are implemented as defensive counter-measures once an enemy missile is launched, rather than assets used in the counter-targeting stages. These counter-measures are deployable upon the event of an enemy weapons launch, and aim to divert inbound enemy missiles that have reached the terminal guidance phase. The chaff, flares, and smoke counter-measures are applied as the final effort to prevent an enemy threat from intercepting a friendly asset once all other hard-kill options have been exhausted or are no longer applicable due to range restrictions.

The quantities and types of mechanical and physical decoys and counter-measures are input variables that are determined prior to the initialization of the model. The decoys, chaff, flares, and smoke are all continuous variables ranging from 0 to a prescribed maximum value, and are incorporated into the model for the defense of the friendly forces against an enemy threat in the engagement phase. These mechanical devices are not associated with any specific platform, and are maintained in a resource pool, similarly to the missiles available for engagements.

The counter-measures are modeled as advantageous to the friendly forces, as the ability to employ a mechanical or physical distraction is determined by the terminal guidance of the inbound threat missile. For example, a chaff counter-measure is not deployable for an enemy launched IR seeking missile, as the chaff would be ineffective at diverting the threat from striking a blue asset. While this assumes that the friendly forces are able to correctly identify all inbound threats and determine the appropriate counter-measure, the tradeoff is that these counter-measures are only employed against missiles that have reached their terminal guidance and are within 10 nautical miles from the targetable asset. This ensures a very limited time for counter-measure employment to defend friendly force platforms, as a function of the terminal speed of the inbound threat. Additionally, a deployed physical counter-measure impacts only 1 enemy threat in the model. For example, the employment of chaff is directed towards only 1 enemy threat, and has no impact on any subsequent missiles.

(3) Electronic Jamming

The controlled radiation of energy to prevent the enemy's unobstructed use of the electromagnetic spectrum is modeled as a counter-targeting measure, or actions taken prior to an adversary missile engagement against friendly forces. The 5 methods of jamming considered in the DMO model are simulated by employing degradation factors against enemy sensors in the finding and targeting phases of the kill chain. These degradation factors are numerical values ranging from 0 to 1, with 0 relating to complete deprivation of the use of a sensor, and 1 corresponding to jamming having no impact on a certain sensor. For example, employing spot jamming to interfere with a frequency agile radar will have a lower degradation factor (value closer to 1), than barrage or DRFM jamming which inhibits multiple operating frequencies simultaneously. The degradation factors are determined relative to each jamming type against all threat sensors in each phase of the kill chain, and are incorporated into the model by multiplying these values by the normal sensor performance parameters. For example, conducting barrage jamming against an enemy Y-8FQ aircraft radar corresponds to a degradation factor of 0.4, resulting in a 60 percent degradation of the adversary aircraft's sensor performance and ability to find the assigned friendly force asset.

The application of jamming in each run of the simulation is an input variable that is determined prior to the start of the model. Each type of jamming is either active or inactive, with allowable values of 0 or 1 and is assumed to remain active or inactive throughout the duration of the simulation. Multiple types of electronic jamming can be practiced in a single run, and are considered as cumulative yet independent effects. Jamming is initiated at the start of the simulation, and is not conducted by any specific friendly platform. Jamming is modeled as advantageous to friendly forces as there is no penalty or degradation to own force sensor performance or additional interference with the employment of multiple jamming types. The only modeled consequence for employing jamming is a larger ESM signature for each friendly platform, resulting in a higher probability of find for enemy threats using an ESM suite to detect and locate assigned blue platforms. The jamming counter-targeting tactic is assumed to impact all threat sensors in the engagement. Additionally, perfect information is assumed for jamming, meaning that the jamming employed is prescribed to be effective against the operating frequency of an adversary sensor. For example, if spot jamming is employed by friendly forces, it is assumed that the exact frequency radiated by an adversary platform is known, and able to be effectively overpowered by the spot jamming signal.

(4) Emissions Control

The final tactic available for employment by friendly forces is the ability for certain platforms to operate in a restrictive EMCON condition. In the model, only the major missile carrier surface combatants (cruisers and destroyers), are able to fully limit their electromagnetic radiation and operate in EMCON Alpha. The decision to limit the employment of EMCON to only the primary missile carriers is due to the simulated impact of EMCON for a specific platform, specifically with regard to the contributions to the common resource pool. The advantage to employing EMCON Alpha for the friendly force missile carriers is that the adversary sensors are not capable of finding the CG, DDG-51, or DDG-1000 warships using the ESM sensors, and the enemy's active radar homing threats have a lowered probability of intercept. The tradeoff for the U.S. fleet is the significant loss in strike capability, as a missile carrier in the restrictive EMCON posture does not contribute any missiles to the shared resource pool, since the platform is required to radiate in order to launch the shipboard missiles.

The application of EMCON is an input to the model, determined as a 2 level variable (EMCON Delta or EMCON Alpha) for the CG, DDG-51, and DDG-1000 platforms. Additionally, if the model prescribes that the cruiser is to operate in EMCON Alpha, all cruisers in the simulation will be set to EMCON Alpha. The employment of EMCON begins at the start of the simulation, and remains constant throughout the duration of the specific replication.

2. Model Assumptions and Limitations

While any model can be improved to incorporate additional fidelity to simulate realistic operating conditions, the project time constraints required the SEA-27 team to make decisions regarding the implementation of simplifying assumptions. Overall, the team objective is to create a simulation that models the DMO concept in terms of a balanced fleet-on-fleet engagement between near-peer adversaries. While many realistic battle environment conditions are simplified in the model, the aim is to facilitate the gathering of insights as to which deceptive tactics and counter-measures best suit the friendly force's objectives of increased lethality and distributed offensive capabilities across all domains. While many of the simplifying assumptions result in advantages to either the friendly or enemy forces, the aim of creating the model and analyzing the results is to examine the impact of the platforms and tactics employed with respect to the overall metrics of success for the blue maritime forces.

One of the primary limitations of the DMO model is the run time for each simulation. The time allocated for the engagements is approximately 3 hours, which is determined as a function of the slowest moving platform in the enemy order of battle, and its speed of advance to reach the location of the friendly forces. With the relatively short run time, the model is effectively examining only the initial round of strikes against the friendly forces providing defense of the island. In addition to the simulation run time, the enemy order of battle remains constant for all replications of the simulation. For both of these simplifying assumptions, only the initial wave of engagements is examined, in which a follow on study could investigate the possibility of extending the run time and considering the loss of major platforms during the first sequence of engagements.

For all platforms and their respective operating parameters, simplifications were implemented with regards to sensors and networking capability. For example, friendly forces are assumed to have a network established for shared offensive strike capabilities, but the enemy platforms are assumed to operate independently with no shared detection or targeting information. To counter-balance this advantage to friendly forces, the sensor performance advantage is provided to the enemy forces. For each adversary platform, their best inherent sensor is assumed operational and able to be employed against friendly assets.

An example of this implementation is a PLAN surface threat being assigned to target and engage an F-35. The enemy surface vessel probabilities of find, target, and engage are determined as a function of the highest performing, most capable radar against the F-35 target. The performance characteristics for the sensors are not specified to the level of considering different variations onboard platforms of different classes. The phased array radar is assumed to be equivalent on the Renhai class destroyer as the phased array radar onboard the Luyang III destroyer.

A simplification for the forces is that each aircraft is considered as an independent entity without consideration of the association to a specific parent platform. For example, an F-35 aircraft may be generated in a run where there is no aircraft carrier or amphibious assault ship that serve as the landing platform for the F-35. The justification for considering aircraft as separate entities from the carrying and landing ship, is the assumption of the ability to utilize regional air bases for additional staging and landing facilities. The proximity of the operating area to U.S. friendly ashore bases such as Clark Air Force Base in the Philippines is advantageous to the friendly forces, while the enemy aircraft are able to utilize the mainland bases as well as the forward staging on the militarized island chains.

With respect to staging and forward deployed operations, the model does not consider logistics as a limiting or enabling factor for either fleet. Due to the short run time of the simulation, it is assumed that all resources needed for maneuver and engagements are contained within the units in the operating area, with no consideration given to the need for refueling or rearming. Additionally, no supply ships or aircraft are incorporated into the either belligerent's order of battle, which would serve as targetable platforms in a realistic engagement.

B. DESIGN OF EXPERIMENTS

Simulating the application of DMO is contingent on the ability to examine alternative force compositions and structures, as well as the various potential implementations of tactics and counter-measures. In order to perform a comparison of a traditional force structure to an innovative, distributed force structure capable of conducting DMO, two separate operational simulations are conducted. The first simulation occurs with a projected baseline or traditional force structure of 2030, which includes a carrier strike group, an expeditionary strike group, and several independent units, as detailed in Table 12. The input variables for the simulation, depicted in Table 13, of the baseline force composition consists of only the various counter-measures and tactics that can be employed by the friendly forces, as the platforms available to be generated and paired against an enemy threat are determined prior to the start of the simulation.

Table 12. Baseline Fixed Force Structure

Carrier Strike Group (CSG)		**Expeditionary Strike Group (ESG)**		**Independent Units**	
1	CVN	1	LHA/LHD	1	CG
1	CG	2	LPD	1	DDG-1000
3	DDG-51	1	DDG-51	2	DDG-51
1	LCS	2	LCS	2	LCS
10	F-35 (Air)	4	F-35 (Air)	4	MDUSV
10	F-35 (Surface)	4	F-35 (Surface)	2	EPF
10	F/A-18 (Air)	4	MH-60 R/S	3	P-8 MPRA
10	F/A-18 (Surface)	6	AH-1	2	MH-60 R/S
6	EA-18	2	MQ-8	6	MQ-8
2	E-2	2	MQ-9	4	MQ-9
4	MH-60 R/S	4	TERN	2	MQ-4
2	MQ-8			12	TERN
2	MQ-9				
4	TERN				

Table 13. Baseline Force Structure Input Variables

Tactics & Counter-Measures			
Variable	Minimum	Maximum	Type
Swarm	0	1	Discrete
Chaff	0	200	Continuous
Flares	0	50	Continuous
Visual Smoke	0	50	Continuous
IR Smoke	0	50	Continuous
Active Decoys	0	25	Continuous
Passive Decoys	0	300	Continuous
Spot Jamming	0	1	Discrete
Barrage Jamming	0	1	Discrete
Sweep Jamming	0	1	Discrete
DRFM Jamming	0	1	Discrete
GPS Jamming	0	1	Discrete
CG EMCON	0	1	Discrete
DDG-51 EMCON	0	1	Discrete
DDG-1000 EMCON	0	1	Discrete

The second event simulation of the experiment considers the employment of non-traditional force architectures, as the discrete integer quantities of the multi-domain platforms are varied within the model. Table 14 details the input variables for the DMO experimental design, which includes not only the application of deceptive counter-targeting tactics and defensive counter-measures, but also the adjustable platform quantities. This design allows for cooperative, networked friendly assets that do not conform to a prescribed action group structure. For example, a single run may consist of non-traditionally grouped platforms such as a DDG-1000, EPF, EA-18s, AH-1s, an MQ-9, and various deceptive tactics and counter-measures that must function in an integrated manner to meet operational objectives and protect own force assets.

Table 14. Variable Force Structure Input Variables

Platforms			Tactics & Counter-measures			
Variable	Min	Max	Variable	Min	Max	Type
CVN	0	2	Swarm	0	1	Discrete
LHA/LHD	0	2	Chaff	0	200	Continuous
LPD	0	4	Flares	0	50	Continuous
CG	0	3	Visual Smoke	0	50	Continuous
DDG-51	0	10	IR Smoke	0	50	Continuous
DDG-1000	0	1	Active Decoys	0	25	Continuous
LCS	0	6	Passive Decoys	0	300	Continuous
EPF	0	3	Spot Jamming	0	1	Discrete
MDUSV	0	6	Barrage Jamming	0	1	Discrete
F-35 (A)	0	30	Sweep Jamming	0	1	Discrete
F-35 (S)	0	30	DRFM Jamming	0	1	Discrete
F/A-18 (A)	0	10	GPS Jamming	0	1	Discrete
F/A-18 (S)	0	10	CG EMCON	0	1	Discrete
EA-18	0	5	DDG-51 EMCON	0	1	Discrete
E-2	0	2	DDG-1000 EMCON	0	1	Discrete
P-8	0	8				
MH-60	0	16				
AH-1	0	6				
MQ-4	0	3				
MQ-8	0	20				
MQ-9	0	15				
TERN	0	54				

Determination of the desired simulation objectives and input variables leads to the selection of the experimental design needed to facilitate the data generation and analysis of various DMO alternatives. With the presence of both continuous and discrete input variables or various levels, and the potential for over several million design points to simulate, the nearly orthogonal balanced (NOB) design is selected as an appropriate method for the DMO simulation and analysis (Vieira et al. 2011).

The NOB process creates a space filling design that enables the consideration of the various variable types and levels, while minimizing correlation between the input variables. The balanced portion of the design refers to the same frequency of occurrence for every factor of an input variable. Nearly orthogonal describes the method that ensures the maximum absolute pairwise correlation between any two factors is less than 0.05, meaning that the effect of one factor is essentially independent of the effects for another factor. Lastly, the space filling capability refers to the creation of a representative sample of the solution space since the examination of every possible combination of variables is impossible due to time constraints (Vieira et al. 2011).

The NOB space filling design enables the creation of 512 design points, or combinations of the input variables including tactics for the baseline force structure, and platforms as well as tactics for the DMO capable force structure. A sample of these design points is detailed in Appendix I. Figure 8 depicts a representation of the input variables for the DMO force structure simulation to demonstrate the space filling capability of the experimental design. The manned platform input variables can accept discrete integer quantities, while the decoys and tactics variables shown on the scatterplot can take on a wider range of continuous values. Additionally, the maximum absolute pairwise comparison between the full set of input variables is 0.0299, which is within acceptable limits for a simulation of this nature. Each of the 512 design points is replicated 30 times to limit the impact of variability, resulting in 15,360 simulation runs for both the baseline and DMO-centric force structures, for an overall total of 30,720 simulation runs. While each run varies due to the changing input variables, the approximate time to run each replication of the simulation is 10 to 30 seconds, resulting in an overall run time of nearly 16 hours.

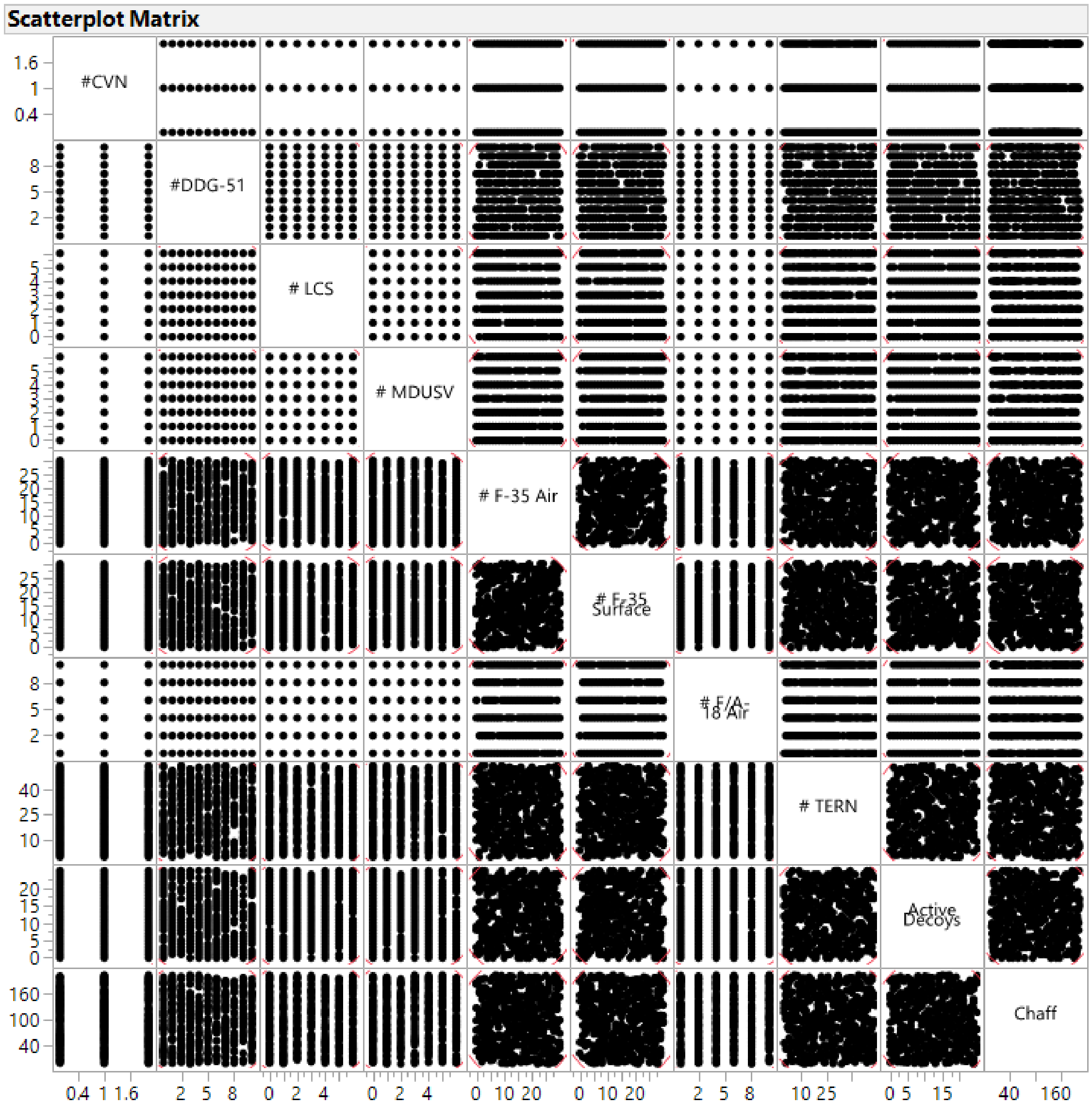

Figure 8. DMO Structure Input Variable Scatterplot Matrix—First 10 Input Variables

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VII. MODEL ANALYSIS

Using the data extracted from the 30,720 total runs of the model as described in Chapter VI.B, the team applies various statistical analysis methods to determine the impact of the various platforms, unmanned systems, counter-measures, and tactics on the ability to perform DMO. The model output is divided into two major groups of 15,360 runs, or 512 observations or data points with 30 replications of each individual data point. The first set of output data corresponds to the baseline fixed force structure that considers only the tactics and counter-measures as model input variables. The second data set refers to the variable DMO force structure in which the tactics and friendly force platforms that can be employed against the enemy forces in the engagement simulation are changed from run to run.

By performing an analysis of both sets of extracted data, the team aims to gain insights and provide evidence to support recommendations for various levels of leadership. The baseline force structure insights are directed towards operational commanders that may not have the ability to determine or allocate the specific forces for employment, but can alter the tactics in order to increase the survivability and lethality of the forces available at the time of the engagement. The analysis conducted on the modifiable DMO force structure enables recommendations that provide insight for the echelons of leadership that are capable of making force architecture recommendations and assignments, as the simulation considers various groupings of platforms, assets, and tactics, for employment in the fleet-on-fleet engagement.

In order to develop these insights from the model outputs, the data captured by the simulation allows for the calculating of the measures of performance and effectiveness as described in Chapter V, as well as several additional metrics that provide further fidelity into the overall performance of the friendly forces participating in the engagement. Table 15 details the parameters captured by the model, which are further detailed in the equations shown in Appendix E.

Table 15. Metrics Captured by the ExtendSim Model

Percentage of Friendly Force Assets Killed	Percentage of Friendly High Value Surface Assets Killed (CVN/LHD/LHA) Percentage of Friendly Missile Carriers Killed (DDG(s), CG) Percentage of Friendly Force High Value Aircraft Killed (E-2) Percentage of Friendly Force Fighter Aircraft Killed (F-35, F/A-18, EA-18)
Percentage of Enemy Killed	Percentage of Enemy Platforms Killed (Surface & Aircraft) Percentage of Enemy Missiles Killed
Percentage of Enemy Complete Find	Percentage Enemy Aircraft Successfully Find Friendly Asset Percentage Enemy Surface Successfully Find Friendly Asset Percentage Enemy Missile Successfully Find Friendly Asset
Percentage of Enemy Complete Targeting	Percentage Enemy Aircraft Successfully Target Friendly Asset Percentage Enemy Surface Successfully Target Friendly Asset Percentage Enemy Missile Successfully Target Friendly Asset Percentage of Enemy Missiles Reach 10 nmi from Friendly Forces
Time to Find	Enemy Aircraft Average Time to Find Assigned Friendly Asset Enemy Surface Average Time to Find Assigned Friendly Asset Enemy Missile Average Time to Find Assigned Friendly Asset
Time to Target	Enemy Aircraft Average Time to Target Assigned Friendly Asset Enemy Surface Average Time to Target Assigned Friendly Asset Enemy Missile Average Time to Target Assigned Friendly Asset
Employment of Counter-Measures	Utilization Percentage of Friendly Force Chaff Utilization Percentage of Friendly Force Flares Utilization Percentage of Friendly Force IR Smoke Utilization Percentage of Friendly Force Visual Smoke Utilization Percentage of Friendly Force Active Decoys Success of Employed Mechanical and Physical Counter-Measures Success of Employed Defensive Missiles
Area of Uncertainty	Enemy Aircraft Average Area of Uncertainty for Friendly Asset Enemy Surface Average Area of Uncertainty for Friendly Asset Enemy Missile Average Area of Uncertainty for Friendly Asset

These metrics are captured, calculated, and analyzed to determine the input variables that have the largest impact on each metric through regression analysis. A statistical analysis program, JMP, is used to assist in the regression analysis and determination of significant factors and relationships between variables with respect to the ability of the friendly force assets to perform DMO. In an effort to create models that appropriately fit the data generated from the model, both the individual input variables are considered in the regression, as well as the first order interactions between variables. Additionally, the regression is performed in a stepwise manner through the application of the Bayesian Information Criterion (BIC) algorithm. The BIC method produces a parsimonious model by considering the singular input variables and impactful interactions between input variables that have an impact on the respective dependent variable or output being examined (Schwarz 1978, 461). The execution of the BIC procedure for the regression analysis assists in the determination of the statistically significant variables that have an impact on the ability to perform DMO.

Not all of the captured data and associated metrics proved to be insightful, and may not be addressed in the following analysis sections. The determination of the insightful metrics as compared to those that did not provide any substantial value during the analysis was accomplished through the use of the JMP statistical software tool, and the selection of a significance criteria. For the following analysis, only the input variables and interactions that present a p-value of less than 0.01 are considered as statistically significant factors.

