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SYSTEMS ENGINEERING CAPSTONE REPORT

UNMANNED VEHICLE CARRIER SUPPORTING DISTRIBUTED MARITIME OPERATIONS

by

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September 2021

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This project informs the concept of operations and system design decisions related to the usage of unmanned systems in support of Distributed Maritime Operations (DMO). The research supports capability-level analysis of an Unmanned Vehicle Carrier (UVC) through systematic variation of system design characteristics and operational activities in a simulation model. The analysis shows that the UVC improves operational availability (Ao) and time-on-station (TOS) for a variety of unmanned systems by providing ready access to maintenance, refueling, and rearming facilities without the need for long transit times to shore-based facilities or distributed support vessels. Improvement in Ao for individual unmanned systems ranged from 6% to 31% when comparing configurations utilizing a UVC vs. configurations that distribute unmanned systems support across the adaptive force package (AFP). The simulation model analysis identified a UVC architecture consisting of at least eight unmanned aerial vehicle (UAV) launch recovery stations, at least three ship side-bays, and at least five well deck bays to maximize Ao.

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ABSTRACT

This project informs the concept of operations and system design decisions related to the usage of unmanned systems in support of Distributed Maritime Operations (DMO). The research supports capability-level analysis of an Unmanned Vehicle Carrier (UVC) through systematic variation of system design characteristics and operational activities in a simulation model. The analysis shows that the UVC improves operational availability (Ao) and time-on-station (TOS) for a variety of unmanned systems by providing ready access to maintenance, refueling, and rearming facilities without the need for long transit times to shore-based facilities or distributed support vessels. Improvement in Ao for individual unmanned systems ranged from 6% to 31% when comparing configurations utilizing a UVC vs. configurations that distribute unmanned systems support across the adaptive force package (AFP). The simulation model analysis identified a UVC architecture consisting of at least eight unmanned aerial vehicle (UAV) launch recovery stations, at least three ship side-bays, and at least five well deck bays to maximize Ao.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2AD	anti-access area denial
AAW	anti-air warfare
AEW	airborne electronic warfare
AFP	adaptive force package
Ao	operational availability
ASW	anti-submarine warfare
ASUW	anti-surface warfare
BIC	Bayesian information criterion
C2	command and control
CBRNE	chemical, biological, radiological, nuclear, explosive
CCM	combatant craft medium
CLF	combat logistics force
CLS	combat logistics ship
CO	commanding officer
CONOPS	concept of operations
CVL	light aircraft carrier
CVN	aircraft carrier (nuclear propulsion)
DES	discrete event simulation
DL	distributed lethality
DMO	distributed maritime operations
DOD	Department of Defense
DoDAF	Department of Defense Architecture Framework
EABO	Expeditionary Advanced Base Operations
EFFBD	enhanced functional flow block diagram
ESM	electronic support measures
FIAC	fast inshore attack craft
IO	information operations
ISR	intelligence, surveillance, and reconnaissance

LCS	Littoral Combat Ship
LDUUV	Large Displacement Unmanned Undersea Vehicle
LHD	landing helicopter dock
LPD	landing platform dock
LSC	large surface combatant
LUSV	Large Unmanned Surface Vessel
MCM	mine countermeasures
MDUSV	Medium Displacement Unmanned Surface Vehicle
MDUUV	Medium Displacement Unmanned Undersea Vehicle
MOE	measure of effectiveness
MOP	measure of performance
MTBM	mean time between maintenance
MTTR	mean time to repair
MUSV	Medium Unmanned Surface Vessel
M&S	modeling and simulation
NPS	Naval Postgraduate School
PEO-USC	Program Executive Office Unmanned and Small Combatants
PMS	planned maintenance system
RHIB	rigid-hull inflatable boat
SATCOM	satellite communication
SOF	Special Operations Forces
SSC	small surface combatant
SSN	Submarine, Nuclear
TASP	teams of autonomous systems and people
TERN	Tactically Exploited Reconnaissance Node
TOS	time on station
UAV	unmanned aerial vehicle
UOC	unmanned operations center
U.S.	United States
USV	unmanned surface vessel

UUV	unmanned undersea vehicle
UVC	Unmanned Vehicle Carrier
UxV	unmanned vehicle
XLUUV	Extra Large Unmanned Undersea Vehicle
XO	executive officer

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EXECUTIVE SUMMARY

In support of Distributed Maritime Operations (DMO), unmanned systems have the potential to act as a force multiplier to increase lethality while simultaneously reducing risk to manned systems. However, transit time to shore-based maintenance, refuel, and rearm facilities reduces the overall time on station (TOS) during which unmanned systems are available to support an adaptive force package (AFP) conducting DMO. This project examines the integration of unmanned surface vessels (USVs), unmanned undersea vehicles (UUVs), and unmanned aerial vehicles (UAVs) aboard an existing U.S. Navy ship that has been repurposed as an Unmanned Vehicle Carrier (UVC). Throughout this report, the term "UxV" is used to describe unmanned systems as a class.

The project team utilized a generalized systems engineering process sequence of system definition, system modeling, and system analysis, as described by Van Bossuyt et al. (2019). During system definition, the team focused on development of a concept of operations (CONOPS) and definition of system requirements for the UVC. System modeling activities focused on construction of a discrete event simulation model of the UVC. In the system analysis phase, the team utilized the developed model to evaluate the effect of various UVC design parameters on the operational availability (Ao) for each unmanned system type.

A. SYSTEM DEFINITION

During the system definition phase, UVC requirements were developed and considered from both top-down and bottom-up viewpoints. From the top-down view, the team analyzed and determined the capabilities necessary to meet the overall mission effectiveness goals, independent of any existing candidate platform. From the bottom-up perspective, the team evaluated a Landing Helicopter Dock (LHD) ship to determine the maximum UVC capabilities that could be realized by that platform. Through literature review and analysis of stakeholder needs, the project team identified the following key capabilities for the UVC: command & control (C2), UxV launch, UxV maintenance, and UxV recovery. The UVC is envisioned to include landing deck UAV launch and recovery stations, UAV maintenance/rearm/refuel bays, ship side bays or stations for large USV/ UUV operations, and well-deck bays for smaller USV/UUV operations.

B. SYSTEM MODELING

The project CONOPS places the UVC as part of an AFP conducting DMO against adversary surface and shore forces. The UVC's role is to support UxVs in the reconnaissance and strike on an enemy shore-based missile site. The UxVs provide 24/7 intelligence, surveillance, and reconnaissance (ISR), targeting, and battle damage assessment coverage before, during, and after the strike phase. The overall UVC goal is to increase UxV TOS by eliminating longer transit times to shore-based support facilities. To address this overall goal, the team chose Ao and persistent dwell time as Measures of Performance (MOPs) and overall UxV Mission Time, UxV Downtime, and Maintenance Bay Utilization as Measures of Effectiveness (MOEs).

A discrete event simulation model was designed and developed to analyze the effect of UVC design parameters on the MOPs and MOEs. The model was developed via the ExtendSim10 modeling program. The model includes UxV launch and recovery, UxV maintenance activities, and UxV rearming and refueling activities. Launch schedules for the UxVs and the total simulation runtime are developed based on the proposed UVC CONOPS. Currently, the model does not consider UxV losses or failures; this represents an area for potential future work. The key model outputs are the Ao for each UxV type.

C. SYSTEM ANALYSIS

A purpose-built space-filling Latin Hypercube design was generated to extensively explore the experiment space while reducing the overall number of trials and model runtime. Simulations were replicated 30 runs per trial and results were collected. The resulting Ao values were combined to obtain an statistical mean for each trial.

The analysis showed that the UVC improves Ao and TOS for each UxV type by providing ready access to maintenance, refueling, and rearming facilities without the need for long transit times to shore-based facilities or distributed support vessels. For any given UxV, the greatest Ao was obtained by increasing the number of UVC launch, recovery, and maintenance stations, thereby eliminating or reducing queuing time for those services. The analysis revealed that the UVC should be designed with a minimum of eight UAV launch/recovery stations, a minimum of three ship side bays, and a minimum of five well-deck bays. No upper-bound for these parameters was identified, and this represents a potential area of future research.

Interestingly, while the presence of the UVC improves Large Unmanned Surface Vessel (LUSV) Ao, the actual design of the UVC appears to have no impact on LUSV Ao. This is likely due to the assumed long-duration mission and assumed maintenance intervals of the LUSV, eliminating the likelihood of any queuing. A single ship side bay appears to be sufficient to service multiple LUSVs, but the availability of even that single ship side bay improves Ao by eliminating transit time to shore-based facilities.

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Van Bossuyt, Douglas L., Paul Beery, Bryan M. O'Halloran, Alejandro Hernandez, and Eugene Paulo. 2019. "The Naval Postgraduate School's Department of Systems Engineering Approach to Mission Engineering Education through Capstone Projects." *Systems* 7 (3) (August): 38. doi:10.3390/systems7030038.

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I. INTRODUCTION

A. BACKGROUND

As the United States (U.S.) Navy develops systems and operational concepts with an emphasis on Great Power Competition, there is a focus on the ability to mass effects while remaining geographically distributed. The U.S. Navy is increasingly prioritizing the ability to project offensive capability using surface forces (Richardson 2018). A recent push towards definition of the Distributed Maritime Operations (DMO) (Jensen 2015) and distributed operations (Rowden, Gumataotao, and Fanta 2015) has emphasized that the future force may rely on non-traditional organizational structures to realize fighting power. This DMO concept will allow the U.S. Navy a greater diversity of options to conduct operations through coordinated use of sensors, platforms, and technologies across the fleet.

In support of the larger DMO objectives, unmanned systems have the potential to act as a force multiplier to increase lethality while simultaneously reducing risk to manned systems. The U.S. Navy currently employs a myriad of unmanned vehicles in support of adaptive force packages (AFP) conducting DMO. These unmanned vehicles include unmanned surface vessels (USV) (Figure 1) such as the Large Unmanned Surface Vessel (LUSV), Medium Unmanned Surface Vessel (MUSV), and unmanned Fast Inshore Attack Craft (FIAC); unmanned undersea vehicles (UUV) (Figure 2) such as the Orca Extra Large Unmanned Undersea Vehicle (XLUUV) and Snakehead Large Displacement Unmanned Undersea Vehicle (LDUUV); and unmanned aerial vehicles (UAV) (Figure 3) such as the MQ-8C Fire Scout and RQ 21 ScanEagle. Throughout this report USVs, UUVs, and UAVs are collectively referred to as UxVs.