In addition to recognizing the statistical significance of certain input variables with respect to performing DMO, the team aims to identify the factors with operational significance that contribute to the MOEs and MOPs. Some factors that are determined to be statistically significant in the output data from the model, may only be considered due to the way in which the forces and engagement is modeled, and not necessarily reflective of any operational significance. The determination of the operational significance of input variables is accomplished through the examination of a partition tree as created by the JMP analysis program. The partition tree allows for the consideration of only the single input variables as the interactions terms are removed from the regression analysis and the data is grouped into sub categories that improve the fit of the overall statistical model. This enables a more detailed analysis of the relative impact of singular factors on a certain metric. For example, if barrage jamming is shown to have a statistically significant impact on the survivability of friendly force aircraft, the creation of a partition tree for a certain measure assists in the identification of any operational impact of conducting barrage jamming with respect to the platforms and tactics employed in the engagement. The leveraging of the team's operational experience serves to provide context for the results within the tactical scenario and an additional level of fidelity when conducting the analysis of the integration of multi-domain platforms, assets, and tactics.

A. BASELINE FIXED FORCE STRUCTURE

The analysis of the baseline force structure considers only tactics and counter-measures as input variables, as the force composition is fixed and remains constant for all 15,360 runs of the simulation. As described in Chapter VI, the variable tactics include the five various types of jamming, employment of swarm assets, mechanical and physical counter-measures, and the limiting of emissions from the primary missile carrying platforms (CG, DDG-51, DDG-1000). These input variables and their interactions are analyzed against the output metrics of the model including the survivability of friendly and enemy forces, as well as the ability of the enemy threats to complete the finding and targeting phases of the kill chain.

1. Analysis of MOE #1: Survivability of Friendly Forces

The survivability of the friendly forces is a metric defined as the proportion of blue force assets that survive the engagement as compared to the quantity of friendly force platforms that are initialized in the specific run. The overall survivability metric is difficult to discern in terms of value due to the lack of weighting for individual platforms. For example, due to the calculation of the MOE, the loss of an aircraft carrier in a run is equivalent to the loss of an unmanned vehicle, as each asset is counted in the equation solely in terms of quantity, rather than total value. While an aircraft carrier would be a much more devastating loss to friendly forces than an MDUSV or TERN asset, this is not accounted for in this metric, and therefore the metric is more valuable in terms of sub-metrics of categorized platform groupings. The decomposition of overall survivability

MOE into several sub-metrics of categorical platform groupings provides additional insight into the ability for certain platforms to persist through the engagement against enemy forces. The team examines the survivability of four major groups; the complete fixed blue force order of battle across all domains, the aircraft carriers and amphibious assault ships, the primary missile carrier surface platforms, and the fighter aircraft (F-35, F/A-18, EA-18). For each of these groupings of platforms, the input variables that significantly contribute to survivability are determined.

Prior to examining the individual significance of the input variables, the first JMP output of the regression analysis is the actual by predicted plot, as depicted in Figure 9 for the overall survivability of the fixed OOB blue forces. The plot provides insight into the fit of the model and the predicted response as compared to the actual model output response. While an ideal R squared value is much closer to a value of 1, this model is acceptable for this simulation due to the relatively low number of input variables, and the high variability for survivability between individual runs.

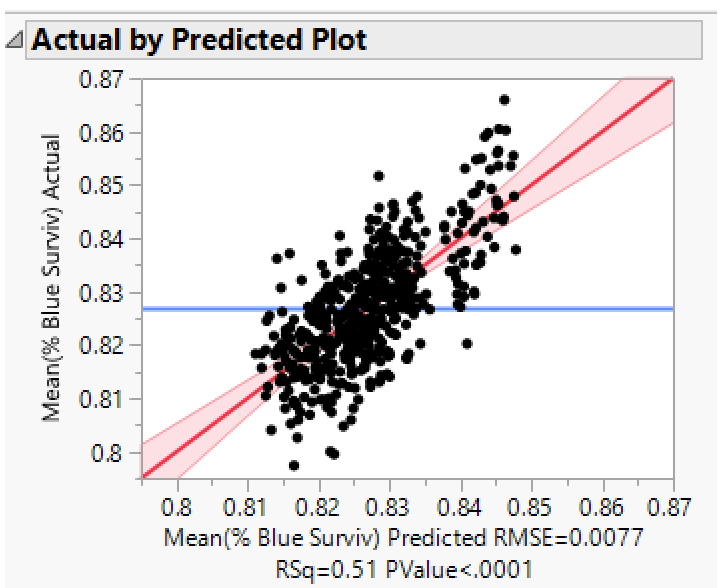


Figure 9. MOE #1: Friendly Force Overall Survivability Regression Model

Upon examining the fit of the model, the analysis of the individual factors and interactions between input variables that contribute to friendly force overall survivability is performed. Table 16 provides a summary of the insights found from the analysis of the data outputs as created by the statistical program. For the survivability of each of the platform groupings in the summarized table, the individual factors that are determined to be statistically significant from the sorted parameter estimates are listed. While the interactions between various input variables may be significant, especially for determining the parameters needed to fit the model to the data, only the individual input variables are listed in the summary tables. For example, the overall survivability of the baseline friendly force structure is impacted by the statistically significant singular input variables of spot jamming, swarm, and barrage jamming. In order to determine which of the factors may have had a positive or negative operational impact on the survivability of the friendly forces in the simulation, additional JMP outputs are considered including the sorted parameter estimates and a partition tree.

Table 16. Analysis Summary of Baseline Structure—MOE #1: Friendly Force Survivability

MOE Calculation	$\text{Percentage}_{\text{Surviving Blue Forces}} = \frac{\text{Quantity of Blue assets surviving at end of simulation}}{\text{Quantity of initial Blue assets}}$			
Statistically Significant Contributing Factors	**Baseline Fixed Force Stucture**			
	Overall Survivability	**High Value Ships**	**Missile Carriers**	**Fighter Aircraft**
	Spot Jamming Swarm Barrage Jamming	Swarm Spot Jamming Barrage Jamming	Swarm Barrage Jamming	Barrage Jamming DRFM Jamming Sweep Jamming

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(JAMMING SPOT-0.52344)*(JAMMING BARRAGE-0.45313)	0.0189575	0.001543	12.29	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING SWEEP-0.54492)	0.0149469	0.001589	9.41	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING DRFM-0.47461)	0.0136887	0.001543	8.87	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING DRFM-0.47461)	0.0096454	0.001557	6.19	<.0001*
JAMMING SPOT	0.0032529	0.000778	4.18	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING SWEEP-0.54492)	0.0055569	0.001526	3.64	0.0003*
Swarm	0.0045302	0.001352	3.35	0.0009*
(JAMMING BARRAGE-0.45313)*(IRSmoke-25)	-0.000156	0.000054	-2.89	0.0040*
(Active Decoy-12.5)*(Visual Smoke-25)	1.0841e-5	3.773e-6	2.87	0.0043*
JAMMING BARRAGE	-0.002121	0.00077	-2.75	0.0062*
(JAMMING GPS-0.52344)*(IR Smoke-25)	0.0001422	5.334e-5	2.67	0.0080*
JAMMING SWEEP	0.0019215	0.000784	2.45	0.0147*

Figure 10. MOE #1: Statistically Significant Factors—Fixed Friendly Force Overall Survivability

Figure 10 depicts a more detailed snapshot of the input variable factors and first order interactions that contribute to overall friendly force survivability. It is observed that for this specific MOE, the interactions between the various types of jamming actually has the most statistically significant impact on the survivability of the fixed blue order of battle. In this particular analysis, a partition tree is valuable in determining the operational impact of each of the statistically significant individual input variables with respect to the overall survivability of friendly forces.

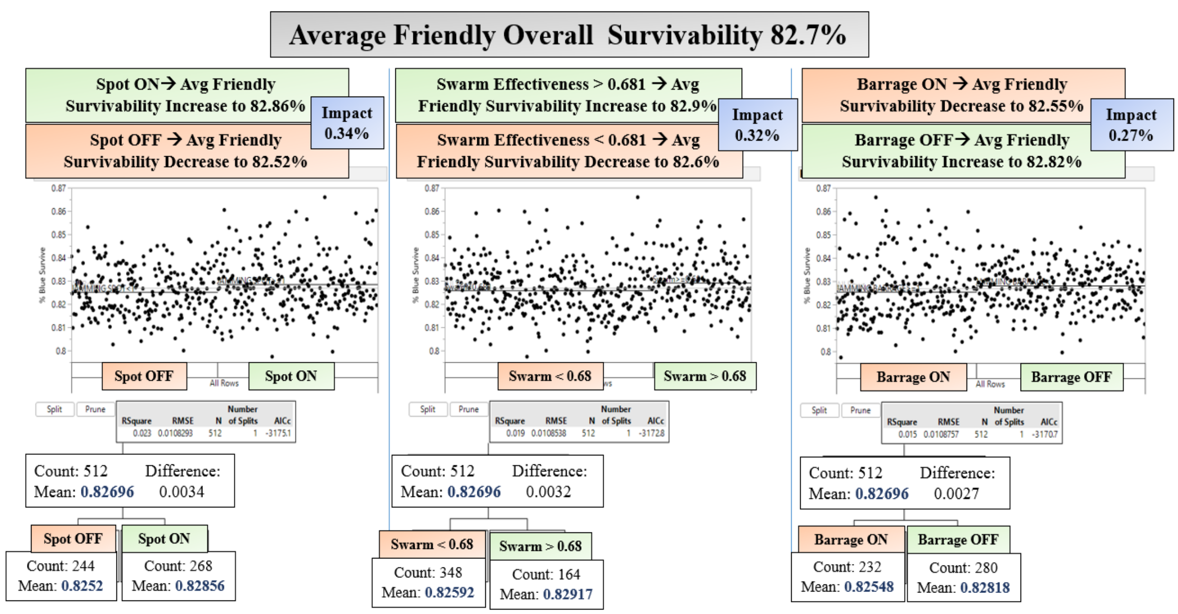


Figure 11. MOE #1: Operational Impact of Statistically Significant Factors—Fixed Friendly Force Overall Survivability

Figure 11 details the partition trees that examine three individual factors that are identified as statistically significant in the regression analysis of the overall friendly force survivability. As observed, the data is not able to be tightly grouped based on a single input factor, and the impact or significance of each of the individual tactics with respect to overall survivability is less than 0.35 percent. Considering each factor as an independent tactical option; either having spot jamming on, swarm employed with an effectiveness of over 68 percent, or barrage jamming on, there is minimal increase in the ability for blue forces to survive and continue to perform DMO in the engagement. With these percentage changes being seemingly minor, the groupings of the blue platforms into subcategories may provide additional fidelity into the significance of these input variables.

For example, the statistically significant factors described in Table 16 for the subgroup of friendly force missile carriers detail the employment of swarm and barrage jamming as having the largest potential impact on the ability for the CG and DDG platforms to remain in the engagement throughout the duration of the simulation. Figure 12 details the parameter estimates that assist in identifying swarm and barrage jamming as the statistically significant input variables. Again, a partition tree is created to further examine these factors for their respective operational significance.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Swarm	0.0795992	0.007372	10.80	<.0001*
JAMMING BARRAGE	0.0299181	0.004257	7.03	<.0001*
(JAMMING SPOT-0.5225)*(JAMMING DRFM-0.47358)	0.0576539	0.008513	6.77	<.0001*
(JAMMING SPOT-0.5225)*(JAMMING SWEEP-0.54599)	0.0486968	0.008536	5.71	<.0001*
(JAMMING SPOT-0.5225)*(JAMMING BARRAGE-0.45205)	0.046249	0.008544	5.41	<.0001*
(JAMMING BARRAGE-0.45205)*(JAMMING DRFM-0.47358)	0.0353568	0.008547	4.14	<.0001*
(JAMMING BARRAGE-0.45205)*(JAMMING SWEEP-0.54599)	0.0268378	0.008562	3.13	0.0018*
JAMMING DRFM	0.0062071	0.004253	1.46	0.1451
JAMMING SWEEP	0.0055179	0.004263	1.29	0.1962
JAMMING SPOT	0.0004059	0.004241	0.10	0.9238

Figure 12. MOE #1: Statistically Significant Factors—Survivability of Friendly Force Missile Carriers

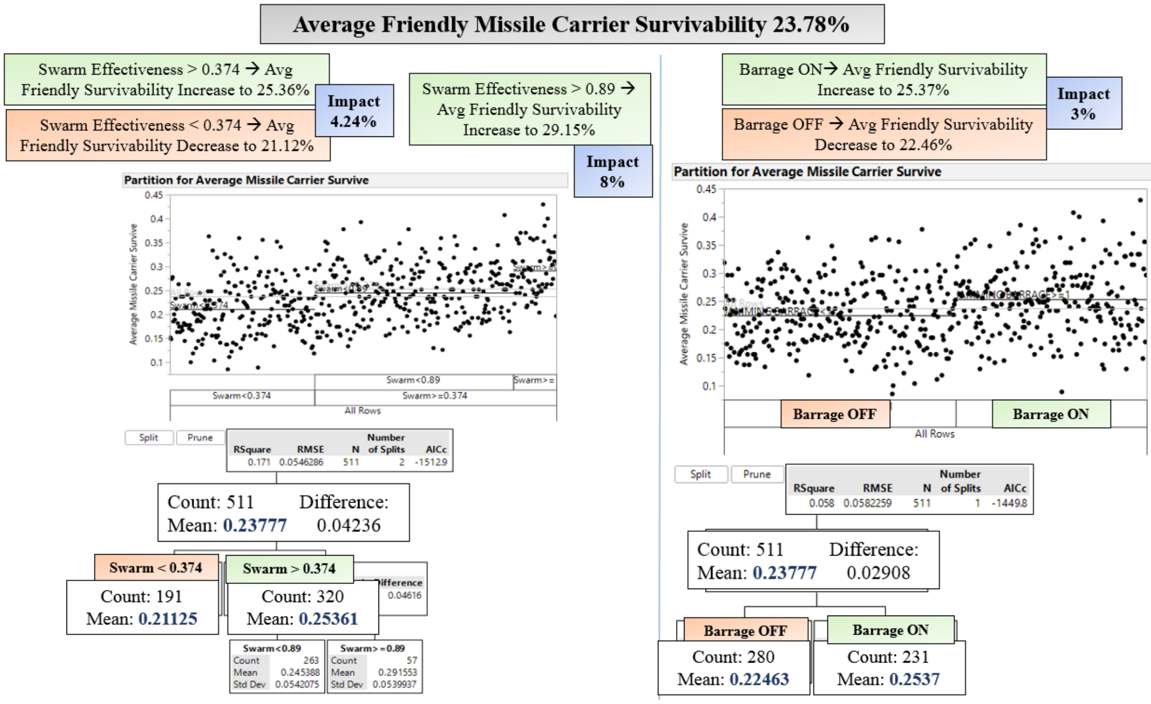


Figure 13. MOE #1: Operational Impact of Statistically Significant Factors—Fixed Friendly Missile Carrier Survivability

From the partition trees detailed in Figure 13, the parameter estimates identified as statistically significant are examined as independent, singular input variables. The tree on the left details the impact of swarm on friendly missile carrier survivability. The employment of swarm with an effectiveness of emulating the high value units is greater than 37.4 percent, results in a four percent increase of CG and DDG platforms that remain at the conclusion of the battle. Additionally, if swarm effectiveness is increased to nearly ninety percent, the overall survivability of missile carriers increases again by over 4 percent, resulting in an overall 8 percent increase in CGs and DDGs remaining at the end of the engagement simulation. This can be attributed to the mission assignment function within the model, when swarm is more effective at deceiving the enemy as the aircraft carrier, additional assignment probability is given to the swarm, and therefore reduced from the missile carrier platforms. Considering the impact of only barrage jamming being employed to impact missile carrier survivability, there is a nearly 3 percent positive relationship between the use of barrage jamming in the battle and the ability for missile carriers to remain operational in the battle.

The detailed analysis for the remaining subgroups of the high value ships and fighter aircraft are considered in Appendix K.

2. Analysis of MOE #2: Survivability of Enemy Forces

A similar process of analysis is applied to the remaining MOEs for the data set that considers the fixed baseline force structure. For this MOE, the enemy survivability is considered as an overall force survivability, and is not decomposed into various subgroupings of similar platforms or domain-centric assets. The data output regarding the overall survivability of enemy forces produces a much more aptly fit model, with an R squared value of 0.97, as depicted in the actual by predicted plot in Figure 14.

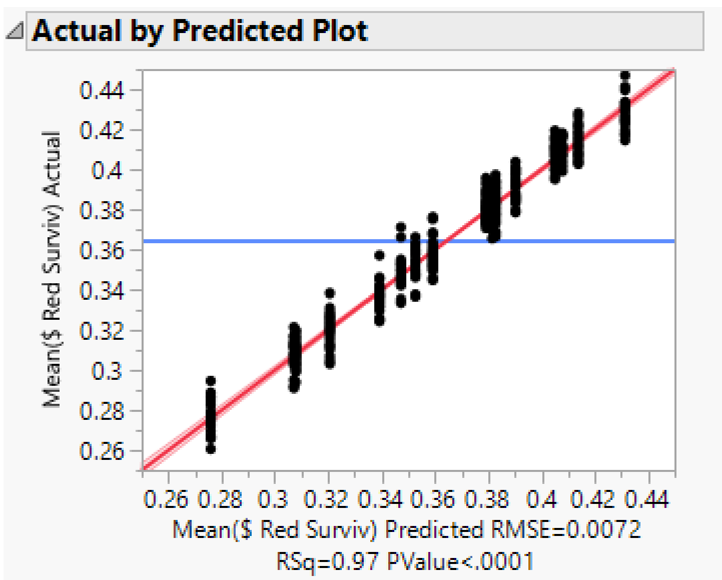


Figure 14. MOE #2: Enemy Force Survivability Regression Model

Again, considering only tactics, counter-measures, and the interactions between these factors as variables for the fixed force structure simulation, the statistically significant factors identified to impact enemy survivability include the following types of jamming; barrage, spot, DRFM, and sweep. As shown in the sorted parameter estimates in Figure 15, as each jamming is employed independently by friendly forces, the enemy force survivability decreases.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE	-0.067775	0.000693	-97.74	<.0001*
JAMMING SPOT	-0.035035	0.000701	-50.00	<.0001*
JAMMING DRFM	-0.027135	0.000679	-39.95	<.0001*
JAMMING SWEEP	-0.023834	0.000706	-33.75	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING BARRAGE-0.45313)	-0.014334	0.001389	-10.32	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING DRFM-0.47461)	-0.00841	0.001389	-6.06	<.0001*

Figure 15. MOE #2: Statistically Significant Factors—Enemy Force Survivability

In order to gain additional insight regarding the operational effectiveness of the individual jamming tactics as applied to the survivability of the enemy threats, a partition tree as shown in Figure 16 is created. With barrage jamming identified as the most statistically significant factor, the model data for the fixed force structure is grouped into barrage jamming on, and barrage jamming off. From the partition tree, it is observed that without conducting barrage jamming, the average survivability of the enemy forces is 39.5 percent. The friendly force employment of barrage jamming results in a decrease of overall red forces remaining to an average of 32.7 percent. The difference between barrage jamming on or off in this data set is approximately seven percent. Further grouping is then performed to consider spot jamming with respect to the employment of barrage jamming. The greatest reduction in overall survivability of the adversary forces is when both barrage and spot jamming tactics are able to be employed. When both jamming tactics are activated in the simulation, this results in a ten percent difference between the ratio of overall enemy assets remaining to the 149 red force platforms and missiles that are generated in the simulation, from 41.08 percent to 30.78 percent.

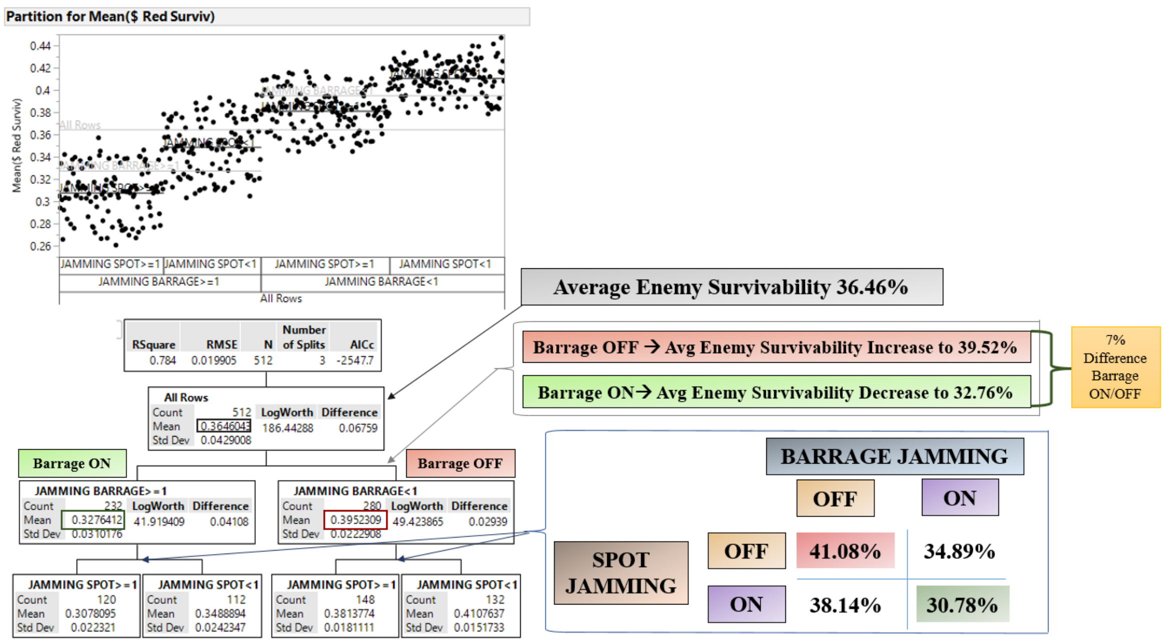


Figure 16. MOE #2: Operational Impact of Statistically Significant Factors—Fixed Force Structure Enemy Survivability

This noticeable reduction in enemy forces can be explained by the implementation of barrage jamming in the model, which has the greatest degradation against numerous enemy sensors used in the finding and targeting stages of the kill chain. Since all of the various jamming types are applied with the objective of confusing and degrading enemy search and targeting radars, the decrease in overall red force survivability can be attributed to the increase in time required for a red threat to successfully generate a targeting solution. With a jammed radar, more time is needed in order to accurately identify and target an assigned blue vessel. Likewise, friendly forces are capable of conducting counter-engagements during the targeting phase, which results in a greater number of potential counter-engagements if the threat requires additional time to obtain a firing solution.

3. Analysis of MOE #3: Enemy Force Effectiveness in Find Sequence of Kill Chain

In addition to the survivability metrics, the MOEs to evaluate the fixed force structure include the percentage of enemy threats that are able to evade friendly force counter-targeting efforts and complete the various stages of the kill chain. The first MOE is the effectiveness of the overall enemy force in completing the find portion of the kill chain. This metric is calculated by determining the percentage of enemy threats that successfully find their assigned blue target.

Table 17 describes the statistically significant individual factors that contribute to the enemy air, surface, and land-based missile threats' ability to find the assigned friendly force asset. Each enemy platform in the various domains experiences different significant factors as a result of the sensors employed to complete the finding stage of the model.

Table 17. Analysis Summary of Baseline Structure—Enemy Find Effectiveness

MOE Calculation	$\text{Percentage}_{\text{Red find Blue}} = \frac{\text{Quantity of Red threats successfully find assigned Blue platform}}{\text{Quantity of total Red threats}}$		
Statistically Significant Contributing Factors	**Baseline Fixed Force Stucture**		
	Enemy Air Find	**Enemy Surface Find**	**Enemy Missile Find**
	Barrage Jamming	Spot Jamming Passive Decoys DRFM Jamming	Spot Jamming DRFM Jamming Barrage Jamming Sweep Jamming

Due to the simulation run time of approximately three hours, the enemy threats are provided ample time to transit the operating area and successfully complete the find phase. Additionally, friendly forces are incapable of conducting counter-engagements while a threat is in the find sequence, therefore the only potential impact to a an enemy threat conducting search is the application of tactics and the associated degradation factors. The only instance in which a red threat could be unsuccessful during this find phase is when the red threat sensor is substantially degraded or incompatible with the assignment platform. This scenario is rarely an issue for the slower surface platforms, but is much more prevalent for the significantly faster red missiles and aircraft that are capable of closing this distance due to their attributed speed of advance. If a red threat is unsuccessful in finding its intended blue target, the enemy platform or missile exits the model and does not proceed to the targeting or engagement portion.

For this specific MOE, air and surface platforms are nearly guaranteed to find their assigned asset in the simulation, and are therefore rarely impacted by any particular tactic of counter-measure. Due to the excessive speeds on the enemy missiles, some tactics can be employed by friendly forces to delay the finding just enough to divert or force the missile out of the model. As depicted in the parameter estimates of the enemy missiles' ability to find an assigned blue force asset in Figure 17, an interaction term is deemed significant in the regression analysis, therefore a partition tree is created to examine the operational impact of the various, independent types of jamming.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
→ JAMMING SPOT	-0.11454	0.001283	-89.28	<.0001*
→ JAMMING DRFM	-0.03648	0.001284	-28.41	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING DRFM-0.47461)	-0.047287	0.002571	-18.39	<.0001*
→ JAMMING BARRAGE	-0.013116	0.001287	-10.19	<.0001*
→ JAMMING SWEEP	-0.012146	0.001287	-9.44	<.0001*

Figure 17. MOE #2: Statistically Significant Factors—Enemy Missile Ability to Find the Assigned Friendly Force Asset

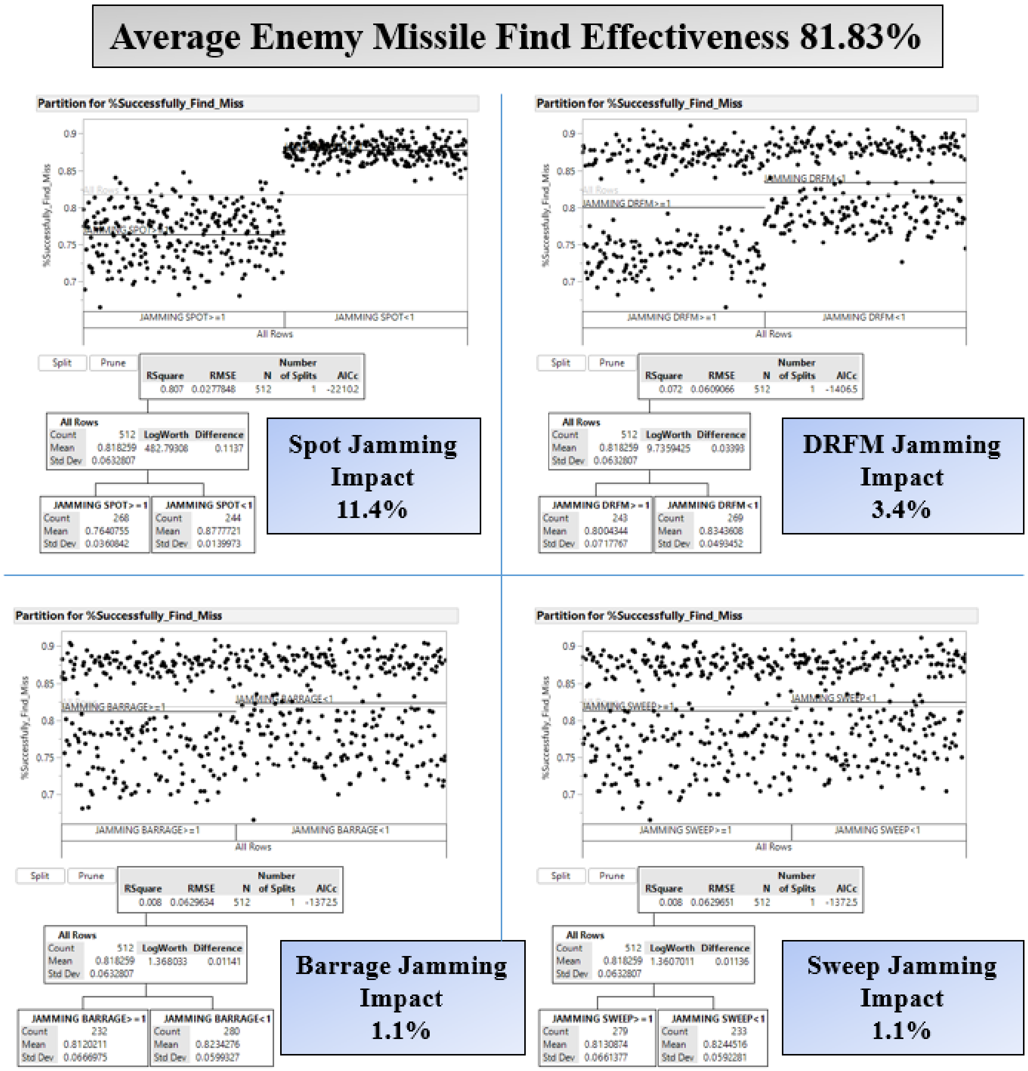


Figure 18. MOE #3: Operational Impact of Statistically Significant Factors—Enemy Missile Ability to Find the Assigned Friendly Force Asset

With respect to the enemy missiles' ability to find an assigned friendly force asset, spot jamming has the greatest operational impact at 11.4 percent. This value represents the difference in the effectiveness of the enemy missile with respect to its ability to find the assigned blue force asset, with either spot jamming on or off in the simulation. Without spot jamming activated, the percentage of enemy missiles that are able to find the assigned target is nearly 88 percent, while the activation of spot jamming results in an eleven percent reduction to 76.4 percent. While this is still a relatively high percentage of successful find for the enemy missiles, additional opportunities to counter the inbound threat occur during the engagement phase with the employment of hard-kill and soft-kill counter-measures. Additional detailed analysis for the air and surface domains considered in MOE #3 of enemy force effectiveness in the find sequence is contained in Appendix K.

4. Analysis of MOE #4: Enemy Force Effectiveness in Target Sequence of the Kill Chain

The fourth MOE for consideration in the analysis of the baseline force structure is the effectiveness of the enemy threats in the targeting and engaging phases of the kill sequence. This metric is calculated as a function of the quantity of enemy threats that successfully complete the targeting phase as compared to the number of platforms that enter the targeting phase. The enemy missiles do not enter the targeting phase, once a missile is able to successfully find the assigned target, it automatically transitions to the engagement portion of the kill chain. Therefore, the threat missiles are not considered in this metric. Additionally, the adversary threats that are unsuccessful in the find phase are not captured in this metric, as a platform cannot progress to the targeting stage until a location is determined for the assigned blue asset. The primary differences between the targeting percentage and the finding percentage is due to the capability of enemy sensor performance for finding as opposed to targeting, as well as the ability for friendly force assets to conduct an engagement against red threats that advance to the targeting phase. Additionally, in the simulation, if the threat is able to complete the targeting sequence, a weapons engagement of the friendly asset is conducted.

Table 18. Analysis Summary of Baseline Structure—Enemy Target Effectiveness

MOE Calculation	$\text{Percentage}_{\text{Red target Blue}} = \frac{\text{Quantity of Red threats that target/engage assigned Blue platform}}{\text{Quantity Red threats that successfully find their assigned Blue}}$	
Statistically Significant Contributing Factors	**Baseline Fixed Force Stucture**	
	Enemy Air Target & Engage	**Enemy Surface Target & Engage**
	Barrage Jamming Spot Jamming DRFM Jamming Sweep Jamming	Barrage Jamming Spot Jamming DRFM Jamming Sweep Jamming

As captured in Table 18 from the parameter estimates from the various domains, four of the jamming types are deemed statistically significant for the targeting sequence of the kill chain, regardless of platform type. To determine the operational significance of these input tactics, the partition tree for the effectiveness of enemy aircraft in the targeting sequence is studied.

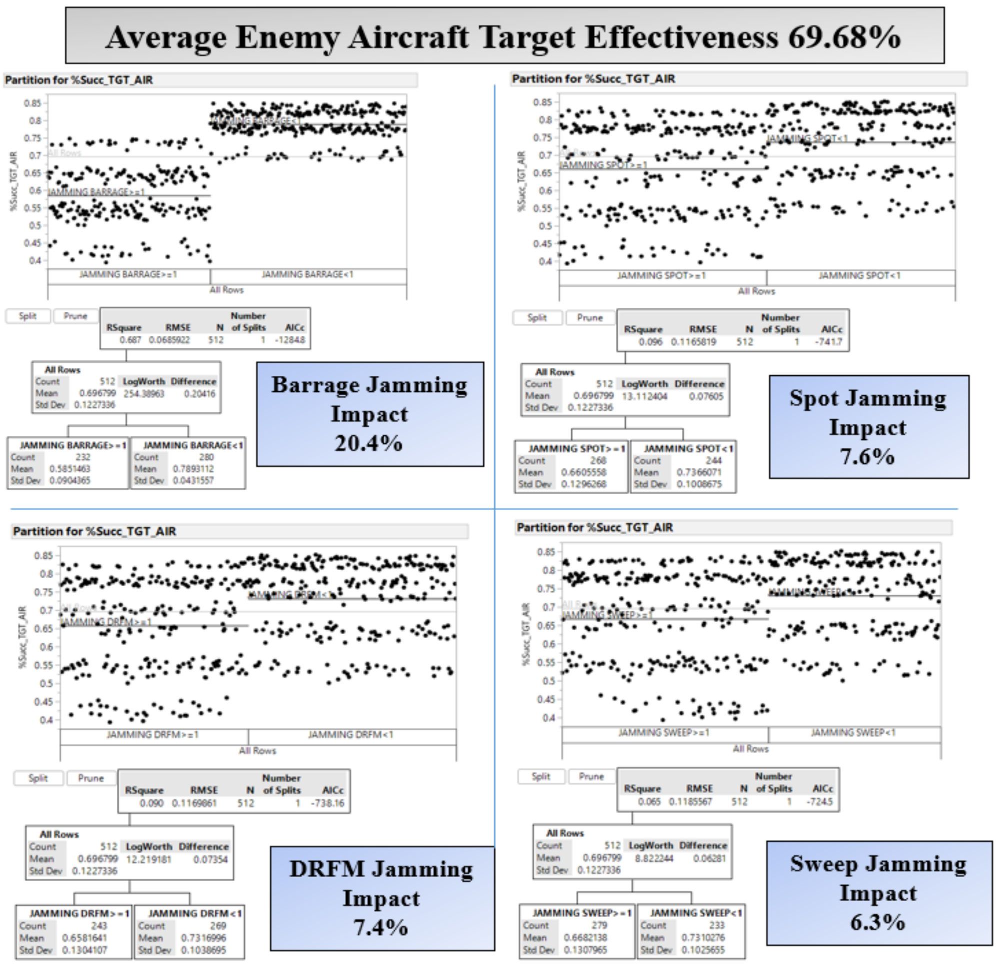


Figure 19. MOE #4: Operational Impact of Statistically Significant Factors—Enemy Aircraft Ability to Target an Assigned Friendly Force Asset

With the activation of barrage jamming as an independent tactic in the model, the percentage of enemy aircraft that are able to successfully complete the targeting phase is reduced by over twenty percent. This reduction in targeting capability subsequently diminishes the ability for the enemy to employ their weapons systems against blue force platforms. Barrage jamming also reduces the percentage of red surface vessels able to reach the engagement phase by 9.4 percent. Both of these reductions can be attributed to the impact barrage jamming has on the adversary targeting radars. By degrading these targeting radars, barrage jamming is able to keep the red threats in the targeting phase longer, where blue has more opportunities to counter-engage the enemy platform or missile.

The employment of spot, DRFM, or sweep jamming as independent tactics also has a noticeable reduction in the ability for enemy aircraft to conduct targeting and engagement. These jamming capabilities lead to scenarios in which the friendly forces are able to successfully engage and destroy an adversary platform before threat missiles can be launched to strike blue forces. Since jamming is modeled in a way that benefits the adversary ESM sensors and degrades enemy radars, this result is noteworthy. It is evident that the drawback of using jamming, as it is currently modeled, is greatly surpassed by the benefit associated with degrading enemy radar systems.

5. Analysis of Measures of Performance

When examining the MOPs for the fixed friendly force structure, similar general trends are observed. This is especially true as many of the measures of performance are capturing similar information to the metrics described in the MOEs. For example, an enemy aircraft time to target is similar and largely correlated to the overall effectiveness for an enemy aircraft in the targeting phase of the kill chain. With the number of input variables limited to only the employment of tactics and counter-measures, the various types of jamming are frequently observed to be a dominant factor for both the MOEs and related MOPs. The correlation between the MOEs and MOPs can be observed in the scatterplot matrix displayed in Figure 20. The six factors depicted in the scatterplot are the MOEs of percentage of enemy threats that successfully target their assigned friendly force asset, as well as the related MOPs of time to target for air, surface, and missile threats. Due to the correlation between the MOEs and MOPs, along with the prevalence of jamming as the dominant factor in each regression analysis, the analysis of the MOPs are omitted from this section, as little additional insight is gained from the specified analysis of the area of uncertainty, time to find, and time to target with respect to the three threat categories of air, surface, and missile threats. The analyses for the fixed force structure MOPs are contained in Appendix K. Additional MOPs are evaluated and discussed in further detail for the analysis of the DMO variable force structure in the following section.

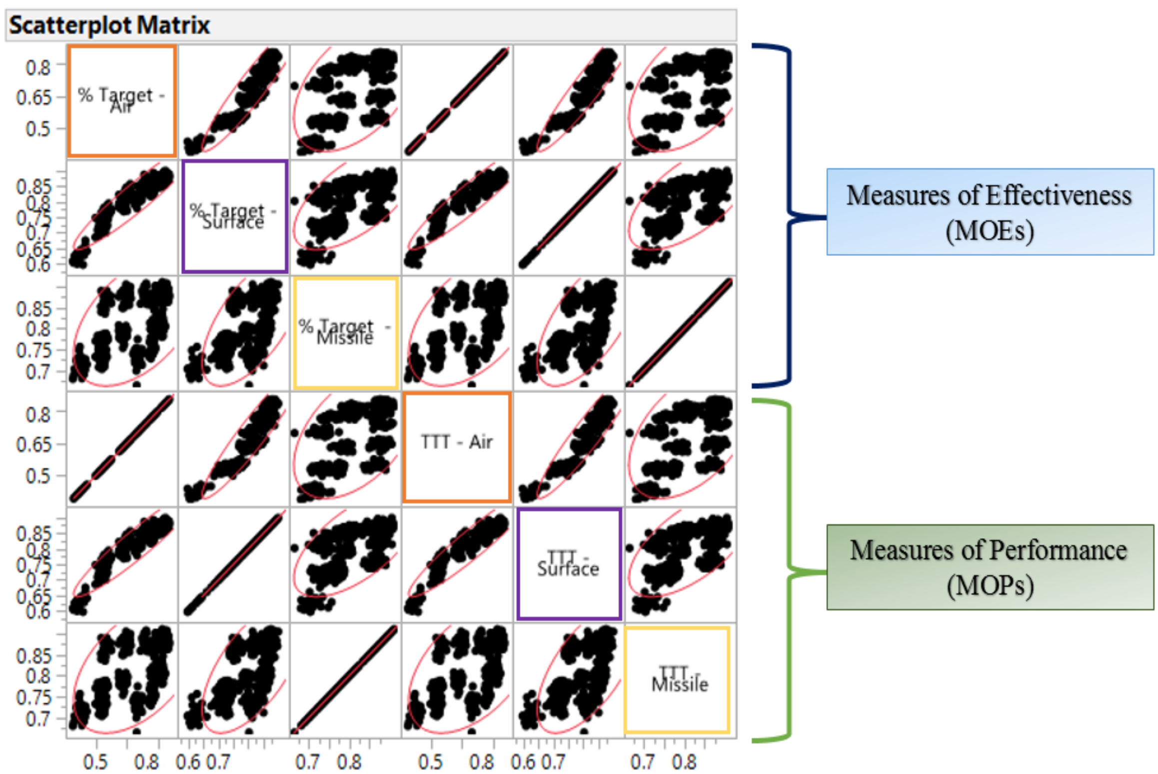


Figure 20. Correlation Analysis—Baseline Force Structure MOEs and MOPs—Enemy Force Ability to Target

B. DMO VARIABLE FORCE STRUCTURE

The second portion of the analysis considers the simulation of a variable force structure, with not only the tactics incorporated as input variables, but also the friendly force platforms and order of battle are generated as a function of the DOE. The tactics and counter-measure variables remain unchanged from the first set of outputted data, but the total quantity of input variables is increased by 23 platforms, with multiple levels per each blue force asset, as previously described in Chapter VI. The expanded input variables list for the modifiable force structure is compared to the same metrics as the first data set, with additional analysis performed to examine not only the MOEs for the scenario, but also several MOPs. In this data set, special attention is paid to identifying the crucial platforms that had the largest impact on these outputs.

1. Analysis of MOE #1: Survivability of Friendly Forces

The first overall MOE examined for the variable force structure is the survivability of the friendly forces. The DMO-centric force structure incorporates any combination of manned and unmanned assets across all domains in the engagement with opposing enemy forces. This metric is particularly useful when considering the ability to employ DMO because it represents the platforms that can defend against attack, as well as conduct offensive strikes against enemy threats prior to engagement. This measure also requires more consideration in each scenario as the variability of the results is much greater due to the wide range of orders of battle that can be generated. For example, a single run in the simulation may have generated the 149 total threats from the enemy order of battle paired against a nearly equivalent friendly force of major surface combatants, fighter aircraft, ISR platforms, and unmanned assets. Another run in the same set of data may have generated the 149 enemy threats to be paired up against a single small surface action group of LCS and rotary wing aircraft. As noted in Table 19, there are more factors that are determined to be significant with the analysis of the variable force structure, but additional levels of analysis can be performed for each metric to determine the operational impact of the statistically significant platforms and tactics in the DMO force structure.

Table 19. Analysis Summary of DMO Structure—Friendly Force Survivability

MOE Calculation	$Percentage_{\text{Surviving Blue Forces}} = \frac{\text{Quantity of Blue assets surviving at end of simulation}}{\text{Quantity of initial Blue assets}}$			
	DMO Force Stucture			
	Overall Survivability	**High Value Ships**	**Missile Carriers**	**Fighter Aircraft**
Statistically Significant Contributing Factors	Qty TERN Qty DDG-51 Qty F-35 Air Qty F-35 Surface Barrage Jamming Spot Jamming	Qty DDG-51 Qty LHA/LHD Swarm Qty CG	Qty DDG-51 Swarm Qty LCS Qty CVN Barrage Jamming Chaff	Qty F-35 Surface Qty F-35 Air Qty DDG-51 Qty EA-18 Qty CG Barrage Jamming Qty F/A-18 Surface Spot Jamming Qty TERN

For the variable DMO force structure, a regression analysis is performed for each of the platform groupings with respect to survivability, including the overall order of battle, high value surface ships, missile carriers, and fighter aircraft. The regression model plots and parameter summaries are further detailed in Appendix K. The sorted parameter estimates output for each of the groups is again used to determine the factors of statistical significance, as summarized in Table 19.

Even with the regression analysis now considering the quantities and types of platforms in the simulation as well as tactics, it can be observed that jamming continues to be an apparent significant factor in the ability for friendly forces to survive the engagement. The application of jamming to interrupt the finding and targeting sequences of the enemy threat platforms and missiles results in fewer engagements of blue force assets. Additionally, the DDG-51 class destroyer is consistently incorporated as a statistically significant factor in the overall and each of the subgroups survival capability. The destroyer is a statistically and operationally critical platform due to the average quantity generated in each simulation which corresponds to a substantially larger quantity of missiles contributed to the shared resource pool, as well as the ability to offensively and defensively sense, target, and engage all enemy threat types.

2. Analysis of MOE #2: Survivability of Enemy Forces

An additional metric for the DMO variable force structure with respect to the ability to perform DMO, particularly in an offensive capacity, is the enemy forces that remain at the end of each simulation as compared to the initially generated 149 enemy entities. Table 20 summarizes the statistically significant factors that contribute to the quantity of red force platforms and missiles that are not engaged or diverted by friendly forces.