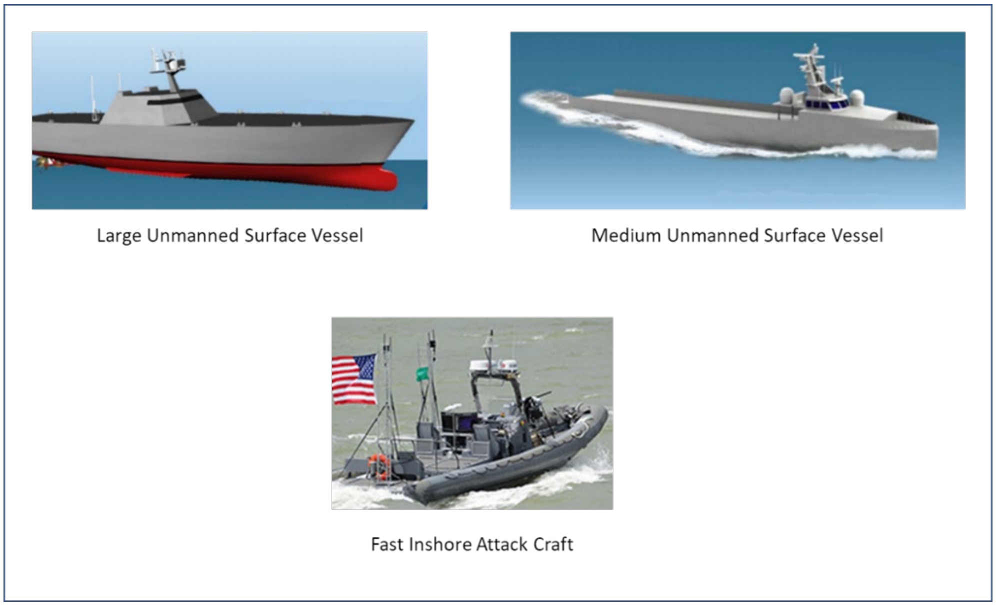

Figure 1. Unmanned Surface Vessels. Adapted from Program Executive Office Unmanned and Small Combatants (PEO-USC) (2021) and Smalley (2014).

Figure 2. Unmanned Undersea Vehicles. Adapted from PEO-USC (2021).

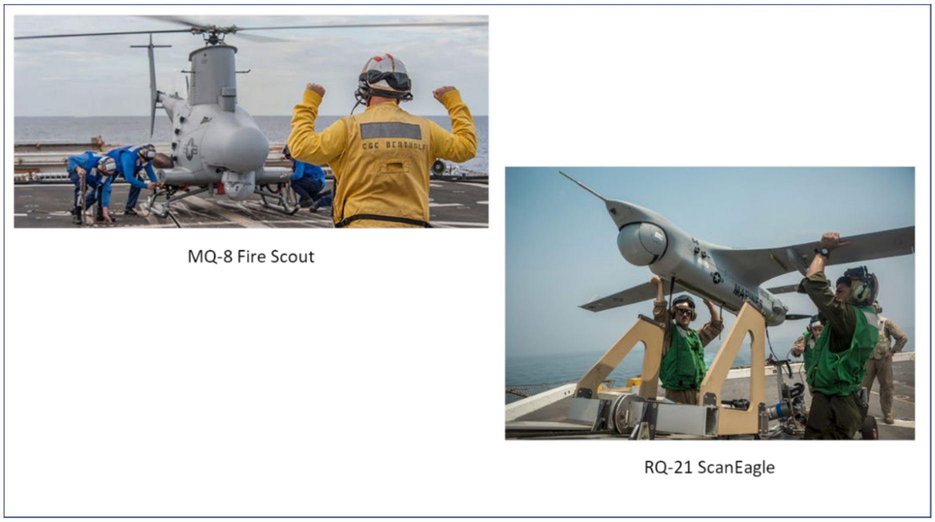

Figure 3. Unmanned Aerial Vehicles. Adapted from Northrup Grumman (n.d.) and Insitu (n.d.).

B. PROBLEM STATEMENT

This project examines the integration of USVs, UUVs, and UAVs aboard an existing U.S. Navy warship that has been re-purposed/modified as an Unmanned Vehicle Carrier (UVC) supporting an AFP conducing DMO. The goal of this project is to evaluate the use of a UVC for UxV launch, recovery, rearming, refueling, storage, and maintenance to maximize UxV time on station (TOS). The project conducts an evaluation of the UVC focused on its impact to UxV TOS, which is a function of transit time, endurance, mean time between maintenance (MTBM), and mean time to repair (MTTR).

The project analysis supports development of a system architecture for a UVC supporting DMO. A capability-level analysis is then conducted through systematic variation of system design characteristics and operational activities via simulation modeling to identify the primary drivers of operational effectiveness.

The following research questions focused the team's efforts:

- Does the presence of the UVC improve operational availability (Ao) of the unmanned systems?
- What is the ideal number of maintenance bays for the UVC?

- Is it preferable to have specific maintenance bays for each type of unmanned system, or should the bays be multi-functional (i.e, able to accommodate the full range of unmanned systems)?
- What is the impact of MTTR on the operational scenario?
- What is the ideal number of launch and recovery stations for each type of UxV?

C. SYSTEMS ENGINEERING PROCESS

Out of the multitude of existing systems engineering process models available (e.g., vee model, spiral model, etc.), the team chose and utilized a generalized sequence of system definition, system modeling, and system analysis, as described by Van Bossuyt et al. (2019). This process was selected due to its tailoring to academic capstone projects and alignment with the goals of this study. The chosen process led the project team through the general activities depicted in Figure 4.

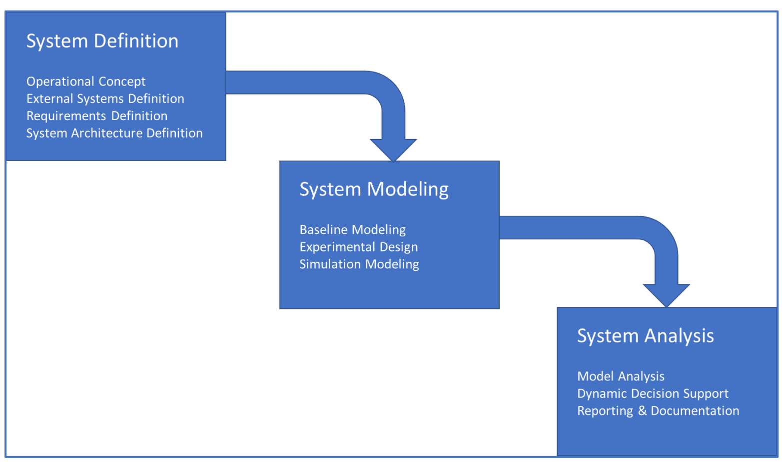

Figure 4. Systems Engineering Process. Adapted from Van Bossuyt et al. (2019).

During the system definition phase, the team focused on developing an initial concept of operations (CONOPS) and definition of system requirements. Additionally, the system architecture was defined and described using the relevant Department of Defense Architecture Framework (DoDAF) schema.

System modeling activities focused on the construction of analytical simulation models consistent with the defined architecture and CONOPS, and tests were designed to assess compliance with the requirements identified during the system definition phase.

The final phase, system analysis, utilized the constructed models to generate data through which the performance factors having the largest impact on operational effectiveness were identified.

Most systems engineering processes are recursive in nature among the various phases of a given project. For example, normally during the system modeling phase, the developed models will be used to verify, validate, and further refine the requirements and architecture defined during the system definition phase. Due to the relatively short-term nature of this project, only limited recursion was performed, and the chosen systems engineering process was executed in a sequential manner.

D. REPORT OUTLINE

In accordance with the described systems engineering process, this report is organized into six chapters. This first chapter provides an overview of the project, the problem statement, and a description of the selected systems engineering process. The second chapter contains a review of available literature related to unmanned systems, DMO, and logistics and resupply concepts. The third chapter presents the system needs analysis and analysis/definition of preliminary requirements for the UVC. The fourth chapter focuses on development of the UVC systems architecture and of a discrete event simulation model to analyze the value added of the UVC in an AFP as well as the appropriate operational concept and preliminary design decisions for the UVC. The fifth chapter contains an analysis and comparison of the baseline model configuration (no UVC) versus the enhanced model configuration (with UVC) to assess the effect of the presence of the UVC. Additionally, an assessment of UVC design characteristics having the greatest impact on UxV Ao is presented. Finally, Chapter VI presents the project team's conclusions and identifies some potential considerations for future analysis.

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II. LITERATURE REVIEW

The team conducted a literature review to evaluate recent work concerning UxVs and DMO. The team reviewed, categorized, and documented literature available from the Naval Postgraduate School (NPS) Dudley Knox Library and other online resources. The literature primarily divides into three general topic areas: Unmanned Systems, Distributed Maritime Operations, and Logistics and Resupply. The objective of this review is to analyze previous relevant research to aid development of an architecture for a UVC supporting DMO.

A. UNMANNED SYSTEMS

The U.S. Navy currently employs a wide array of unmanned systems, including unmanned surface vessels, unmanned undersea vehicles, and unmanned aerial vehicles. These vehicles are employed primarily in intelligence, surveillance, and reconnaissance (ISR) roles; although, there has been some recent adaptation for use in more direct tactical roles.

The Department of Defense (2007) identifies the following primary UxV missions: reconnaissance and surveillance, target identification/designation, mine countermeasures, and chemical, biological, radiological, nuclear, and explosives (CBRNE) reconnaissance. The document further identifies a series of Department of Defense (DOD) goals for effective development of and fielding of UxVs.

Nissen and Gallup (2019) utilized computational modeling and simulation to study integration of UxVs and manned systems in the context of DMO to determine system capabilities and functions necessary for implementation. The authors make the argument that people are better at some tasks, and UxVs are better at others, but complementary integrated performance can be superior in many situations. This is referred to as teams of autonomous systems and people (TASP). The authors concluded that unmanned missions "will make more mistakes; experience increasing time pressure; require greater effort, more time and higher cost to conduct missions; and operate under conditions of substantially higher mission risk" (Nissen and Gallup 2019, 73).