Table 20. Analysis Summary of DMO Structure—Enemy Force Survivability

MOE Calculation	$\text{Percentage}_{\text{Remaining Red Forces}} = \dfrac{\text{Quantity of Red platforms remaining at end of simulation}}{\text{Quantity of total Red platforms}}$
Statistically Significant Contributing Factors	**DMO Force Stucture**
	Overall Enemy Force Survivability
	Quantity of DDG-51 Quantity of CG Barrage Jamming Quantity of F-35 (Air) Sweep Jamming Spot Jamming DRFM Jamming

The most statistically significant factors contributing to the MOE of enemy forces remaining are the number of DDG-51s, CGs, and anti-air F-35 assets available, as well as the ability to perform barrage jamming against enemy targeting sensor. The number of DDG-51s, CGs and F-35s (Air) are statistically significant and have a notable operational impact due to the number and types of missiles they bring to the fight. Additionally, jamming decreases the enemy’s ability to successfully target their intended friendly force asset, while also increasing the time that the enemy threat needs to acquire a targeting solution. This increase in time spent in the targeting sequence allows friendly force platforms more opportunities to successfully counter-engage, which has a significant impact on the percentage of surviving forces. In summary, more missiles and more time to counter-engage significantly decreases the percentage of surviving red forces.

The operational impact of these assets and tactics on red survivability is supported by the sorted parameter estimates in Figure 21. An increase in the quantity of DDG-51 platforms results in approximately a 1 percent reduction in overall enemy survivability per friendly destroyer, while each additional CG in the simulation decreases the overall enemy survivability by nearly 2.6 percent. The biggest reduction in red force survivability is noticed as a result of the employment of barrage jamming, with an approximate predicted percentage decrease of 5.5 percent.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
# DDG-51 DOE	-0.010756	0.000253	-42.49	<.0001*
# CG DOE	-0.025917	0.000725	-35.74	<.0001*
JAMMING BARRAGE DOE	-0.054297	0.001632	-33.28	<.0001*
# F-35 Air DOE	-0.001395	9.355e-5	-14.91	<.0001*
JAMMING SWEEP DOE	-0.023486	0.001627	-14.44	<.0001*
JAMMING SPOT DOE	-0.023332	0.00162	-14.40	<.0001*
JAMMING DRFM DOE	-0.022194	0.001624	-13.66	<.0001*

Figure 21. MOE #2: Statistically Significant Factors—DMO Structure Enemy Force Survivability

3. Analysis of MOE #3: Enemy Force Effectiveness in the Find Sequence of the Kill Chain

The final set of MOEs analyzed with respect to the variable force structure details the impact of various platforms and tactics to degrade enemy sensor performance in the finding and targeting stages of the kill chain. Table 21 details the input factors identified as statistically significant for enemy aircraft, surface vessels, and land-based missiles in their finding of an assigned friendly force asset.

Table 21. Analysis Summary of DMO Structure—Enemy Find Effectiveness

MOE Calculation	$\text{Percentage}_{\text{Red find Blue}} = \frac{\text{Quantity of Red threats successfully find assigned Blue platform}}{\text{Quantity of total Red threats}}$		
Statistically Significant Contributing Factors	**DMO Force Stucture**		
	Enemy Air Find	**Enemy Surface Find**	**Enemy Missile Find**
	Barrage Jamming Spot Jamming DRFM Jamming Sweep Jamming Quantity of DDG-51 Quantity of CG	Spot Jamming DRFM Jamming Sweep Jamming Barrage Jamming	Spot Jamming Quantity of TERN DRFM Jamming Quantity of F-35 Surface

While the regression analysis identified factors that were statistically significant with respect to the percentage of enemy aircraft, surface assets, and land-based missiles that find their assigned target, the data shows that these factors have limited operational impact within the model. Both enemy air and surface assets found their targets in over 97 percent of simulation runs, indicating that while certain factors may be statistically significant, the reduction from 99 percent success in finding the blue force to 97 percent is operationally inconsequential. This overall insignificance of friendly force platforms and tactics for the find phase of the kill chain is attributed to the run time of the simulation, which grants the enemy platforms more than adequate time to transit and conduct multiple iterative searches of the operational area for the friendly force assets.

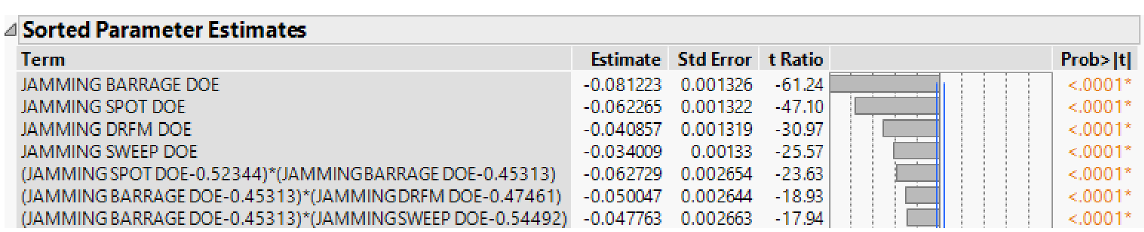
4. Analysis of MOE #4: Enemy Force Effectiveness in the Target Sequence of the Kill Chain

With the platforms and tactics having minimal operational impact on the ability for the enemy forces to find the blue force asset it is assigned, additional analysis is conducted to determine if the same conclusion is true about the targeting phase of the kill chain. Table 22 represents the factors determined to be statistically significant for the percentage of enemy aircraft, warships, and land-based missiles that reach the targeting portion of the simulation and are successful in targeting their assigned friendly force asset.

Table 22. Analysis Summary of DMO Structure—Enemy Target Effectiveness

MOE Calculation	$\text{Percentage}_{\text{Red target Blue}} = \frac{\text{Quantity of Red threats that target/engage assigned Blue platform}}{\text{Quantity Red threats that successfully find their assigned Blue}}$		
	DMO Force Stucture		
	Enemy Air Target & Engage	**Enemy Surface Target & Engage**	**Enemy Missile Target & Engage**
Statistically Significant Contributing Factors	Barrage Jamming Spot Jamming DRFM Jamming Sweep Jamming Quantity of DDG-51 Quantity of CG Quantity of F-35 Air	Barrage Jamming Spot Jamming DRFM Jamming Sweep Jamming Quantity of DDG-51 Quantity of CG Quantity of TERN	Spot Jamming Quantity of TERN DRFM Jamming Quantity of F-35 Surface Quantity of F-35 Air Quantity of FireScout Quantity of MH-60

This metric of targeting effectiveness is decomposed into the various platform types to consider the individual ability of enemy aircraft, surface combatants, and land-based missiles to successfully obtain a targeting solution and engage the assigned blue force asset. The resulting statistically significant factors are similar to many other analyzed measures for both the fixed and variable force structures, as the prevalence of jamming is apparent, especially in the case of enemy surface vessels targeting an assigned asset. The sorted parameter estimates detailed in Figure 22 depict the various types of jamming as the most impactful tactic, with several interactions between the jamming measures also determined to be statistically significant.


Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE DOE	-0.081223	0.001326	-61.24	<.0001*
JAMMING SPOT DOE	-0.062265	0.001322	-47.10	<.0001*
JAMMING DRFM DOE	-0.040857	0.001319	-30.97	<.0001*
JAMMING SWEEP DOE	-0.034009	0.00133	-25.57	<.0001*
(JAMMING SPOT DOE-0.52344)*(JAMMING BARRAGE DOE-0.45313)	-0.062729	0.002654	-23.63	<.0001*
(JAMMING BARRAGE DOE-0.45313)*(JAMMING DRFM DOE-0.47461)	-0.050047	0.002644	-18.93	<.0001*
(JAMMING BARRAGE DOE-0.45313)*(JAMMING SWEEP DOE-0.54492)	-0.047763	0.002663	-17.94	<.0001*

Figure 22. MOE #4: Statistically Significant Factors—DMO Structure Enemy Surface Vessels Targeting Effectiveness

In order to determine the operational impact of the factors detailed in the parameter estimates, the partition tree can serve as an additional tool to provide these insights. As detailed in Figure 23, the ability for an enemy aircraft to successfully target the assigned friendly asset is largely affected by the employment of barrage jamming. With barrage jamming off in the simulation, the average proportion of enemy aircraft that are able to successfully target the assigned friendly asset is 79 percent, but with the employment of barrage jamming by friendly forces, this enemy aircraft targeting success rate is reduced to 61 percent. Additionally, the presence of greater than 4 DDG-51 surface combatants results in a reduction of enemy targeting effectiveness by nearly 4 percent.

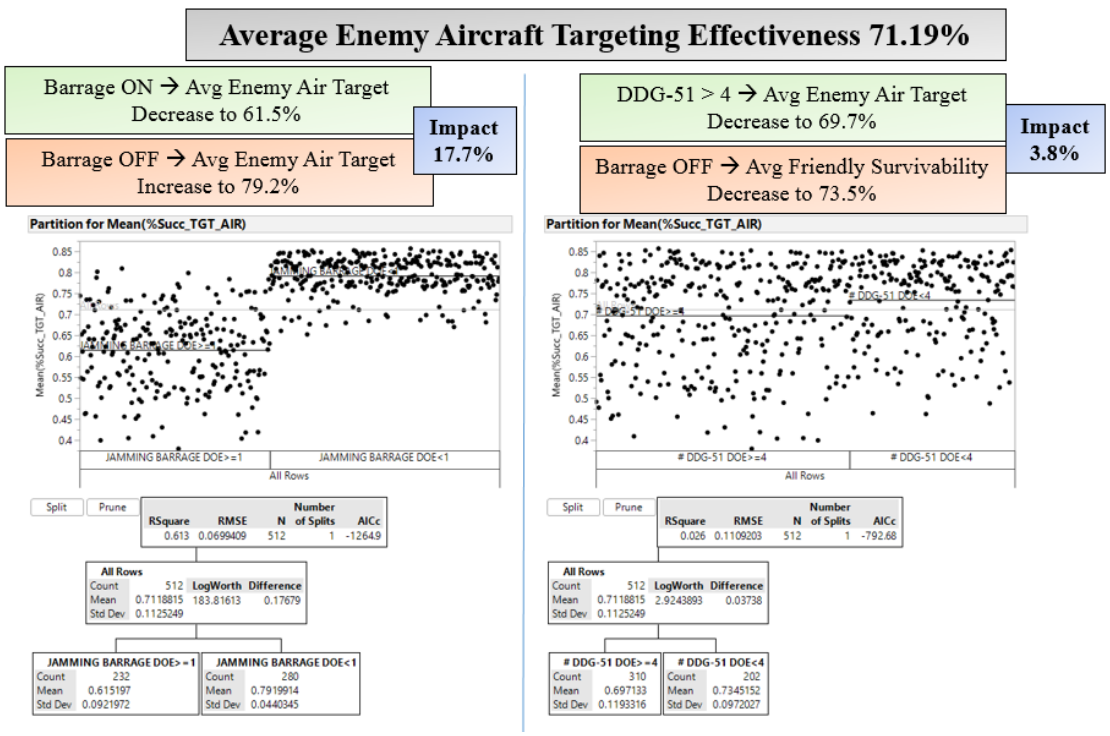


Figure 23. MOE #4: Operational Impact of Statistically Significant Factors—Enemy Aircraft Ability to Target an Assigned Friendly Asset

5. Analysis of MOPs for the DMO Variable Force Structure

While the MOPs analyzed for the fixed force structure did not provide any specific insight into the impact of the various tactics on the enemy kill chain, the DMO force structure incorporates many additional input variables; and therefore, the regression analysis for the various DMO MOPs facilitates the determination of several statistically and operationally significant factors for consideration. The statistical analysis of the output data from the DMO force structure provides many opportunities for further consideration of tactics and platforms, which are fully detailed in Appendix K.

The primary set of MOPs considered to be insightful during the analysis of the variable force structure is the time spent by each of the enemy force threats in the finding and targeting sequences of the kill chain. The time dedicated to finding and targeting an assigned friendly force asset is impacted by factors that degrade the ability for a threat to detect and locate as well as obtain a targeting solution. These MOPs are particularly interesting due to the tradeoff that exists for the survivability of friendly forces. While an increase in the time spent by an enemy threat in either the find or targeting phase may force the adversary platform out of the simulation if time expires or the separation distance is closed prior to the obtaining of a firing solution, there is also potential for reduced opportunities for friendly forces to engage the inbound threat if the adversary does not reach the targeting stage until close range. Tables 23 and 24 depict the statistically significant factors as determined by the regression analysis for both the mean time to find for all platform types, as well as the average time to target for adversary air and surface platforms that have successfully completed the find stage of the kill chain. The enemy land based missiles do not progress through the targeting phase in the model, therefore this platform type is not considered for time to target.

Table 23. Analysis Summary of DMO Structure—Enemy Time to Find

	DMO Force Stucture		
	Enemy Air Time to Find	**Enemy Surface Time to Find**	**Enemy Missile Time to Find**
Statistically Significant Contributing Factors	Quantity of TERN Quantity of F-35 Surface Quantity of F-35 Air Quantity of FireScout Quantity of MH-60 Quantity of Reaper	Spot Jamming Barrage Jamming Quantity of TERN DRFM Jamming Sweep Jamming Quantity of F-35 Surface	Spot Jamming DRFM Jamming Quantity of TERN Sweep Jamming Barrage Jamming

Table 24. Analysis Summary of DMO Structure—Enemy Time to Target

	DMO Force Stucture	
	Enemy Air Time to Target	**Enemy Surface Time to Target**
Statistically Significant Contributing Factors	Barrage Jamming Spot Jamming DRFM Jamming Sweep Jamming Quantity of F-35 Air	Barrage Jamming Spot Jamming DRFM Jamming Sweep Jamming Quantity of F-35 Surface Quantity of DDG-51 Quantity of F/A-18 Surface

The various types of jamming tend to have the greatest statistical and operational impact, while other unmanned clutter factors such as TERN and Fire Scout are also incorporated as potential contributing factors in the ability to find for the various platforms of the air and surface domains. The variants of the F-35 fighter aircraft also impact the time an adversary threat spends in the find and target stages due to both the sheer quantity of these friendly platforms generated in each run, as well as the counter-engagement capability carried onboard.

Figure 24 depicts the analysis conducted to gain additional fidelity into the impact of the F-35 aircraft and TERN unmanned system with respect to an enemy aircraft's time to find. The initial average time for a red force aircraft in the finding stage is approximately 90 seconds. When examining the grouped output data as a function of quantities of TERN and F-35, this mean value for time spent in the searching stage changes. The best case scenario occurs with the maximum time to find of nearly 98 seconds, when the quantities of TERN and F-35 platforms is greater, as this increases the clutter and additional contacts that an enemy platform has to sort through in order to locate the assigned asset. Conversely, the least desirable time to find for an enemy platform or missile occurs with fewer air assets in the model. While these insights are very specific in terms of quantity of assets needed to make a substantial impact on time in the targeting sequence, the ability to determine an approximate number of assets needed is potentially useful for leaders charged with determining the resources needed to be successful in a major engagement against a capable adversary.

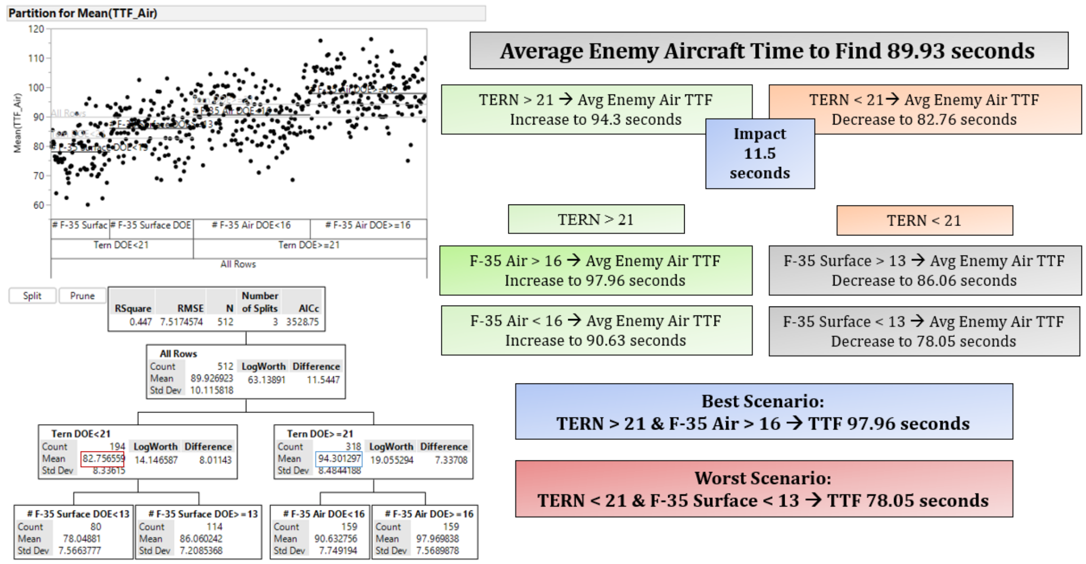


Figure 24. MOP: Operational Impact of Statistically Significant Factors—Enemy Aircraft Time to Find

Similarly to Figure 24, the partition tree shown in Figure 25 details the analysis of the independent tactics and platforms that can be employed to prolong the time to target for an enemy aircraft. Jamming, the F-35 aircraft and the F/A-18 serve as the primary factors that impact the ability for an adversary aircraft to target a friendly force vessel or aircraft. With a mean time of nearly 13 seconds for a threat aircraft to obtain a targeting solution upon finding the assigned asset, a delay of 10 seconds caused by jamming is substantial.

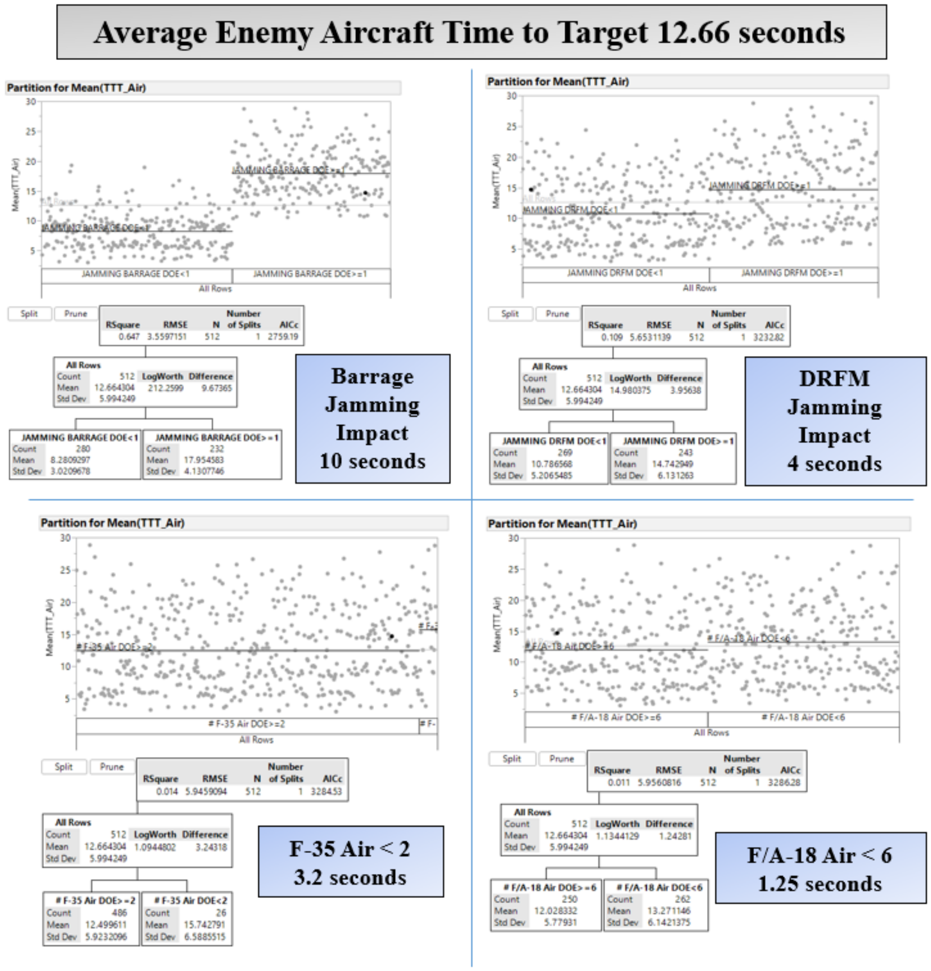


Figure 25. MOP: Operational Impact of Statistically Significant Factors—Enemy Aircraft Time to Target

C. SUMMARY OF ANALYSIS

Overall, the application of the statistical analysis software to the data sets of a fixed force structure and a variable force composition enable the team to develop insights into the relative performance of the platforms and tactics employed in the scenario. From each of the model outputs represented by the MOEs and MOPs, the team identifies the most statistically significant factors that contribute to the overall success of the friendly forces when considering survivability, lethality, and defense of the operational units. For each of the recognized statistically significant factors, the level of significance is captured as well as the frequency of occurrence. For example, spot jamming has a high frequency of occurrence as it is noticed as a significant factor in the majority of the regression analysis outputs, but for most metrics spot jamming has a relatively low level of operational significance. Another parameter or input variable is the quantity of the DDG-51 class destroyer, which is not as frequently mentioned as a significant factor, but for the metrics in which it appears, the tendency is for the platform to have a much higher level of significance.

The team considers the data sets for the variable and fixed force structures separately due the difference in input variables as the variable force structure includes the potential for modifying the underlying major fleet platforms that comprise the majority of the overall friendly force structure. The conclusions developed from the consideration of the frequency of occurrence and level of significance regarding the factors that have the greatest contributions to the success of the friendly forces in the DMO scenario are listed in Table 25. For both the fixed and variable force structure MOEs and MOPs, spot and barrage jamming were consistently noticed as key performance enablers in measuring friendly force success. The jamming tactics have an evident impact due to the ability for the tactic to degrade the adversary in the critical phases of targeting and engagement within the kill chain. Additionally, with a minimal penalty imposed on friendly forces for employing jamming, it is apparent that this tactic demonstrates the greatest impact on the survivability and associated ability to conduct offensive engagements against degraded enemy threats.

Table 25. Ranking of the Significant Factors for Fixed and Variable Force Structures

Fixed Baseline Force Structure	**Variable Force Structure**
Spot Jamming	Barrage Jamming
Barrage Jamming	Spot Jamming
DRFM Jamming	Quantity of DDG-51
Sweep Jamming	DRFM Jamming
Swarm	Sweep Jamming
EMCON (DDG-51)	Quantity of CG

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VIII. CONCLUSIONS AND RECOMMENDATIONS

The SEA-27 Capstone project team aimed to examine the capabilities of various manned platforms, unmanned assets, tactics, and counter-measures in an effort to investigate the ability for the Navy's fleet assets to perform DMO against a capable adversary in a contested environment. In order to gain insights into the potential force assets of the future 2030 timeframe, the team developed an event-based model to simulate the operation of integrated and distributed force compositions. The team considered the performance parameters of various aircraft, surface vessels, and weapons systems along with the ability of these platforms to employ both offensive and defensive tactics to enforce a more forward-leaning posture during an engagement with enemy forces. With the objective of increasing lethality and offensive firepower across all operating domains, the model served to provide quantitative data for analysis in support of fleet level recommendations.