Popa et al. (2018) conducted research focusing on deception tactics in DMO. The authors utilized a discrete event simulation to model a fleet engagement against a near-peer adversary, with a focus on employment of countermeasure, counter-targeting, and counter-engagement tactics using UxVs. The authors concluded that employment of jamming/deceptive swarms provided a significant impact on operational effectiveness by disrupting and delaying the enemy's finding and targeting phases of the engagement. The study's model suggested that the Tactically Exploited Reconnaissance Node (TERN) UAS provides greater value as a clutter-creator than as a purely tactical asset. Finally, the team concluded that missile carrier platforms, such as destroyers and cruisers, provide the single most significant contribution to the outcome of a DMO engagement.

1. Unmanned Surface Vessels

Casola (2017) conducted a systems engineering analysis of the MUSV operating in a surface warfare role in a Distributed Lethality (DL) environment. The researcher employed modeling and simulation to assess the value of USVs in a force-on-force engagement. The author concluded that the MUSV can be a capable surface warfare asset contributing to the DL construct, and that "[i]ntegrating a team of [Medium Displacement Unmanned Surface Vessel]-specific maintainers and watchteam operators on a manned ship, such as [a Littoral Combat Ship], would likely be similar to the inclusion of a Fire Scout detachment" (Cassola 2017, 58).

The Department of the Navy (2007) has identified seven high-priority USV missions (listed in priority order): mine countermeasures (MCM), anti-submarine warfare (ASW), maritime security, surface warfare, special operations forces support, electronic warfare, and maritime interdiction operations support. FIAC, as a harbor class USV, supports the primary missions of maritime security (ISR and gun support) and electronic warfare (information operations). LUSV and MUSV, as fleet class USVs, support MCM sweep, protected passage ASW, and surface warfare missions.

Geiss (2019) investigated a proposed systems architecture for the integration of USVs into an AFP conducting DMO. The research focuses on command and control (C2), and the author utilized modeling and simulation (M&S) analysis to study AFP characteristics influencing operational success against a near-peer enemy. Geiss concluded that while AFP C2 structure did not significantly impact operational performance, the optimized mixture of vessels within the AFP consists of a relatively small number of large surface combatants (LSC), a somewhat larger number of small surface combatants (SSC), and an even larger number of USVs.

Honecker et al. (2019) described how the Sea Hunter MUSV could be employed to increase AFP mission success in DMO. The project allocates to the MUSV four functions supporting DMO: communication, sensing, C2, and self-defense. The authors concluded that the sensing function was the greatest contributor to mission success, with a robust electronic support measures (ESM) capability leading to reduced MUSV susceptibility and improved AFP operational effectiveness.

Richter (2006) identified three primary missions for USVs: anti-surface warfare (ASUW), anti-air warfare (AAW), and point defense. These missions would be supported by mounting gun, HELLFIRE missiles, and/or Javelin missiles onboard a USV. The author also conducted a manpower analysis associated with launch and recovery of USVs, concluding that USV launch and recovery is more manpower-intensive than rigid-hull inflatable boats (RHIBs).

Winstead (2018) examined the integration of USVs into the DMO concept to explore their potential mission areas. The study created a model for the concept using three alternative USVs and simulated fleet-on-fleet engagements to compare the effectiveness the USVs based on established Measures of Effectiveness (MOEs). Lastly, the study performed cost analysis of the USV alternatives. The study suggested specific classifications of USVs to integrate into the DMO concept and concluded with a recommendation for continued U.S. Navy investment in USVs.

2. Unmanned Undersea Vehicles

Blandin et al. (2013) identified the following missions as most suitable/beneficial for UUVs: ISR, information operations (IO), MCM, and offensive attack (ASW, ASUW, and offensive minelaying). The authors particularly examined the use of UUVs as anti-access, area-denial (A2AD) systems. The project team conducted a systems analysis and recommended a UUV force consisting of 26 LDUUVs, 120 recoverable 21-inch UUVs, and 121 expendable 21-inch UUVs.

Button et al. (2009) identify seven potential missions for UUVs: MCM, surveillance sensor array deployment, near-land monitoring, oceanography, monitoring undersea infrastructure, ASW, and inspection/identification. The authors identified development of UUVs to be launched from submarine torpedo tubes as a significant technical challenge to the fielding of UUVs.

Emmersen et al. (2011) focused on replacing expensive manned submarines with lower-cost UUVs for operations in contested littoral environments. The authors identified the ability to contribute to the common operating picture through ISR as a critical need that could be addressed by UUVs in high-risk littoral environments.

Trask, Gallup, and Tanalega (2018) examined integration of a Medium Displacement Unmanned Undersea Vehicle (MDUUV) into a distributed lethality structure. The authors define DL as "the operational and organizational principle for achieving and sustaining sea control at will and is composed of three tenets: increase the offensive lethality of all warships, distribute offensive capability geographically, and give ships the right mix of resources to persist in a fight" (Trask, Gallup, and Tanalega 2018, 3). The project team constructed and utilized modeling and simulation and concluded that the MDUUV provides significant value to an AFP conducting DL operations.

Vandenburg (2010) examines systems engineering analysis for a notional UUV, with a focus on manpower and maintenance requirements. The author puts forth ISR, communications relay, and ASW as primary UUV missions. The author further identifies launch, recovery, and other manned-unmanned interactions as the biggest technical challenges to effective integration of UUVs into the force structure.

3. Unmanned Aerial Vehicles

Alkire et al. (2010) concluded that use of UAVs is advantageous in applications that are "too 'dangerous,' 'dirty,' 'dull,' 'demanding,' or 'different'" to warrant use of manned aircraft (25).

Cox (2016) investigated a system of systems concept which would create a communications network capable of passing targeting information to AFPs conducting DMO in contested environments using UAVs. The research performed trade studies and analysis to determine a realistic configuration and number of nodes in the network, UAV types, and supportability. The team utilized M&S in their analysis of the problem to determine a CONOPS.

B. DISTRIBUTED MARITIME OPERATIONS

Englehorn (2017) summarizes a workshop with personnel from the U.S. Navy, NPS students and faculty, and industry. The workshop participants were tasked with applying emerging technologies to DMO. The report provides an overview of DMO and potential future U.S. Navy plans regarding DMO. The workshop focused on three major concepts: autonomy in support of operations and logistics, man-machine teaming, and organizational change and adoption.

Coles-Cieply and Weisser (2009) investigated the operational utility of smaller Light Aircraft Carriers (CVLs), either in conjunction with larger Aircraft Carriers (Nuclear Propulsion) (CVNs) or alone. The team determined the optimum configuration and type of aircraft on the CVL as well as the missions for which the ships would be best suited. M&S was used to determine the maximum tempo for air operations. The authors concluded that two CVLs would provide greater strike, ISR, and airborne electronic warfare (AEW) effectiveness than would a single CVN.

Davis, Beery, and Paulo (2020) demonstrate that the DMO concept has the potential to enhance offensive capabilities without substantial reduction to the performance of related missions, such as integrated air and missile defense, provided an appropriate composition of offensive and defensive missiles are employed as part of an AFP.

C. LOGISTICS AND RESUPPLY

Krenz, Mannila, and Streetzel (n.d.) described a distributed logistics system specific to the South China Sea. The presentation detailed several concepts which included combat logistics force (CLF)-only networks, combat logistics ship (CLS) 5000 networks, and the use of civilian tankers. M&S was used to analyze the different concepts and their effectiveness. It was concluded that the CLF-only networks significantly outperform CLS 5000 networks.

Stricklan, Tan, and Vanderzee (n.d.) described an expeditionary and distributed logistics system in support of DMO. Two concepts were considered for application to the South China Sea: delivered fuel versus “gas station” refueling (i.e., using designated refueling areas). Using M&S it was concluded that gas station refueling is the most sustainable method during high operational tempo situations. The MOEs used for this project were utilization of surface and supply ships, and consumption of resources.

III. SYSTEM DEFINITION

This section develops a potential systems architecture of the UVC system. The approach is consistent with the general DoDAF approach, which emphasizes traceability from high level capabilities to specific operations and associated systems. Accordingly, this chapter presents a needs analysis and a functional analysis that are used as the basis for UVC requirements definition.

A. NEEDS ANALYSIS

Based on the information obtained through the literature review and interaction with project stakeholders, the identified key capabilities for UVC mission success are C2, Launch, Maintenance, Recovery, and Communication. Each of the identified capabilities helps to accomplish the overall goal of the UVC. The capabilities are displayed in the form of a CV-2 Capability Taxonomy shown in Figure 5.

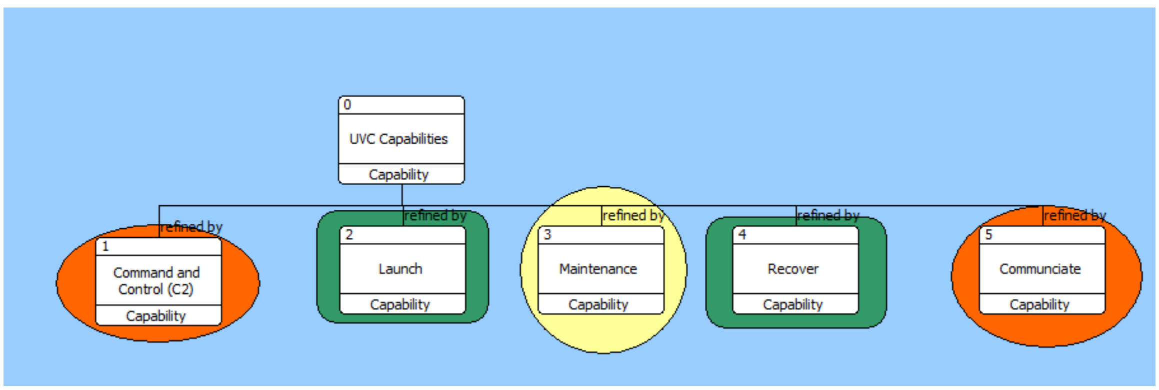

Figure 5. UVC CV-2 Capability Taxonomy

The CV-6 Capabilities to Operational Activities Matrix depicted in Figure 6 identifies the operational activities necessary to provide the required capabilities identified in the CV-2 Capability Taxonomy.