In order to compare the innovative DMO concept to current operating procedures, 2 major sets of data were generated and analyzed. The first simulation investigated the impact of various tactics as employed by a traditional fixed force structure. The insights gained from the fixed force structure can be provided as supporting evidence for operational commanders who are unable to allocate additional forces or assets, but can alter the tactical employment of the forces he or she has been provided. The second set of data generated from the model reflects the variable, DMO-oriented force structure than is intended to operate as a unified force structure comprised of dissimilar platforms in all domains. The recommendations produced from the analysis of the variable force structure data applies towards the higher echelons of leadership that have the authority to make force level decisions regarding the acquisition of new platforms or technologies in order to further the DMO concept.

While the model and analysis is subject to limitations and simplifications as a function of the project timeline and level of expertise within the group, the simulation provides fundamental insights for the architectures of various force structure and the relative employment of offensive counter-targeting assets and defensive counter-measures with respect to survivability and lethality of the friendly forces. The foremost limitations or assumptions that impacted the model outputs include the modeling of only the first possible set of engagements, the assumption of perfect information for jamming, the lack of networking capability for enemy forces, and the abridged order of battle for both participants in the engagement.

The implementation of jamming within the model is advantageous to friendly forces due to the assumption of correct knowledge for an enemy sensors operating frequencies and parameters. For example, if barrage jamming is determined to be active in the model, the jamming is assumed to impact all enemy threats simultaneously. While this is a simplification that impacts the outputs of the simulation, the understanding that jamming is modeled as a major advantage to friendly forces can be accounted for and considered in the analysis of the statistical outputs. Additionally, the simplification that friendly forces share a common tactical operating picture and resource pool for offensive strike capability and defensive counter-measures is not matched by the enemy fleet, as the assumption is that each threat platform or missile is independent as it progresses through the kill chain. Furthermore, the simplification of the potential technologies able to be employed in the 2030 timeframe resulted in swarms of unmanned assets that served as only additional clutter for enemy sensors. Even with today's swarm capabilities, the technology may be able to provide additional lethal and ISR capabilities that were not considered in this model. Lastly, the order of battle was consolidated for the model to incorporate only the major platform variants in each category. For example, only one variant of the PLAN Frigate class ships is considered, while the current and projected future inventory includes several different variants and classes of the Frigate. From the previously discussed assumptions and limitations the team attempts to balance the overall assumptions and consequences of the limitations in order to simulate a fair engagement and analyze subjective data to provide useful insights into employable tactics and counter-measures.

A. CONCLUSIONS

From the analysis of the model outputs and the consideration of the prevalence of the significant factors, the primary factors that contribute to the DMO concept as employed in the simulation can be determined and summarized. The various jamming tactics provide blue forces with the capability to lower the probability of being found and targeted, while also increasing the time a threat dedicates to the targeting and engagement sequence. This time delay results in a greater number of opportunities for counter-engagements of enemy platforms. The targeting phase is not only critical in terms of jamming, but the ability to delay a threat who has successfully located a friendly force asset must be achieved in order to allow friendly forces the ability to conduct a counter-engagement or deploy defensive counter-measures. Swarms, or clutter created by unmanned assets, is also an effective counter-targeting measure that serves to prevent the enemy from being able to obtain a targeting solution, especially if the collection of unmanned vehicles is capable of successfully emulating a manned platform or high value unit. The primary operational significance of swarm is noticed in the analysis of the survivability of the missile carriers. Even though the swarm in the model is generated to imitate an aircraft carrier or E-2, the redistribution of the mission assignment probabilities to the unmanned swarm reduces the chance of a critical missile carrier being targeted and engaged by an enemy threat.

B. RECOMMENDATIONS

The continued development and practicable employment of jamming techniques is critical to the success of naval warfare in the age of electromagnetic sensors that dominate the battle space. Further research and development to improve the friendly force ability to employ jamming while incurring only minor penalties is paramount to success in a contested environment, specifically within the context of the DMO concept. Additionally, with the apparent effectiveness of jamming, it can be assumed that the enemy will also apply electronic warfare to prevent friendly force use of the electromagnetic spectrum. The efforts to reduce or mitigate the risks of the impact of electronic warfare against friendly units is critical, especially with the reliance on current and future advanced radars and network capabilities.

For the purposes of what the Navy could focus on in terms of force restructuring is the continued development and integration of unmanned systems in the construct of carrier strike groups, expeditionary strike groups, and surface action groups. From the analysis of the variable force structure, the team identified the TERN as a significant factor for both the measures of effectiveness and performance. Specifically, the significance became apparent only when the model generated a quantity greater than 15-20 TERN assets. The presence of the TERN vehicle in the simulation is represented not with respect to the specific functionality of the TERN, but instead as a clutter-creating aerial vehicle that provides additional targets for the adversary to sift through in order to ascertain the location of their blue platform assignment or develop a firing solution. Additionally, the small payload of air to surface missiles facilitates the presence of an unconventional air to surface threat to conduct counter-engagement of enemy forces. The value of the additional unmanned systems, such as the TERN vehicle, is to force the enemy to allocate resources and dedicate time to identify, classify, and potentially target the unmanned vehicles, especially if they possess combat capabilities such as jamming or the ability to employ weapons.

Similarly, the swarm tactic was also a significant factor that used unmanned systems. The swarm played a key role in both the fixed and variable force structure data analysis. The result of a swarm that successfully impersonates a CVN proved to be an asset for all friendly force platforms in the simulation as the swarm detracted from the enemy's ability to develop viable targeting solutions. Follow-on recommendations would be to consider using swarm assets with deceptive radar cross sections to impersonate carriers or destroyers, as this tactic could potentially influence red platforms to prioritize their target selection to missile platforms more than they would the aircraft carriers. Also, utilizing unmanned surface vessels as not only a missile sponge, but as a legitimate offensive threat against enemy platforms could influence the outcome of the success of friendly forces.

Lastly, the team identified that the number of destroyers and cruisers that the Navy brought to the fight significantly increased the overall survivability of the friendly forces remaining at the end of the engagement, and decreased the percentage of enemy platforms remaining. The missile carrier platforms serve as the primary force multipliers in the DMO concept. This was apparent due to the number of missiles that each surface combatant brought to the fight, even in a shared resource pool environment which facilitated the employment of friendly offensive and defensive missile by any combat capable asset. The obvious recommendation would be to increase the number of destroyers and cruisers, but realistically, due to the financial constraints, this just is not a feasible option for the future. Moving towards what DMO brings to the fight: allowing time for decision makers, counter-targeting, deception, and confusing the adversary; the integration of the tactics discussed throughout this report will provide an effective alternative vice relying solely on our missile carriers to win the fight. The team determined that the approximately two-thirds of the missiles fired from blue platforms were employed in a defensive capacity. The obvious recommendation for the Navy is to move towards a more offensive, "strike first" mentality. If the adversary is targeted and engaged before they get a chance to engage blue forces, especially with the presence of the advanced missile technologies available to state and non-state actors, the overall stability and presence of the force is able to be maintained.

C. AREAS OF FURTHER RESEARCH

Due to the limited timeframe to complete this Capstone project, there are many avenues of future research that can be explored to better examine the ability to perform tactical offensive operations in contested environments. A considerable boundary that the SEA-27 team implemented was to focus efforts only on the traditional warfare areas including air, surface and land warfare, while limiting the inclusion of today's critical domains of sub-surface, space, and cyber warfare. In the current and future environment that relies on shared information and network connectivity, the ability to interrupt this capability would be instrumental in winning a fleet-on-fleet engagement against a capable adversary. Further analysis of the available innovative technologies that can be employed on unmanned assets could be incredibly beneficial in analyzing the impact of tactical systems employment within the DMO framework of increased offensive power and deceptive tactics. Finally, as discussed with the limitations of the model, additional fidelity could be applied to the tactics and counter-measures to ensure a more realistic employment of the counter-targeting and defensive measures in the operational environment.

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APPENDIX A. MARITIME WAR OF 2030 SCENARIO

The scenario detailed in the following narrative is used to provide the framework for the prescribed DMO operational scenario for the fleet-on-fleet engagement. The narrative is adapted from the Naval Postgraduate School's Joint Campaign Analysis (JCA) course.

<u>2030 Political, Social, and Economic Narrative:</u>

*Although **China's** economic growth began to slow in 2018, she continued her political, fiscal, economic, and military expansionism. In 2030 China is the world's first economy, has a large and growing middle class population and consequently generates a higher demand for oil and natural gas. Relationships between **Russia** and China are thriving, underwritten by a strong energy trade. China depends on the trans-Siberian pipeline developed after negotiations with Russia on oil purchases were signed in 2014. Further economic ties were generated by a series of trade agreements that began in 2019.*

*Since 2015 the increased economic and social ties between mainland **China and Taiwan**, combined with an economically (yet not necessary democratically) more liberal Chinese central government, resulted in a 2025 non-aggression treaty between the two states with agreements to begin discussions on unification. By 2030, although not yet under "one government", the Taiwan parliament has Communist party representation and the joint government, military and economic initiatives between China and Taiwan have grown to the point they are a de-facto Chinese economic and military federation. For example, Taiwan has allowed China to build High Frequency Surface Wave radar stations and passive collection systems on Taiwan with joint intelligence sharing responsibilities. Taiwan no longer relies on military sales from the United States.*

China has populated several islands terra-formed through dredging in 2015 with military installations. For example, Fiery Cross Reef has a squadron of J-20s (fifth generation plus) with 10 Dark Sword UCAVs, while both Fiery Reef, Gaven Reef , and Hughes Reefs have both surface to air installations (S-500) and anti-surface cruise missile mobile sites (advanced YJ-62s). China is now building facilities on terra-formed islands made from the western end of the Scarborough Shoal reef, protested by the Philippines and the United States.

*Tensions remain high on the **Korean Peninsula** with **North Korea** developing greater ballistic missile and cruise missile capabilities. The successful submarine launched ballistic missile in 2017 was followed by a series of failures, then successes of both land launched and sea launched ballistic missiles and well as shore to ship cruise missiles. North Korea retains a nuclear capability.*

***Japan and the United States** have strengthened their social, economic, and military ties in response to China's and Russia's growing influence. The Yokosuka naval facility has evolved to a joint JMSDF and United States Navy base with GEORGE WASHINGTON and its air wing, three United States DDGs, eight United States LCSs, and the Japanese fleet sharing the installation. In Sasebo, the United States Navy retains LHA-6, LPD-25 and LSD-52 and two LCS for mine clearance and protection.*

*The United States also established closer ties to **Singapore**, stationing eight LCSs, a squadron of P-8s and their shore support in the city-nation. In addition, the United States now maintains logistic support bases in Diego Garcia and pre-positioned expeditionary supplies in Subic, with joint agreements with the U.K. and Philippines respectively. These bases can act as "rapid build-up" support bases if the host country agrees. Additionally the Philippines have invited the United States Air Force to use Clark AFB as an expeditionary field. It is currently used in joint training exercises. The United States Air Force has retained Kadena AFB on Okinawa, and III MEF completed its move from Futenma to the newly constructed land-fill air base in Henoko village.*

<u>South and East China Sea:</u>

In the spring of 2029, a Vietnamese fisher was rammed and sunk by a Chinese maritime security ship. The Chinese government justified the unfortunate action as an enthusiastic Captain defending China's EEZ rights, although similar incidents have occurred over the past 20 years. Vietnam did not accept the rationale and vowed their fishing fleet, as well as their at sea drilling rigs, would henceforth be protected. Two weeks later a Chinese deep-sea exploration ship exploded without warning 100 nautical miles north of Natuna Besar.

China claimed either Vietnam, Indonesia or the Philippines were responsible. They mobilized their South China Seas fleet and demanded restoration from all three countries or they would "secure" their sea. One month later the Chinese sank a patrolling Vietnamese ship using a land-based surface to surface missile launched from Woody Island (YJ-83) in the Paracels and moved a squadron of SU-37s to Woody Island. They announced all traffic through the South China Sea would henceforth be subject to inspection and control by Chinese forces. They threatened to assume governorship of the island of Natuna Besar Indonesia to control the South China Sea's southern approaches and in compensation for the attack on their deep sea exploration ship. The 1st Marine Brigade at Zhanjiang, Guangdong has embarked in the South China fleet's amphibious flotilla (13 landing ships modernized Type 71 LPDs and Type 72II LSTH). They can be underway in one day's notice and intelligence indicates their objective is the occupation of Natuna Besar.

During these events a Philippine helicopter fired on a PLAN Type 56 corvette conducing gunnery exercises four miles from Palawan Island. In response, China also threatened invasion of Palawan. Increased activity by the PLA's 124th Amphibious Mechanized Infantry Division in Guangzhou district indicates they may be readying for this operation.

Indonesia, Vietnam, and the Philippines have requested UN support, specifically calling on the United States and Japan to act. In response, China has warned Japan and the United States any interference with their enforcement policy will lead to war, with the threat of nuclear escalation. To show their resolve, China mobilized the East Sea and South Sea fleets and sailed at least 50 submarines from both fleets, including two SSGN on what are assessed to be strategic deterrence patrols. They have declared a quarantine on all military logistics support (including oil) to Okinawa and have set up ships in blocking positions around the island to conduct MIO.

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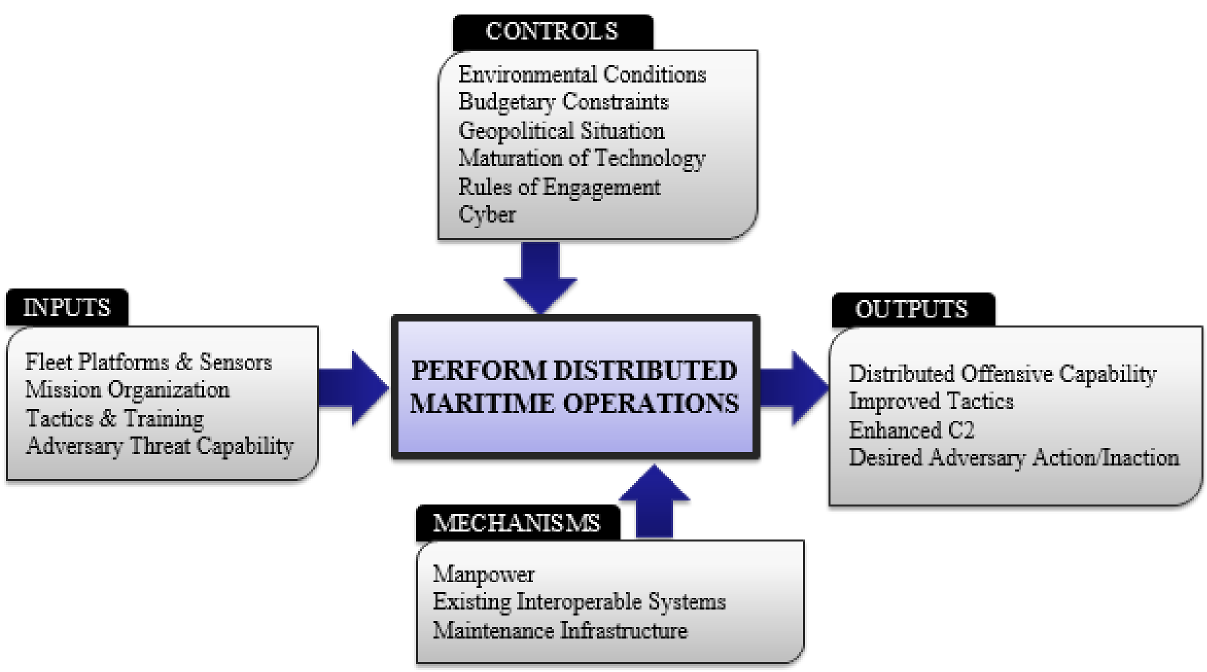
APPENDIX B. ICOM AND CONTEXT DIAGRAMS

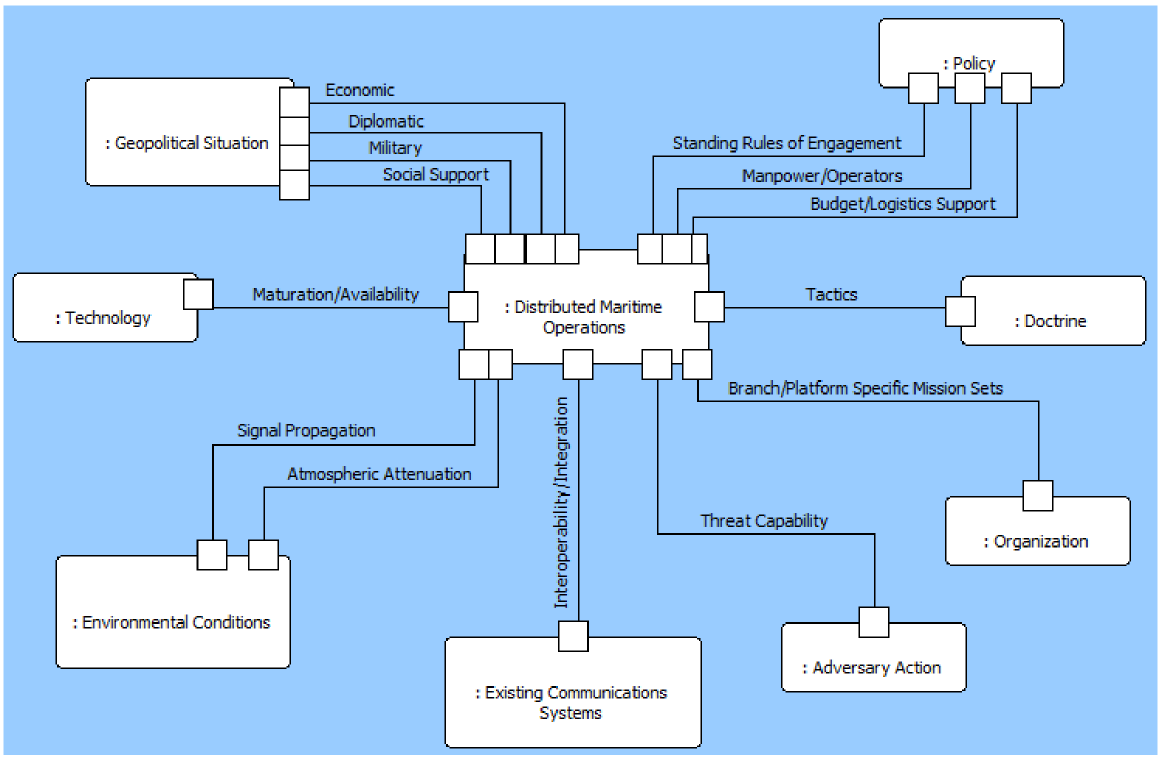
A. ICOM DIAGRAM

The ICOM diagram is generated in an effort to decompose the primary inputs, controls, mechanisms, and outputs for a given function. The function described for this project is performing DMO. The team determined the primary inputs for DMO as a fleet level strategic concept as the platforms and sensors that conduct the operations, the organization of the fleet as a whole, the employed tactics and associated training for the operators of the DMO systems, as well as the known adversary capabilities. The controls that bound or restrict the ability to perform DMO include environment, budgetary considerations, availability and trust in innovative technologies, as well as the geopolitical environment and related policy restrictions. The mechanisms that enable a composition of fleet assets to perform DMO are the operators, existing platforms and systems, and the infrastructure required to support the platforms and personnel. The primary desired output of performing DMO include is the improved ability to conduct offensive operations from a group of integrated and distributed fleet assets.



B. CONTEXT DIAGRAM

The context diagram serves to distinguish the system being considered from the surrounding systems that interact and impact the central system. For the DMO concept, several external systems affect the ability to conduct tactical offensive operations in a contested environment. The context diagram enabled the team to discern which systems were considered within the scope of the project as variable that can be modeled, and which are considered external or uncontrollable when simulating the ability to perform DMO.



APPENDIX C. ENVIRONMENTAL CONDITIONS

## A.	WEATHER CONDITIONS

Percentage of Occurrence	Weather Condition	Sensor Degradation Factor
70%	1: Negligible	0%
20%	2: Marginal	10%
10%	3: Poor	30%

## B.	CLUTTER CONDITIONS

Model: Mean Clutter (Neutral Traffic): 65 vessels. Standard Deviation: 10 vessels.

Figure 26.	AIS Tracks in the Prescribed Area of Operations. Source: Marine Vessel Traffic (2018).