Capabilities	OA.1.1 Communicate	OA.1.1.1 Theater Assets send maintenance/ resupply request	OA.1.1.2 Receive Task Organization orders	OA.1.1.3 Prioritize maintenance/ resupply request with UOC	OA.1.1.4 Send Report to UOC	OA.1.2 Recover UxVs	OA.1.2.1 Receive Request	OA.1.2.2 Communicate with operator	OA.1.2.3 Command Operator	OA.1.2.4 Recover System
Command and Control						x		x	x	
Launch										
Maintenance										
Recover						x	x			x
Communicate	x	x	x	x	x	x	x	x		

Capabilities	OA.1.3 Maintain UxVs	OA.1.3.1 Receive Maintenance / Resupply request	OA.1.3.2 Perform Maintenance Operations	OA.1.3.2.1 Complete Maintenance Requests	OA.1.3.2.2 Perform PM inspection	OA.1.3.2.3 Document	OA.1.3.2.4 Log maintenance action	OA.1.3.3 Complete re-arm of UxV	OA.1.3.4 Refuel UxV	OA.1.3.5 Send maintenance & resupply report
Command and Control										
Launch										
Maintenance	x	x	x	x	x	x	x	x	x	x
Recover										
Communicate										x

Capabilities	OA.1.4 Launch UxVs	OA.1.4.1 Prep UxV	OA.1.4.2 Communicate w/ Control Cell	OA.1.4.3 Launch UxV	OA.1.4.4 Perform deck launch operations	OA.1.4.5 Release from ship	OA.1.4.6 launch vessel	OA.1.4.7 return control to AFP
Command and Control	x		x	x	x			x
Launch	x	x		x	x	x	x	
Maintenance								
Recover								
Communicate	x		x					x

Figure 6. UVC CV-6 Capabilities to Operational Activities Matrix

To determine the information that must be defined and managed in a model of UVC operations, a DoDAF OV-2 Operational Resource Flow Description (Figure 7) was developed, which identifies the performers associated with satisfaction of the capabilities presented in the CV-2 and defines the information exchanged between each performer.

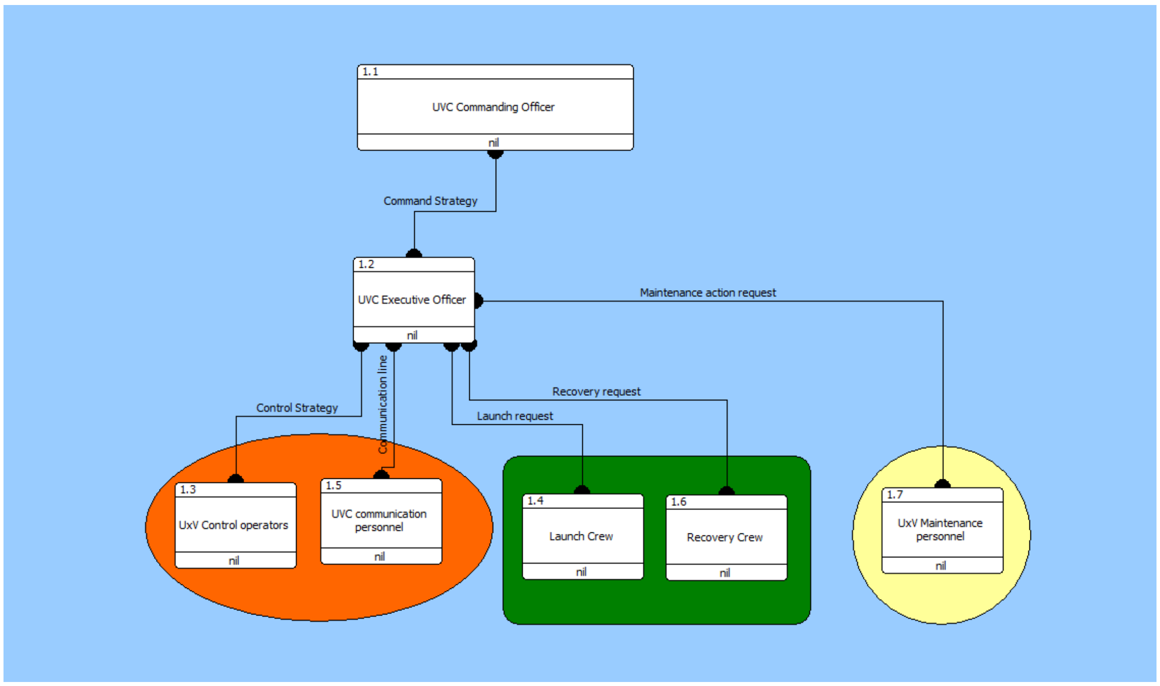

Figure 7. UVC Operational Resource Flow Description (OV-2)

The UVC Commanding Officer (CO) is responsible for ensuring the ship is operational and able to support the assets within the AFP. This position passes down the theater information which includes maintenance and resupply requests. The orange ellipse encompasses the UxV control operators and UxV communication personnel. The control operators are responsible for the control aspect of the UVC's C2 capability. These operators guide and communicate with the UxV's operator to ensure successful launch, recovery, and control handoff to/from the UVC. In the green rectangle, the launch and recovery crews are grouped. These crews are responsible for ensuring the unmanned systems are recovered and launched properly. These nodes receive orders from the UVC Executive Officer (XO), who receives orders from the CO. The XO node serves as a conduit between the CO and the rest of the ship, ensuring that the CO's orders and intentions are executed. This node is linked with the UxV maintenance personnel by maintenance action requests. These requests from the fleet contain needed information for the maintenance personnel to perform the necessary operations to perform scheduled and unscheduled maintenance on the unmanned vehicle.