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APPENDIX D. DETAILED ORDERS OF BATTLE

A. FRIENDLY FORCES

1. Platforms and Quantities (Variable Force Structure)

Surface Combatants		Aircraft	
0-2	CVN Aircraft Carrier	0-30	F-35 (Air)
0-2	LHA/LHD Amphibious Assault	0-30	F-35 (Surface)
0-4	LPD Amphibious Transport Dock	0-10	F/A-18 (Air)
0-3	CG Guided Missile Cruiser	0-10	F/A-18 (Surface)
0-10	DDG-51 Guided Missile Destroyer	0-5	EA-18
0-1	DDG-1000 Guided Missile Destroyer	0-2	E-2
0-6	LCS Littoral Combat Ship	0-8	P-8
0-3	EPF Expeditionary Fast Transport	0-16	MH-60
0-6	MDUSV Medium Displacement Unmanned Surface Vessel	0-6	AH-1
		0-3	MQ-4 Triton
		0-20	MQ-8 Fire Scout
		0-15	MQ-9 Reaper
		0-54	TERN
Total U.S. Assets in Model = 1 - 246			

2. Missile Loadouts

	SM-2	SM-3	SM-6	LRASM	MST	HARPOON	ESSM/RAM	AIM	HELFIRE	AMRAAM	HARM
CVN							24				
LHA/LHD							24				
LPD							21				
CG	36	5	25	8	14	8	12				
DDG-51	32	5	10	8	8	8	12				
DDG-1000	10		10	6	30		12				
LCS						4	21				
EPF											
MDUSV											
F-35 (A)								2	4	4	
F-35 (S)				4		2			2		2
F/A-18 (A)								2	4	4	
F/A-18 (S)				4		2			2		2
EA-18								4			
E-2											
P-8											
MH-60									4		
AH-1								2	16		
MQ-4											
MQ-8									2		
MQ-9									2		
TERN									4		

3. Missile Ranges

Missile	Range (Nautical Miles)
Standard Missile-2	60
Standard Missile-3	1000
Standard Missile-6	With E-2: 250 Without E-2: 150
Long Range Anti-Ship Missile	300
Maritime Strike Tomahawk	100
Harpoon	65
Evolved Sea Sparrow Missiles	12
Sidewinder	18
Hellfire	4
Advanced Medium Range Air to Air Missile	75
High Speed Anti-Radiation Missile	80

4. Platform and Missile Speeds

Surface Combatants		Aircraft		Missiles	
CVN	34	F-35	1100	SM-2	2300
LHA/LHD	25	F/A-18	1085	SM-3	6620
LPD	25	EA-18	1085	SM-6	2300
CG	32	E-2	400	LRASM	650
DDG-51	32	P-8	550	MST	650
DDG-1000	35	MH-60	120	HARPOON	470
LCS	45	AH-1	120	ESSM	2630
EPF	45	MQ-4	320	AIM	1650
MDUSV	30	MQ-8	150	Hellfire	864
		MQ-9	330	AMRAAM	2630
		TERN	70	HARM	1200
Speeds in Knots (Nautical Miles per Hour)					

B. ENEMY FORCES

1. Platforms and Quantities

Surface Combatants		Aircraft		Land Based Missiles	
2	Type 001/002/003 Carrier	14	J-11 Fighter	8	DF-21D
4	Type 055 Renhai	16	J-15 Fighter	4	DF-26
6	Type 052 Destroyer	16	J-16 Fighter	8	YJ-62
8	Type 054 Frigate	4	J-16D EW	4	HY-2
8	Type 056 Corvette	8	J-20 Fighter		
14	Type 022 Missile Boat	4	Q-5 Surface Attack		
1	Type 075 LHD	3	H-6K Bomber		
2	Type 071 LPD	1	KJ-3000 AEW		
2	Type 072 LST	1	Y-8FQ MPRA		
		6	Z-18 Helo		
		2	Z-8AEW		
		1	Soaring Dragon		
		1	Pterodactyl		
		1	Dark Sword		
Total Red Threats in Model = 149					

2. Sensor Ranges

Sensor	Range (Nautical Miles)
Visual	10
Infrared	25
ESM (Electronic Support Measures)	150
Air Search Radar	160
Surface Search Radar	60
Fire Control Radar	40
Navigation Radar	40
Phased Array Radar	180
AESA (Active Electronic Scanned Array Radar)	200
Over the Horizon Radar	1800
Synthetic Aperture Radar—Maritime	530
Synthetic Aperture Radar—Space	4000

3. Missile Loadouts

	YJ-12	YJ-18	YJ-83	YJ-100	FN-16	HQ-10	HQ-16	CM-102	PL-9	PL-12	VLRAAM
Carrier	10					120					
Renhai		20		50			20				
Luyang		30	10				10				
Jiangkai			6				18				
Jiangdao			4								
Houbei			6		2						
LHD					10						
LPD					10						
LST					5						
J-11									4	4	
J-15(A)									2	4	
J-15 (S)		4									
J-16 (A)									4	6	
J-16 (S)		4	6								
J-16D (EW)								8			
J-20									4	6	
Q-5	4									4	
H-6K	6			6							
KJ-3000											
Y-8FQ											
Z-18			2								
Z-8AEW			2								

Land Based Missiles	Quantity
DF-21D	8
DF-26	4
YJ-62	8
HY-2	4

4. Missile Ranges

Missile	Terminal Guidance	Range (Nautical Miles)
DF-21D ASBM	Active Radar	800
DF-26 ASBM	Infrared	1730
HY-2 ASCM	Infrared	125
YJ-12 ASCM	GPS	215
YJ-18 ASCM	Active Radar	290
YJ-62 ASCM	Active Radar	215
YJ-83 ASCM	Active Radar	100
YJ-100 ASCM	Active Radar	430
FN-16 MANPAD	Infrared	4
HQ-10 SAM	Infrared	65
HQ-16 SAM	Active Radar	65
CM-102 ARM	Radiation Seeking	65
PL-9 Air to Air	Infrared	12
PL-12 Air to Air	Active Radar	60
VLRAAM Air to Air	Active Radar	180

5. Platform and Missile Speeds

Surface Combatants		Aircraft		Missiles	
Type 001/002/003 Carrier	22	J-11 Fighter	660	DF-21D	6620
Type 055 Renhai	25	J-15 Fighter	1130	DF-26	7920
Type 052 Destroyer	22	J-16 Fighter	660	YJ-62	465
Type 054 Frigate	20	J-16D EW	660	HY-2	540
Type 056 Corvette	20	J-20 Fighter	1130	YJ-12	1980
Type 022 Missile Boat	30	Q-5 Surface Attack	370	YJ-18	1980
Type 075 LHD	20	H-6K Bomber	560	YJ-62	465
Type 071 LPD	20	KJ-3000 AEW	220	YJ-83	600
Type 072 LST	20	Y-8FQ MPRA	350	YJ-100	465
		Z-18 Helo	120	FN-16	1110
		Z-8AEW	120	HQ-10	1330
		Soaring Dragon	300	HQ-16	2770
		Pterodactyl	120	CM-102	2380
		Dark Sword	600	PL-9	2300
				PL-12	2625
				VLRAAM	3990

Speeds in Knots (Nautical Miles per Hour)

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APPENDIX E. METRICS EQUATIONS

This appendix presents the various calculations performed to transform the raw data outputted from the model to the MOEs and MOPs used in the analysis of the variable and fixed force structures.

A. MEASURES OF EFFECTIVENESS

Survivability of Friendly Forces	$\text{Percentage}_{\text{Surviving Blue Forces}} = \frac{\text{Quantity of Blue assets surviving at end of simulation}}{\text{Quantity of initial Blue assets}}$
Survivability of Enemy Forces	$\text{Percentage}_{\text{Remaining Red Forces}} = \frac{\text{Quantity of Red platforms remaining at end of simulation}}{\text{Quantity of total Red platforms}}$
Enemy Threats Successfully Find Friendly Asset	$\text{Percentage}_{\text{Red find Blue}} = \frac{\text{Quantity of Red threats successfully find assigned Blue platform}}{\text{Quantity of total Red threats}}$
Enemy Threats Successfully Engage Friendly Asset	$\text{Percentage}_{\text{Red target Blue - Total}} = \frac{\text{Quantity of Red threats that target/engage assigned Blue platform}}{\text{Quantity of total Red threats}}$ $\text{Percentage}_{\text{Red target Blue}} = \frac{\text{Quantity of Red threats that target/engage assigned Blue platform}}{\text{Quantity Red threats that successfully find their assigned Blue}}$

B. MEASURES OF PERFORMANCE

Friendly Missiles used in an Offensive Capacity (Targeting Red Platform)	$= \frac{\text{Quantity of Blue missiles targeting Red platforms}}{\text{Quantity of total Blue missiles shot in run}}$
Offensive Missile Success	$= \frac{\text{Quantity of successful Blue offensive missiles}}{\text{Quantity of Blue missiles targeting Red platforms}}$
Friendly Missiles Used in a Defensive Capacity (Targeting Red Missile)	$= \frac{\text{Quantity of Blue missiles targeting Red threat missiles}}{\text{Quantity of total Blue missiles shot in run}}$
Defensive Missile Success	$= \frac{\text{Quantity of successful Blue defensive missiles}}{\text{Quantity of Blue missiles targeting Red missiles}}$

Defensive Success	$= \frac{\text{Quantity successful Blue defensive missiles + successful M / P countermeasures}}{\text{Quantity of Blue missiles targeting red missiles + total M / P countermeasures used}}$
Enemy Aircraft Successfully Find	$= \frac{\text{Quantity Red Aircraft that successfully find their assigned Blue platform}}{\text{Quantity Red Aircraft that entered the Find Phase}}$
Enemy Surface Successfully Find	$= \frac{\text{Quantity Red Surface Platforms that successfully find their assigned Blue platform}}{\text{Quantity Red Surface Platforms that entered the Find Phase}}$
Enemy Missiles Successfully Find	$= \frac{\text{Quantity Red Land Based Missiles that successfully find their assigned Blue platform}}{\text{Quantity Red Land Based Missiles that entered the Find Phase}}$
Enemy Aircraft Successfully Target	$= \frac{\text{Quantity Red Aircraft that successfully target their assigned Blue platform}}{\text{Quantity Red Aircraft that entered the Target Phase}}$
Enemy Surface Successfully Target	$= \frac{\text{Quantity Red Surface Platforms that successfully target their assigned Blue platform}}{\text{Quantity Red Surface Platforms that entered the Target Phase}}$
Enemy Missiles Successfully Target	$= \frac{\text{Quantity Red Land Based Missiles that successfully target their assigned Blue platform}}{\text{Quantity Red Land Based Missiles that entered the Target Phase}}$
Enemy Aircraft Successfully Target (Total)	$= \frac{\text{Quantity Red Aircraft that successfully target their assigned Blue platform}}{\text{Quantity total Red Aircraft threats in simulation}}$
Enemy Surface Successfully Target (Total)	$= \frac{\text{Quantity Red Surface Platforms that successfully target their assigned Blue platform}}{\text{Quantity total Red Surface Platforms in simulation}}$
Enemy Missiles Successfully Target (Total)	$= \frac{\text{Quantity Red Land Based Missiles that successfully target their assigned Blue platform}}{\text{Quantity total Red Land Based Missile threats in simulation}}$
Enemy Missiles in M/P Range (10 nmi)	$= \frac{\text{Quantity Red missiles within M / P countermeasure range}}{\text{Quantity of total Red missiles}}$
Success of M/P Countermeasures	$= \frac{\text{Quantity of successful Blue M/P countermeasure engagements}}{\text{Quantity Red missiles within M/P countermeasure range}}$
M/P Utilization Metrics	$= \frac{\text{Quantity Blue Active Decoys employed}}{\text{Quantity of Blue Active Decoys available for employment}}$ $= \frac{\text{Quantity Blue Chaff employed}}{\text{Quantity of Blue Chaff available for employment}}$ $= \frac{\text{Quantity Blue Flares employed}}{\text{Quantity of Blue Flares available for employment}}$ $= \frac{\text{Quantity Blue IR Smoke employed}}{\text{Quantity of Blue IR Smoke available for employment}}$ $= \frac{\text{Quantity Blue Visual Smoke employed}}{\text{Quantity of Blue Visual Smoke available for employment}}$

APPENDIX F. MISSION ASSIGNMENT CRITERIA AND SCORING

This appendix details the weighting or scoring of the capabilities of friendly force vessels to facilitate a systematic method of assigning probabilities for the adversary mission assignment to target and engage the friendly force assets.

A. SCORING CRITERIA DEFINITION

COMBAT POWER	SCORE	LEVEL OF REACH
Platform & Assets > 300 missiles/bombs	10	Range > 1000 nautical miles
Platform & Assets 250—299 missiles/bombs	9	Range 800—999 nautical miles
Platform & Assets 200—249 missiles/bombs	8	Range 600—799 nautical miles
Platform & Assets 100—199 missiles/bombs	7	Range 400—599 nautical miles
Platform & Assets 80—99 missiles/bombs	6	Range 200—399 nautical miles
Platform & Assets 50—79 missiles/bombs	5	Range 100—199 nautical miles
Platform & Assets 25—49 missiles/bombs	4	Range 60—99 nautical miles
Platform & Assets 10—24 missiles/bombs	3	Range 25—59 nautical miles
Platform & Assets 5—9 missiles/bombs	2	Range 10—24 nautical miles
Platform & Assets 3—4 missiles/bombs	1	Range 4—9.99 nautical miles
Platform & Assets 0—2 missiles/bombs	0	Range 0—3.99 nautical miles

B. SCORING OF FRIENDLY PLATFORMS

FRIENDLY PLATFORM	COMBAT POWER SCORE	LEVEL OF REACH SCORE	OVERALL SCORE	RANKING
CVN	10	7	8.95	1
LHA/LHD	7	7	7	3
LPD	3	5	3.7	7
CG	7	8	7.35	2
DDG-51	6	8	6.7	4
DDG-1000	6	8	6.7	5
LCS	2	5	3.05	11
EPF	1	5	2.4	16
MDUSV	0	4	1.4	19
F-35	3	7	4.4	6
F/A-18	3	5	3.7	8
EA-18	0	7	2.45	15
E-2	0	10	3.5	9
P-8	0	9	3.15	10
MH-60	1	5	2.4	17
AH-1	2	4	2.7	14
MQ-4	0	8	2.8	13
MQ-8	0	8	2.8	12
MQ-9	0	5	1.75	18
TERN	0	4	1.4	20

APPENDIX G. DEGRADATION FACTORS

THREAT SENSOR TYPE	EMCON A	SPOT JAMMING	BARRAGE JAMMING	SWEEP JAMMING	DRFM JAMMING	GPS JAMMING
Visual						
Infrared	0.95					
ESM (Electronic Support Measures)	0	1.5	1.5	1.5	1.5	1.5
Air Search Radar	0	0.6-0.9	0.3-0.6	0.6-0.9	0.6-0.9	
Surface Search Radar		0.6-0.9	0.3-0.6	0.6-0.9	0.6-0.9	
Fire Control Radar	0	0.6-0.9	0.3-0.6	0.6-0.9	0.6-0.9	
Navigation Radar		0.6-0.9	0.3-0.6	0.6-0.9	0.6-0.9	
Phased Array Radar	0.8	0.6-0.9	0.3-0.6	0.6-0.9	0.6-0.9	
AESA (Active Electronic Scanned Array Radar)	0.8	0.6-0.9	0.3-0.6	0.6-0.9	0.6-0.9	
Over the Horizon Radar	0.8	0-0.3	0.6-0.9	0.6-0.9	0.3-0.6	
Synthetic Aperture Radar—Maritime	0.6	0.6-0.9	0.3-0.6	0.6-0.9	0-0.3	
Synthetic Aperture Radar—Space						
0 = Maximum/Complete Degradation 1 = No Degradation to Sensor >1 = Adverse Impact (Increased Signature) for Friendly Platforms Ranges follow a uniform distribution between noted minimum and maximum values in table						

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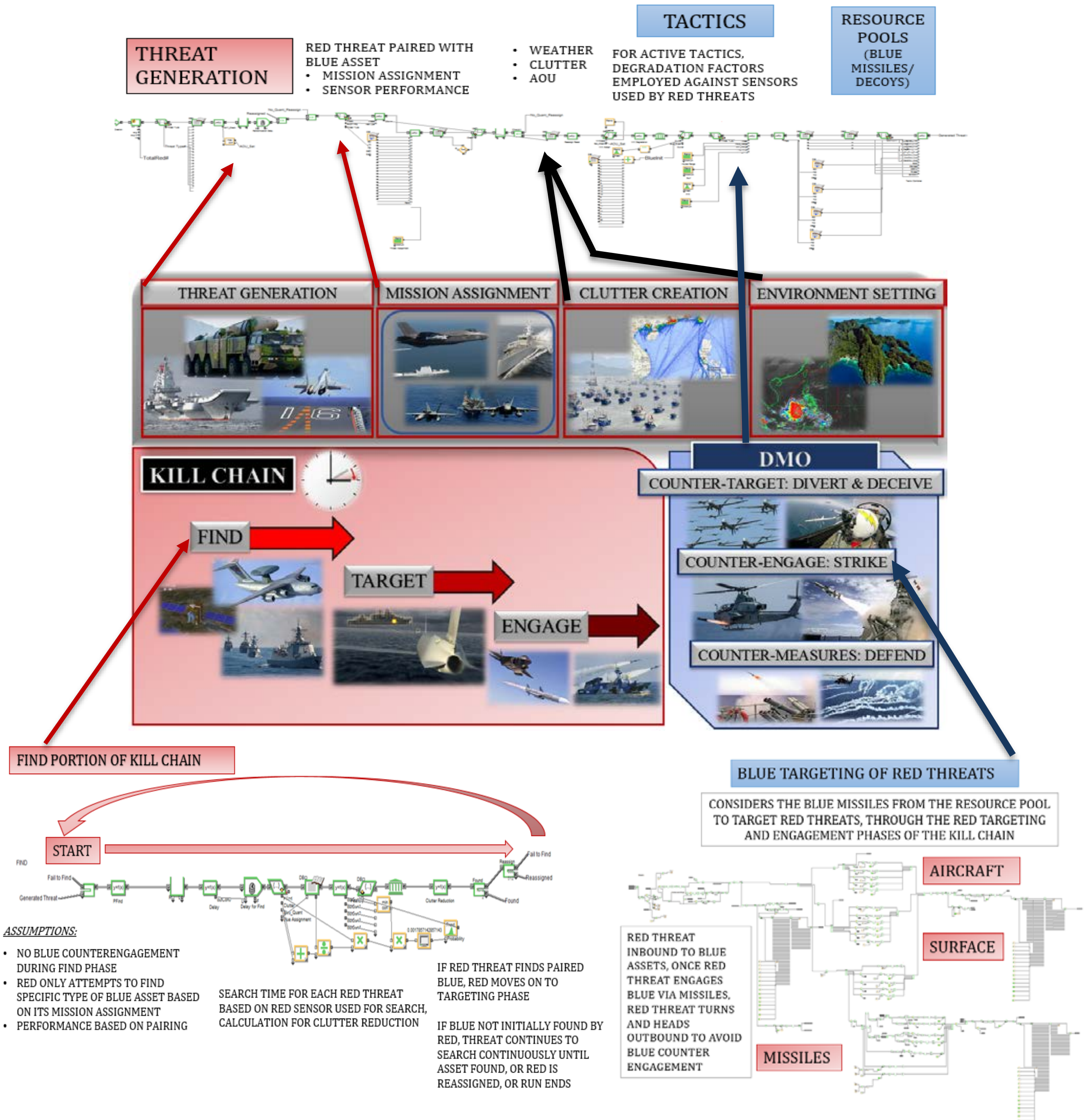
APPENDIX H. ANNOTATED EXTENDSIM MODEL DESCRIPTION



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APPENDIX I. SAMPLE MODEL INPUT DATA DMO FORCE STRUCTURE—DESIGN OF EXPERIMENTS

Set	Replication	Run #	# CVN	# CG	# DDG-51	# MDUSV	# F-35 AIR	# P-8	# TERN	DRFM Jamming	EMCON CG	Swarm	# Flares	# Chaff
1	1	1	1	1	4	1	2	2	48	0	1	0.746	33	87
1	2	513	1	3	7	2	15	4	29	1	0	0.417	16	102
1	3	1025	0	0	0	1	11	4	19	1	1	0.562	12	50
1	4	1537	2	1	10	3	13	0	19	0	1	0.804	4	28
1	5	2049	1	1	8	6	24	2	36	1	1	0.219	19	153
1	6	2561	2	2	1	2	30	8	21	0	0	0.072	41	90
1	7	3073	0	0	5	3	27	4	13	0	1	0.916	30	126
1	30	14849	1	3	6	6	14	0	37	0	0	0.871	17	45
2	1	2	1	1	4	1	4	8	4	0	0	0.569	12	148
2	2	514	1	2	2	3	13	6	16	1	1	0.831	8	112
2	3	1026	0	0	2	2	2	0	18	0	0	0.534	42	169
2	4	1538	2	2	9	2	16	2	34	1	1	0.135	13	84
2	5	2050	2	0	2	3	12	0	22	0	1	0.973	0	59
2	6	2562	1	0	10	3	27	4	39	1	0	0.135	26	70
2	7	3074	0	1	4	4	24	2	21	1	0	0.778	12	144
2	30	14850	2	0	6	1	6	2	38	0	1	0.820	45	171
512	1	512	0	2	9	5	0	6	1	0	0	0.209	23	4
512	30	15360	1	1	7	3	19	8	35	1	0	0.009	34	200

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APPENDIX J. SAMPLE DATA EXTRACTED FROM MODEL

Set	Replication	Run #	% Friendly Blue Killed	% Red Enemy Killed	% CVN/ LHA/ LHD Killed	% Missile Carriers Killed	% Fighter Aircraft Killed	% Enemy Success-fully Target	Avg AOU (Enemy Missile)	% Success-fully Find (Surface)	% Success-fully Target (Missile)	Time to Target (Air)
1	1	1	0.1724	0.6472	1.000	0.7259	0.0654	0.6641	37.539	0.9993	0.7194	13.589
1	2	513	0.1752	0.6074	1.000	0.7333	0.0438	0.7453	50.990	1.0000	0.8486	9.981
1	3	1025	0.1790	0.6374	1.000	0.7185	0.0772	0.6350	22.916	1.0000	0.8944	16.239
1	4	1537	0.1464	0.7179	1.000	0.5926	0.0327	0.4132	43.578	0.9986	0.7042	26.628
1	5	2049	0.2026	0.6579	1.000	0.9111	0.0605	0.6175	53.568	1.0000	0.7944	17.693
1	6	2561	0.1843	0.6660	1.000	0.8630	0.0605	0.5974	60.470	0.9993	0.7972	17.599
1	7	3073	0.1690	0.6058	1.000	0.7741	0.0327	0.7560	29.232	1.0000	0.9028	9.176
1	30	14849	0.1755	0.6425	1.000	0.8444	0.0475	0.6338	28.008	1.0000	0.8708	14.274
2	1	2	0.1733	0.6136	1.000	0.7630	0.0444	0.7487	45.600	1.0000	0.8653	10.327
2	2	514	0.1712	0.5890	1.000	0.7889	0.0364	0.7889	21.058	1.0000	0.8861	6.411
2	3	1026	0.1712	0.6877	1.000	0.7556	0.0556	0.5111	59.392	1.0000	0.7375	20.073
2	4	1538	0.1652	0.6054	0.983	0.7852	0.0364	0.7432	38.143	0.9993	0.7917	9.459
2	5	2050	0.1798	0.6506	1.000	0.7741	0.0642	0.6637	90.327	0.9993	0.7250	13.767
2	6	2562	0.1848	0.6794	1.000	0.8370	0.0463	0.5308	38.163	1.0000	0.8625	19.072
2	7	3074	0.1752	0.6553	1.000	0.7111	0.0630	0.6479	30.573	1.0000	0.7403	14.359
2	30	14850	0.1402	0.7217	1.000	0.6407	0.0315	0.3940	44.584	0.9993	0.7125	25.457
512	1	512	0.1567	0.7235	1.000	0.6481	0.0395	0.3915	62.767	1.0000	0.7000	24.190
512	30	15360	0.1683	0.6857	1.000	0.7519	0.0556	0.5316	58.811	0.9993	0.7722	19.946
Sample Values for Visualization												

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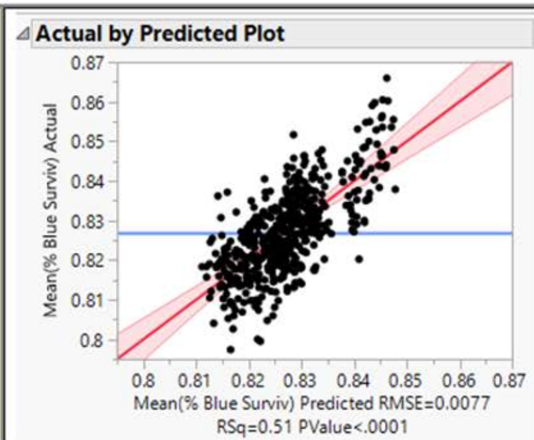
APPENDIX K. MODEL ANALYSIS OUTPUTS

This appendix presents additional regression analysis outputs as created through the JMP statistical program. These plots and summaries are not presented in the analysis chapter of the report, but are provided for further support of the conclusions made regarding the analysis of both the baseline fixed force structure, and the DMO variable force structure.

A. FIXED FORCE STRUCTURE

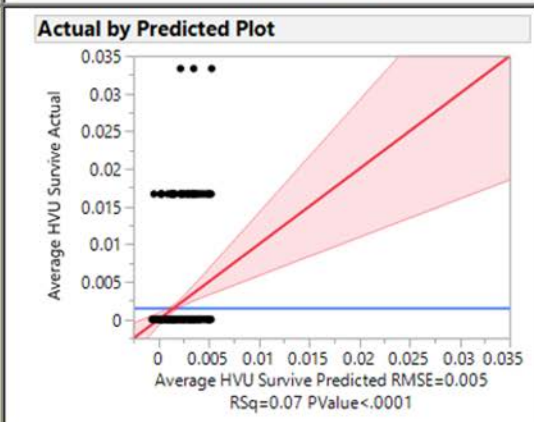
MOE #1: Friendly Force Overall Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(JAMMING SPOT-0.52344)*(JAMMING BARRAGE-0.45313)	0.0189575	0.001543	12.29	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING SWEEP-0.54492)	0.0149469	0.001589	9.41	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING DRFM-0.47461)	0.0136887	0.001543	8.87	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING DRFM-0.47461)	0.0096454	0.001557	6.19	<.0001*
JAMMING SPOT	0.0032529	0.000778	4.18	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING SWEEP-0.54492)	0.0055569	0.001526	3.64	0.0003*
Swarm	0.0045302	0.001352	3.35	0.0009*
(JAMMING BARRAGE-0.45313)*(IRSmoke-25)	-0.000156	0.000054	-2.89	0.0040*
(Active Decoy-12.5)*(Visual Smoke-25)	1.0841e-5	3.773e-6	2.87	0.0043*
JAMMING BARRAGE	-0.002121	0.00077	-2.75	0.0062*
(JAMMING GPS-0.52344)*(IR Smoke-25)	0.0001422	5.334e-5	2.67	0.0080*
JAMMING SWEEP	0.0019215	0.000784	2.45	0.0147*

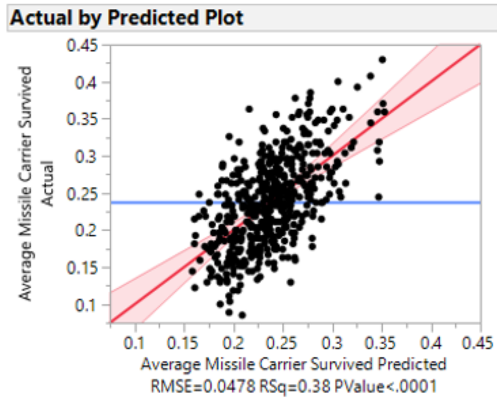
MOE #1a: Friendly Force CVN/LHA Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Swarm	0.002702	0.000763	3.54	0.0004*
JAMMING SPOT	0.00153	0.000441	3.47	0.0006*
(JAMMING SPOT-0.5225)*(Swarm-0.49938)	0.0045526	0.001534	2.97	0.0031*
JAMMING BARRAGE	0.0011252	0.000444	2.54	0.0115*

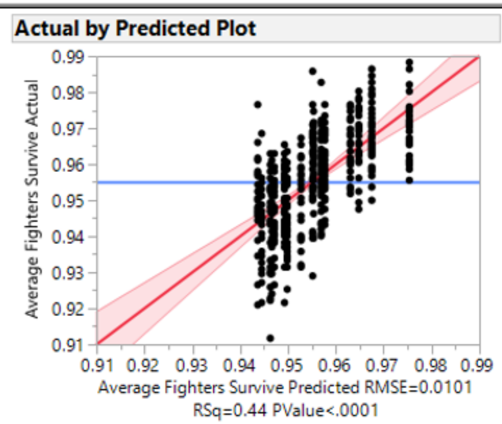
MOE #1b: Friendly Force Missile Carrier Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Swarm	0.0795992	0.007372	10.80	<.0001*
JAMMING BARRAGE	0.0299181	0.004257	7.03	<.0001*
(JAMMING SPOT-0.5225)*(JAMMING DRFM-0.47358)	0.0576539	0.008513	6.77	<.0001*
(JAMMING SPOT-0.5225)*(JAMMING SWEEP-0.54599)	0.0486968	0.008536	5.71	<.0001*
(JAMMING SPOT-0.5225)*(JAMMING BARRAGE-0.45205)	0.046249	0.008544	5.41	<.0001*
(JAMMING BARRAGE-0.45205)*(JAMMING DRFM-0.47358)	0.0353568	0.008547	4.14	<.0001*
(JAMMING BARRAGE-0.45205)*(JAMMING SWEEP-0.54599)	0.0268378	0.008562	3.13	0.0018*
JAMMING DRFM	0.0062071	0.004253	1.46	0.1451
JAMMING SWEEP	0.0055179	0.004263	1.29	0.1962
JAMMING SPOT	0.0004059	0.004241	0.10	0.9238

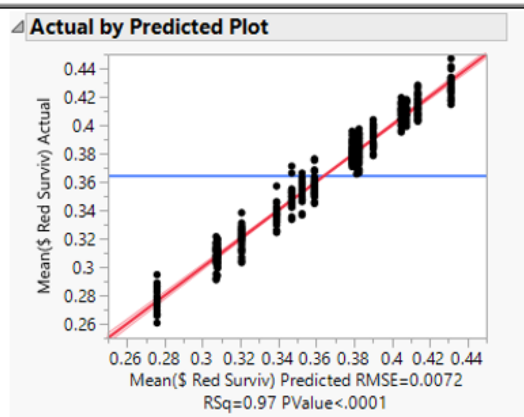
MOE #1c: Friendly Force Fighter Aircraft Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE	-0.012646	0.000896	-14.12	<.0001*
(JAMMING SPOT-0.5225)*(JAMMING BARRAGE-0.45205)	0.0135236	0.001793	7.54	<.0001*
(JAMMING BARRAGE-0.45205)*(JAMMING DRFM-0.47358)	0.0131752	0.001795	7.34	<.0001*
(JAMMING BARRAGE-0.45205)*(JAMMING SWEEP-0.54599)	0.010496	0.001799	5.84	<.0001*
JAMMING DRFM	-0.003643	0.000893	-4.08	<.0001*
JAMMING SWEEP	-0.003111	0.000897	-3.47	0.0006*
(JAMMING SPOT-0.5225)*(JAMMING DRFM-0.47358)	0.0052524	0.00179	2.93	0.0035*
JAMMING SPOT	-0.001966	0.000892	-2.20	0.0280*

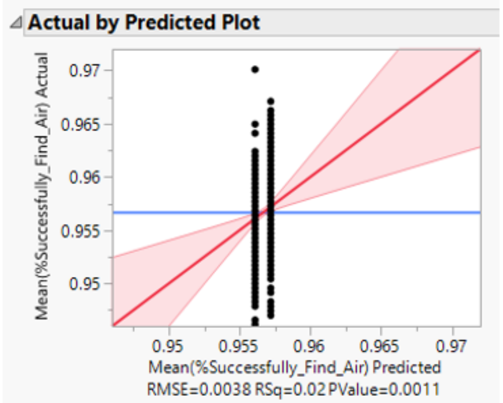
MOE #2: Enemy Force Overall Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE	-0.068256	0.00064	-106.6	<.0001*
JAMMING SPOT	-0.035108	0.000638	-55.03	<.0001*
JAMMING DRFM	-0.027373	0.00064	-42.78	<.0001*
JAMMING SWEEP	-0.024101	0.00064	-37.65	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING BARRAGE-0.45313)	-0.013659	0.001282	-10.65	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING SWEEP-0.54492)	-0.00895	0.001286	-6.96	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING DRFM-0.47461)	-0.008377	0.001283	-6.53	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING SWEEP-0.54492)	-0.004718	0.001283	-3.68	0.0003*

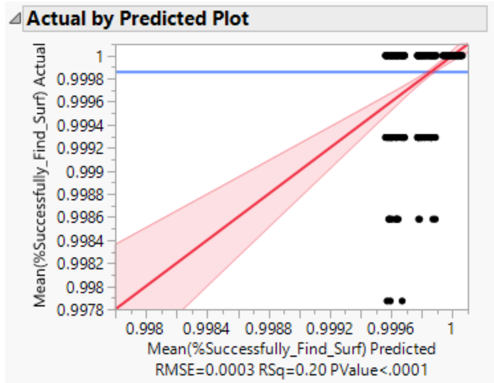
MOE #3: Enemy Ability to Find – Aircraft



Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9572024	0.000228	4192.5	<.0001*
JAMMING BARRAGE	-0.001109	0.000339	-3.27	0.0011*

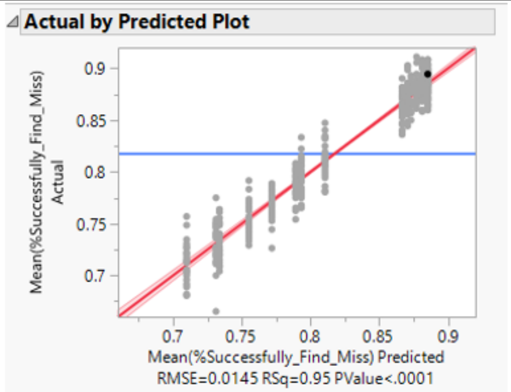
MOE #3: Enemy Ability to Find—Surface



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING SPOT	-0.000252	0.000031	-8.09	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING DRFM-0.47461)	-0.000253	6.218e-5	-4.07	<.0001*
JAMMING DRFM	-0.000111	3.013e-5	-3.69	0.0003*
JAMMING SWEEP	-7.68e-5	3.133e-5	-2.45	0.0147*
(JAMMING SPOT-0.52344)*(IR Smoke-25)	-4.715e-6	2.133e-6	-2.21	0.0277*
(JAMMING DRFM-0.47461)*(Flare-25)	-4.604e-6	2.149e-6	-2.14	0.0327*

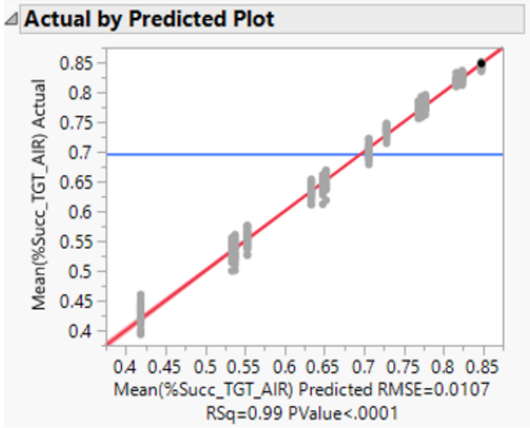
MOE #3: Enemy Ability to Find—Missiles



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING SPOT	-0.11454	0.001283	-89.28	<.0001*
JAMMING DRFM	-0.03648	0.001284	-28.41	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING DRFM-0.47461)	-0.047287	0.002571	-18.39	<.0001*
JAMMING BARRAGE	-0.013116	0.001287	-10.19	<.0001*
JAMMING SWEEP	-0.012146	0.001287	-9.44	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING SWEEP-0.54492)	-0.017424	0.002577	-6.76	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING BARRAGE-0.45313)	-0.01738	0.002574	-6.75	<.0001*
(JAMMING DRFM-0.47461)*(JAMMING SWEEP-0.54492)	-0.006636	0.002578	-2.57	0.0103*

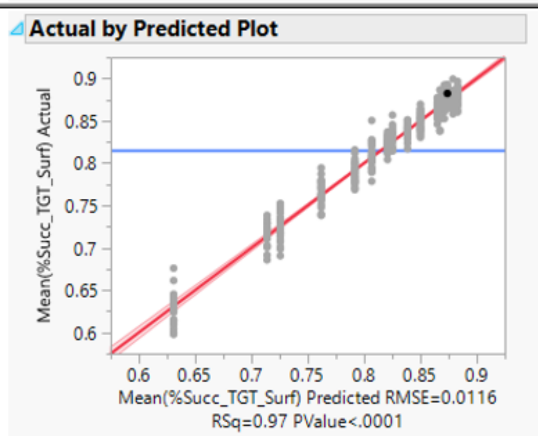
MOE #3: Enemy Ability to Target—Aircraft



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE	-0.205896	0.000953	-216.1	<.0001*
JAMMING SPOT	-0.08045	0.00095	-84.66	<.0001*
JAMMING DRFM	-0.072146	0.000951	-75.85	<.0001*
JAMMING SWEEP	-0.066972	0.000953	-70.24	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING BARRAGE-0.45313)	-0.063079	0.001906	-33.09	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING DRFM-0.47461)	-0.052615	0.001908	-27.58	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING SWEEP-0.54492)	-0.05221	0.001911	-27.32	<.0001*

MOE #3: Enemy Ability to Target—Surface

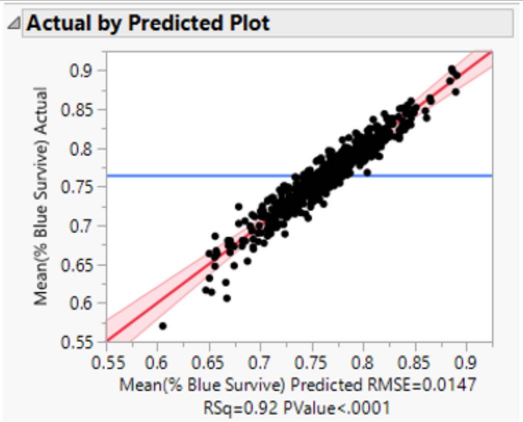


Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE	-0.093828	0.001033	-90.84	<.0001*
JAMMING SPOT	-0.067149	0.00103	-65.17	<.0001*
JAMMING DRFM	-0.043939	0.001031	-42.61	<.0001*
JAMMING SWEEP	-0.034661	0.001034	-33.53	<.0001*
(JAMMING SPOT-0.52344)*(JAMMING BARRAGE-0.45313)	-0.0666	0.002067	-32.22	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING DRFM-0.47461)	-0.051497	0.002069	-24.89	<.0001*
(JAMMING BARRAGE-0.45313)*(JAMMING SWEEP-0.54492)	-0.0512	0.002072	-24.71	<.0001*

B. DMO VARIABLE FORCE STRUCTURE

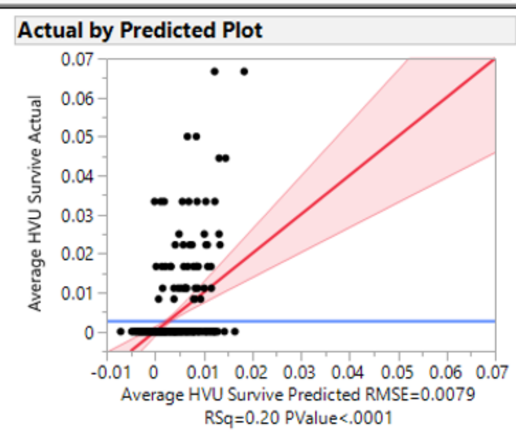
MOE #1: Friendly Force Overall Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Tern DOE	0.0016082	4.254e-5	37.80	<.0001*
# DDG-51 DOE	0.0051346	0.000212	24.27	<.0001*
# F-35 Air DOE	0.0017663	7.633e-5	23.14	<.0001*
# F-35 Surface DOE	0.0015738	7.659e-5	20.55	<.0001*
JAMMING BARRAGE DOE	0.0256058	0.001332	19.23	<.0001*
JAMMING SPOT DOE	0.0174549	0.001345	12.98	<.0001*
# Firescout DOE	0.0013152	0.000117	11.23	<.0001*

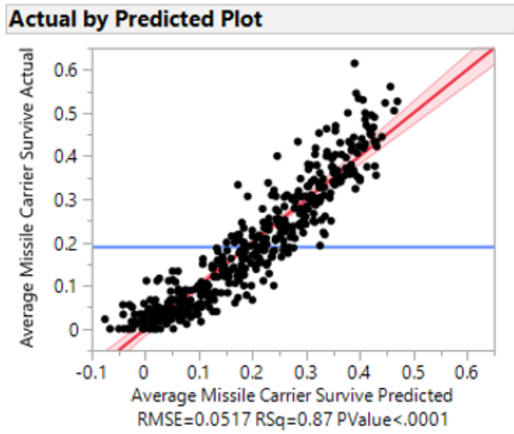
MOE 1a: Friendly Force CVN/LHA Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
# DDG-51 DOE	0.0006866	0.000116	5.91	<.0001*
# LHD/LHA DOE	0.0023166	0.000477	4.85	<.0001*
(# LHD/LHA DOE-1.08036)*(# DDG-51 DOE-4.80134)	0.0006377	0.000147	4.33	<.0001*
Swarm DOE	0.0050052	0.001321	3.79	0.0002*
# CG DOE	0.0010822	0.00034	3.18	0.0016*
(# DDG-51 DOE-4.80134)*(#F-35 Surface DOE-15.1585)	4.3181e-5	1.383e-5	3.12	0.0019*
# F-35 Surface DOE	0.0001022	4.362e-5	2.34	0.0196*

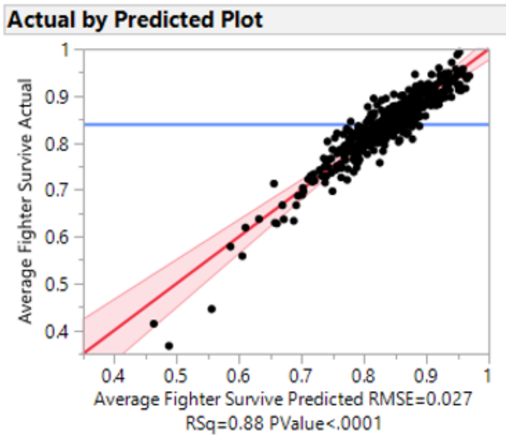
MOE 1b: Friendly Force Missile Carrier Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
# DDG-51 DOE	0.0405043	0.000786	51.50	<.0001*
Swarm DOE	0.0594022	0.008652	6.87	<.0001*
(JAMMING SPOT DOE-0.52154)*(JAMMING DRFM DOE-0.46259)	0.0447707	0.010118	4.42	<.0001*
# LCS DOE	0.0045676	0.001209	3.78	0.0002*
(JAMMING SPOT DOE-0.52154)*(JAMMING BARRAGE DOE-0.45578)	0.0374943	0.010014	3.74	0.0002*
(JAMMING SPOT DOE-0.52154)*(JAMMING SWEEP DOE-0.54422)	0.0368712	0.009972	3.70	0.0002*
# CVN DOE	0.0108585	0.003214	3.38	0.0008*
JAMMING BARRAGE DOE	0.015062	0.004956	3.04	0.0025*
Chaff DOE	0.0001176	4.336e-5	2.71	0.0070*
JAMMING DRFM DOE	0.0083594	0.004956	1.69	0.0924
JAMMING SPOT DOE	0.0039389	0.004933	0.80	0.4250
JAMMING SWEEP DOE	0.0032571	0.004964	0.66	0.5121

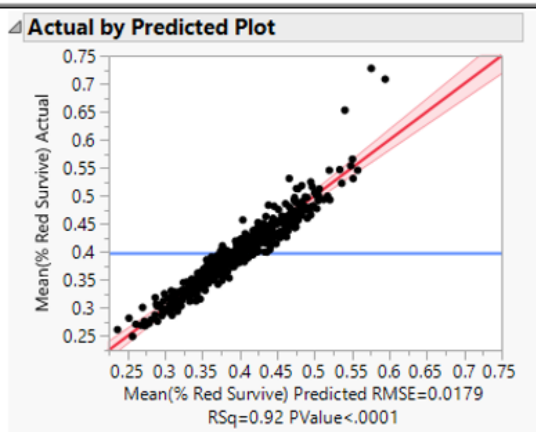
MOE 1c: Friendly Force Fighter Aircraft Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
# F-35 Surface DOE	0.0038841	0.000153	25.40	<.0001*
# F-35 Air DOE	0.0032966	0.000151	21.83	<.0001*
# DDG-51 DOE	0.0068328	0.00041	16.66	<.0001*
E/A-18 DOE	-0.012832	0.000778	-16.49	<.0001*
# CG DOE	0.0138184	0.001193	11.58	<.0001*
JAMMING BARRAGE DOE	0.0299287	0.002622	11.41	<.0001*
# F/A-18 Surf DOE	0.0038297	0.00038	10.07	<.0001*
(# F-35 Air DOE-14.931)*(# F-35 Surface DOE-15.1292)	-0.000158	1.73e-5	-9.10	<.0001*
JAMMING SPOT DOE	0.0176855	0.002645	6.69	<.0001*
Tern DOE	-0.000516	8.363e-5	-6.17	<.0001*
(JAMMING BARRAGE DOE-0.45657)*(# DDG-51 DOE-4.80846)	0.0049388	0.000845	5.84	<.0001*
JAMMING DRFM DOE	0.0148502	0.002658	5.59	<.0001*
(E/A-18 DOE-2.56347)*(# F-35 Surface DOE-15.1292)	0.0005145	9.255e-5	5.56	<.0001*
(AH-1Z DOE-3.06459)*(# F-35 Surface DOE-15.1292)	-0.000359	6.788e-5	-5.29	<.0001*
(E/A-18 DOE-2.56347)*(# Passive Decoys DOE-149.187)	4.7122e-5	9.109e-6	5.17	<.0001*
(# F/A-18 Air DOE-4.89978)*(# F-35 Surface DOE-15.1292)	-0.000226	4.513e-5	-5.00	<.0001*
(# F/A-18 Surf DOE-4.87305)*(# F-35 Air DOE-14.931)	-0.000229	4.579e-5	-5.00	<.0001*
JAMMING SWEEP DOE	0.0126805	0.002604	4.87	<.0001*
(AH-1Z DOE-3.06459)*(Visual Smoke DOE-25.0713)	0.00017	0.00004	4.26	<.0001*
(EMCON DDG-51 DOE-0.53898)*(# F/A-18 Surf DOE-4.87305)	0.0031715	0.000766	4.14	<.0001*
(# LCS DOE-2.87528)*(# DDG-51 DOE-4.80846)	-0.000813	0.000211	-3.86	0.0001*
(E/A-18 DOE-2.56347)*(# DDG-51 DOE-4.80846)	0.0009203	0.000241	3.81	0.0002*
(AH-1Z DOE-3.06459)*(# Passive Decoys DOE-149.187)	-2.637e-5	6.924e-6	-3.81	0.0002*
(JAMMING GPS DOE-0.5167)*(# CG DOE-1.42539)	0.0086586	0.002408	3.60	0.0004*
(JAMMING SPOT DOE-0.52116)*(# P-8 DOE-3.86637)	-0.003322	0.000932	-3.56	0.0004*
(JAMMING GPS DOE-0.5167)*(# F-35 Air DOE-14.931)	0.001096	0.000311	3.52	0.0005*
(# F/A-18 Surf DOE-4.87305)*(Tern DOE-27.0557)	8.5667e-5	2.463e-5	3.48	0.0006*
(# CVN DOE-1.07572)*(Flare DOE-24.8953)	-0.000375	0.000119	-3.15	0.0017*
(# CVN DOE-1.07572)*(# F-35 Surface DOE-15.1292)	-0.000613	0.000198	-3.10	0.0021*
(EMCON DDG-51 DOE-0.53898)*(# F-35 Surface DOE-15.1292)	0.0009659	0.000314	3.08	0.0022*
EMCON DDG-51 DOE	-0.007982	0.002621	-3.05	0.0025*
(JAMMING SWEEP DOE-0.54566)*(# F/A-18 Surf DOE-4.87305)	-0.002301	0.000772	-2.98	0.0030*
Flare DOE	0.0002641	9.071e-5	2.91	0.0038*
(# P-8 DOE-3.86637)*(Visual Smoke DOE-25.0713)	-9.18e-5	3.232e-5	-2.84	0.0047*
JAMMING GPS DOE	-0.007323	0.002611	-2.80	0.0053*
(# F/A-18 Surf DOE-4.87305)*(# F-35 Surface DOE-15.1292)	-0.000126	0.000045	-2.80	0.0053*
(# DDG-51 DOE-4.80846)*(# F-35 Air DOE-14.931)	-0.000133	4.757e-5	-2.80	0.0053*
(# F/A-18 Air DOE-4.89978)*(# F-35 Air DOE-14.931)	-0.000118	4.37e-5	-2.71	0.0071*
(# F-35 Surface DOE-15.1292)*(Tern DOE-27.0557)	2.6859e-5	1.022e-5	2.63	0.0089*
Visual Smoke DOE	-0.000228	9.043e-5	-2.52	0.0122*

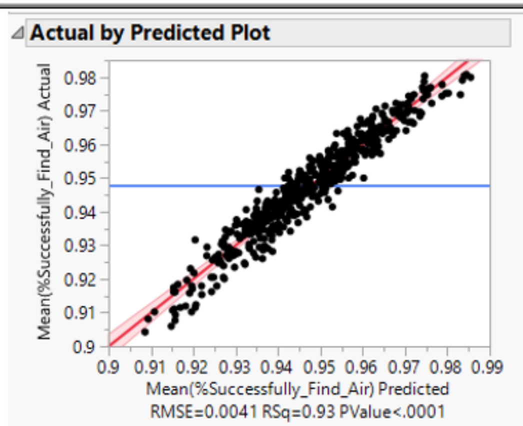
MOE #2: Enemy Force Overall Survivability



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
# DDG-51 DOE	-0.010756	0.000253	-42.49	<.0001*
# CG DOE	-0.025917	0.000725	-35.74	<.0001*
JAMMING BARRAGE DOE	-0.054297	0.001632	-33.28	<.0001*
# F-35 Air DOE	-0.001395	9.355e-5	-14.91	<.0001*
JAMMING SWEEP DOE	-0.023486	0.001627	-14.44	<.0001*
JAMMING SPOT DOE	-0.023332	0.00162	-14.40	<.0001*
JAMMING DRFM DOE	-0.022194	0.001624	-13.66	<.0001*

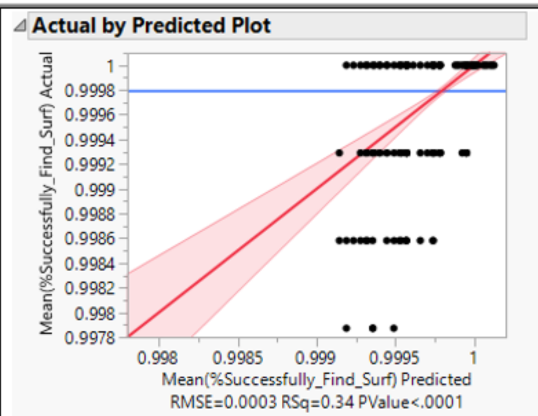
MOE #3: Enemy Ability to Find – Aircraft



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE DOE	-0.18013	0.00146	-123.3	<.0001*
JAMMING SPOT DOE	-0.070587	0.001468	-48.07	<.0001*
JAMMING DRFM DOE	-0.064726	0.001463	-44.23	<.0001*
JAMMING SWEEP DOE	-0.062875	0.001459	-43.09	<.0001*
# DDG-51 DOE	-0.006035	0.000232	-25.97	<.0001*
# CG DOE	-0.014093	0.00066	-21.36	<.0001*
(JAMMING BARRAGE DOE-0.45313)*(#DDG-51 DOE-4.83008)	-0.009031	0.000464	-19.47	<.0001*

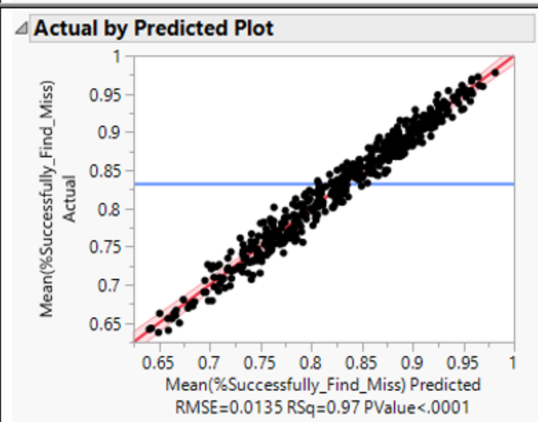
MOE #3: Enemy Ability to Find—Surface



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING SPOT DOE	-0.000392	3.026e-5	-12.94	<.0001*
JAMMING DRFM DOE	-0.000161	3.024e-5	-5.33	<.0001*
(JAMMING SPOT DOE-0.52344)*(JAMMING DRFM DOE-0.47461)	-0.000317	6.077e-5	-5.22	<.0001*
JAMMING SWEEP DOE	-0.000117	3.037e-5	-3.84	0.0001*
(JAMMING SPOT DOE-0.52344)*(JAMMING SWEEP DOE-0.54492)	-0.000199	6.137e-5	-3.25	0.0012*
JAMMING BARRAGE DOE	-0.000094	3.029e-5	-3.10	0.0020*
(JAMMING DRFM DOE-0.47461)*(#F/A-18 Surf DOE-4.90234)	-2.27e-5	8.68e-6	-2.62	0.0092*
(JAMMING SPOT DOE-0.52344)*(JAMMING BARRAGE DOE-0.45313)	-0.000156	6.08e-5	-2.57	0.0105*
# F/A-18 Surf DOE	-1.032e-5	4.326e-6	-2.39	0.0174*

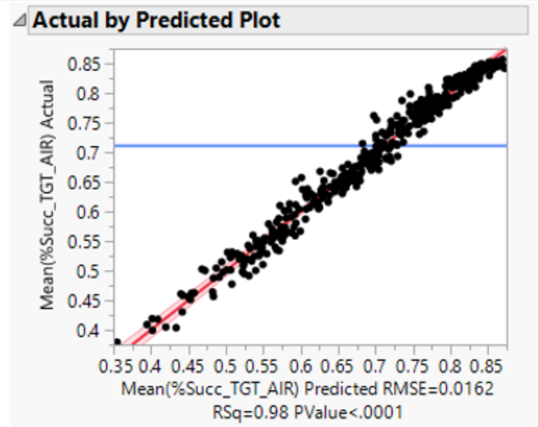
MOE #3: Enemy Ability to Find—Missiles



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING SPOT DOE	-0.121507	0.001214	-100.1	<.0001*
Tern DOE	-0.001608	3.888e-5	-41.35	<.0001*
JAMMING DRFM DOE	-0.039399	0.001209	-32.59	<.0001*
# F-35 Surface DOE	-0.001621	0.00007	-23.16	<.0001*
# F-35 Air DOE	-0.00163	7.057e-5	-23.10	<.0001*
(JAMMING SPOT DOE-0.52344)*(JAMMING DRFM DOE-0.47461)	-0.049546	0.002477	-20.00	<.0001*
# Firescout DOE	-0.001789	0.000105	-16.97	<.0001*

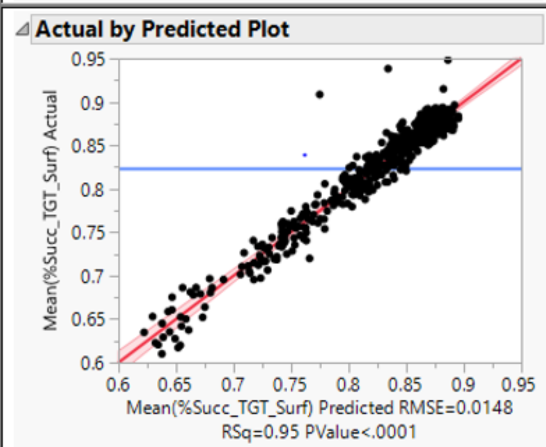
MOE #3: Enemy Ability to Target—Aircraft



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE DOE	-0.18013	0.00146	-123.3	<.0001*
JAMMING SPOT DOE	-0.070587	0.001468	-48.07	<.0001*
JAMMING DRFM DOE	-0.064726	0.001463	-44.23	<.0001*
JAMMING SWEEP DOE	-0.062875	0.001459	-43.09	<.0001*
# DDG-51 DOE	-0.006035	0.000232	-25.97	<.0001*
# CG DOE	-0.014093	0.00066	-21.36	<.0001*
(JAMMING BARRAGE DOE-0.45313)*(#DDG-51 DOE-4.83008)	-0.009031	0.000464	-19.47	<.0001*

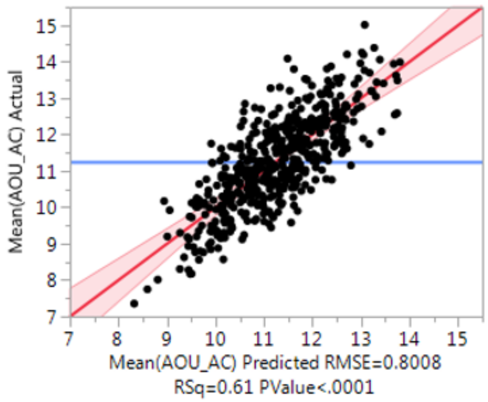
MOE #3: Enemy Ability to Target—Surface



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE DOE	-0.081223	0.001326	-61.24	<.0001*
JAMMING SPOT DOE	-0.062265	0.001322	-47.10	<.0001*
JAMMING DRFM DOE	-0.040857	0.001319	-30.97	<.0001*
JAMMING SWEEP DOE	-0.034009	0.00133	-25.57	<.0001*
(JAMMING SPOT DOE-0.52344)*(JAMMINGBARRAGE DOE-0.45313)	-0.062729	0.002654	-23.63	<.0001*
(JAMMING BARRAGE DOE-0.45313)*(JAMMINGDRFM DOE-0.47461)	-0.050047	0.002644	-18.93	<.0001*
(JAMMING BARRAGE DOE-0.45313)*(JAMMINGSWEEP DOE-0.54492)	-0.047763	0.002663	-17.94	<.0001*

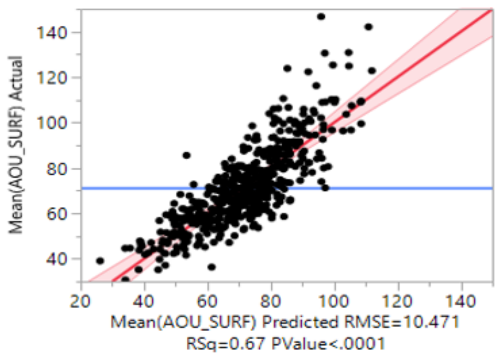
MOP: Area of Uncertainty —Enemy Aircraft



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Tern DOE	0.0397362	0.002266	17.54	<.0001*
# F-35 Surface DOE	0.0420746	0.004079	10.32	<.0001*
# F-35 Air DOE	0.0388881	0.004079	9.53	<.0001*
Swarm DOE	-1.134785	0.122433	-9.27	<.0001*
MH-60 R/S DOE	0.0474242	0.006838	6.94	<.0001*
# Firescout DOE	0.0407456	0.006116	6.66	<.0001*
# F/A-18 Air DOE	0.040978	0.010118	4.05	<.0001*

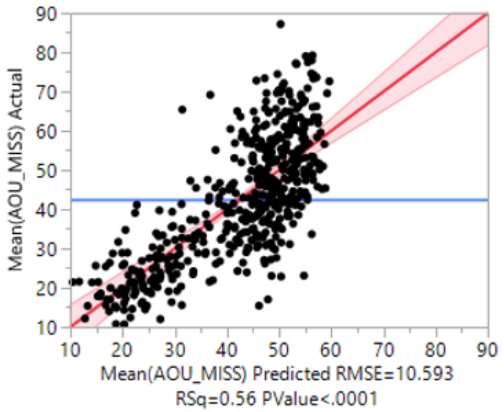
MOP: Area of Uncertainty —Enemy Surface



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING SPOT DOE	17.032402	0.927728	18.36	<.0001*
JAMMING BARRAGE DOE	12.999407	0.933304	13.93	<.0001*
Tern DOE	0.4036524	0.029623	13.63	<.0001*
# F-35 Air DOE	0.4632203	0.053398	8.67	<.0001*
JAMMING DRFM DOE	6.4306403	0.927864	6.93	<.0001*
Swarm DOE	-11.13048	1.611962	-6.90	<.0001*
# F-35 Surface DOE	0.3545509	0.053337	6.65	<.0001*

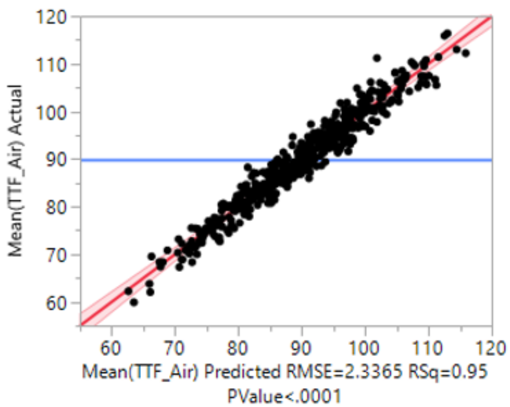
MOP: Area of Uncertainty —Enemy Land-Based Missiles



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio		Prob>|t|
JAMMING SPOT DOE	17.345466	0.937677	18.50		<.0001*
(JAMMING SPOT DOE-0.52344)*(JAMMING DRFM DOE-0.47461)	-17.90967	1.887351	-9.49		<.0001*
JAMMING DRFM DOE	7.9730749	0.939101	8.49		<.0001*
Swarm DOE	-11.73601	1.624167	-7.23		<.0001*
Tern DOE	0.1130783	0.030033	3.77		0.0002*
(JAMMING SPOT DOE-0.52344)*(Tern DOE-27)	-0.224879	0.060153	-3.74		0.0002*
(JAMMING SPOT DOE-0.52344)*(JAMMINGBARRAGE DOE-0.45313)	-6.92987	1.895387	-3.66		0.0003*

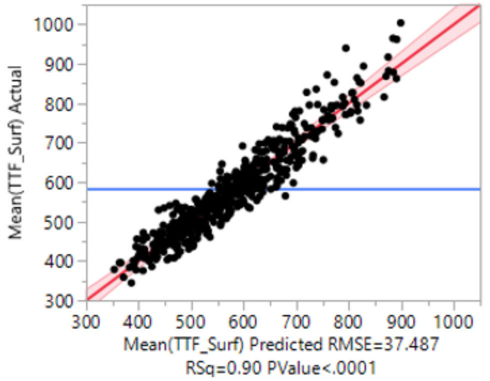
MOP: Time to Find—Enemy Aircraft



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio		Prob>|t|
Tern DOE	0.4166929	0.006643	62.73		<.0001*
# F-35 Surface DOE	0.4258145	0.012007	35.46		<.0001*
# F-35 Air DOE	0.4142609	0.012041	34.40		<.0001*
# Firescout DOE	0.4512759	0.017984	25.09		<.0001*
MH-60 R/S DOE	0.4073606	0.020045	20.32		<.0001*
Reaper DOE	0.3919322	0.023754	16.50		<.0001*
# F/A-18 Air DOE	0.4153356	0.029768	13.95		<.0001*

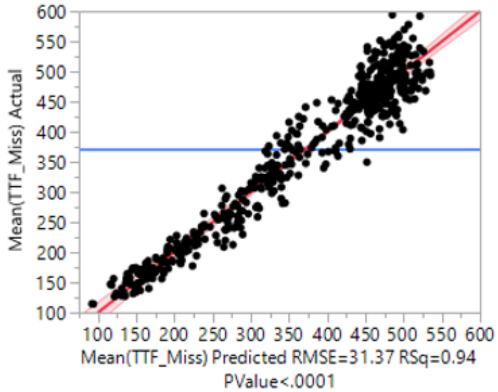
MOP: Time to Find— Enemy Surface



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING SPOT DOE	141.24966	3.324868	42.48	<.0001*
JAMMING BARRAGE DOE	103.62476	3.336191	31.06	<.0001*
Tern DOE	2.3301866	0.106864	21.81	<.0001*
JAMMING DRFM DOE	69.644438	3.350409	20.79	<.0001*
JAMMING SWEEP DOE	42.465868	3.377904	12.57	<.0001*
# F-35 Surface DOE	2.2189904	0.192619	11.52	<.0001*
# F-35 Air DOE	2.135715	0.191631	11.14	<.0001*

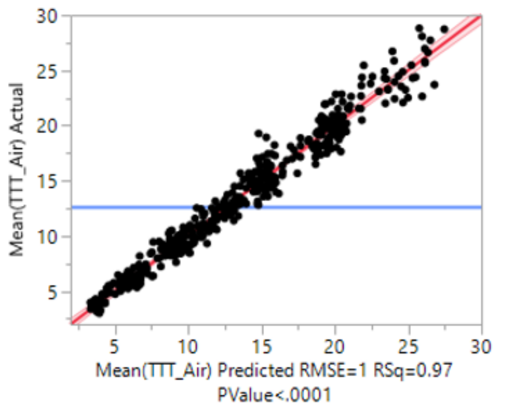
MOP: Time to Find— Enemy Missiles



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING SPOT DOE	214.49252	2.777883	77.21	<.0001*
JAMMING DRFM DOE	77.61588	2.788068	27.84	<.0001*
(JAMMING SPOT DOE-0.52344)*(JAMMING DRFM DOE-0.47461)	-97.46232	5.653936	-17.24	<.0001*
Tern DOE	1.315535	0.089154	14.76	<.0001*
JAMMING SWEEP DOE	26.324985	2.80482	9.39	<.0001*
JAMMING BARRAGE DOE	20.697072	2.792282	7.41	<.0001*
# F-35 Surface DOE	1.1506841	0.160317	7.18	<.0001*

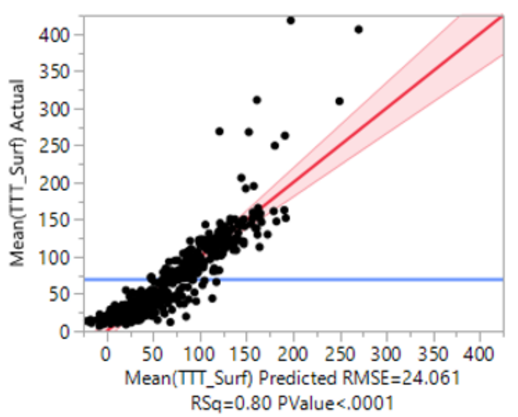
MOP: Time to Target—Enemy Aircraft



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE DOE	9.748514	0.089166	109.33	<.0001*
JAMMING SPOT DOE	4.0260154	0.088915	45.28	<.0001*
JAMMING DRFM DOE	3.8092616	0.089287	42.66	<.0001*
JAMMING SWEEP DOE	3.4027435	0.089735	37.92	<.0001*
# F-35 Air DOE	-0.073574	0.005133	-14.33	<.0001*
(# F/A-18 Air DOE-4.92578)*(# F-35 Air DOE-15)	0.0116249	0.001467	7.92	<.0001*
(JAMMING BARRAGE DOE-0.45313)*(JAMMING DRFM DOE-0.47461)	1.2248637	0.179322	6.83	<.0001*

MOP: Time to Target—Enemy Surface



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JAMMING BARRAGE DOE	63.534521	2.164497	29.35	<.0001*
JAMMING SPOT DOE	36.631332	2.153677	17.01	<.0001*
JAMMING DRFM DOE	27.115179	2.144895	12.64	<.0001*
JAMMING SWEEP DOE	18.86514	2.155648	8.75	<.0001*
(# DDG-51 DOE-4.83008)*(# F-35 Surface DOE-15)	0.2537097	0.040112	6.33	<.0001*
(# F/A-18 Surf DOE-4.90234)*(# DDG-51 DOE-4.83008)	0.608424	0.096442	6.31	<.0001*
# F-35 Surface DOE	-0.781637	0.124126	-6.30	<.0001*

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