B. REQUIREMENTS ANALYSIS

The requirements analysis compared the operational requirements with the stakeholder demands. The stakeholders envisioned a system that supports an AFP performing DMO by providing delivery, recovery, maintenance, and logistics support to the UxVs assigned to the AFP. This capability will help to increase the UxVs' time on station, providing 24/7 ISR capability to the AFP. The project team considered the UVC requirements from both top-down and bottom-up viewpoints. From the top-down viewpoint, the team analyzed and determined capabilities required to meet the overall mission effectiveness goals, independent of any specific repurposed UVC candidate. For the bottom-up view, the team analyzed a Landing Helicopter Dock (LHD) ship to determine the maximum capabilities that could be realized with respect to operational effectiveness within the current physical configuration constraints of the LHD. Ultimately, the team chose to conduct a hybrid analysis whereby the initial analysis focused on the ship characteristics needed to satisfy the MOEs (i.e., top-down analysis) and then attempted to identify any current U.S. Navy ships that could satisfy those requirements with minimal modification. The top-level requirements, based on the initial stakeholder needs, are listed in Table 1.

Table 1. Top-Level Requirements

Number	Requirement	Capability
R.1	The system shall be able to provide Preventative and Corrective afloat maintenance to UxVs.	Maintain
R.2	The system shall be able to store and transport unmanned systems to the area of operations.	Storage
R.3	The system shall be able to perform necessary Command, Control, and communication actions to coordinate with the AFP and the UxVs.	Communication and C2
R.4	The system shall contain the ability to perform afloat UxV rearm and refuel operations.	Maintain

Identification of the UVC operational requirements enables the next step in the systems engineering process, which is development of the functional and systems architectures. Development of the architectures will further enable development of the discrete event simulation model for analysis of design characteristics and trade-offs.

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IV. MODEL DEVELOPMENT

Upon completion of the system definition phase, the team began development of the systems engineering models by further defining the UVC system, analyzing alternative architectures, defining and refining measures of effectiveness, and development of a discrete event model to be used in the system analysis phase.

A. SYSTEM DEVELOPMENT

The first step in development of the model was development and refinement of the system architecture on which the model would be based. This entailed development of the operational scenario, functional analysis to determine the required functions for the UVC, identification of required operational activities, and system decomposition.

1. Operational Scenario

The development of the model for the maintenance and resupply of unmanned systems supporting DMO began with building an operational scenario, or CONOPS. Figure 8 depicts the OV-1 High-Level Operational Graphic for the UVC.

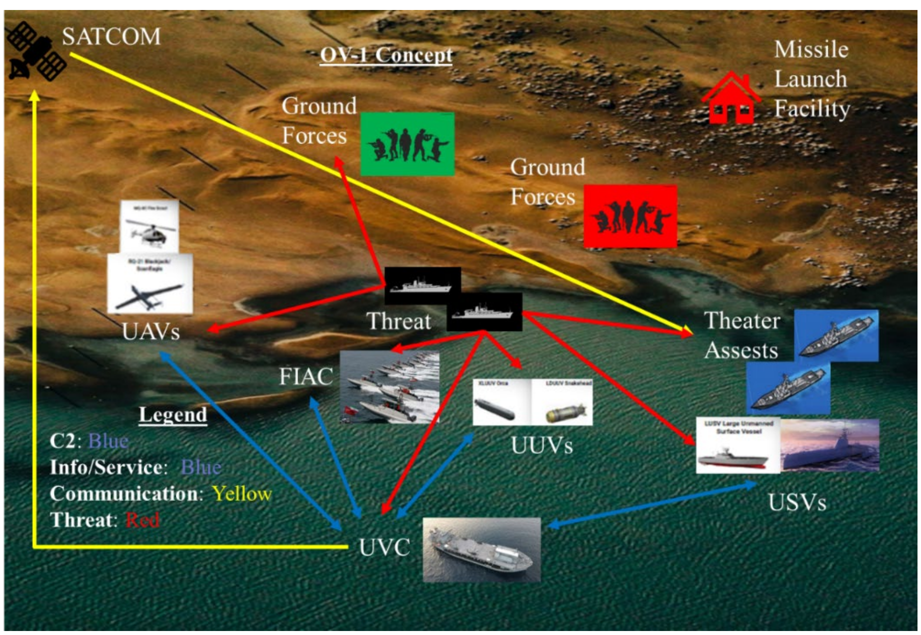

Figure 8. UVC High Level Operational Graphic (OV-1)

The scenario takes place in the Mid-Azure Sea. Country Red is attempting to extend its military presence and influence further into disputed waters. They have made efforts to place a missile launch facility on an artificial reef, which is controlled by Country Red's military. It is suspected that recent activity of ships laying communication cables has been taking place in the vicinity of the reef. This effort will further support the missile facility's C2 capabilities. Armed with missile emplacements, the artificial reef would represent a clear and present danger to friendly shipping, partner nation sovereignty, and Country Blue's military operations in the region. An effort by Country Blue to disrupt Country Red's operations is being supported by a nearby Expeditionary Advanced Base of Operations (EABO). An AFP has been assembled consisting of a Cruiser, a Destroyer, a Littoral Combat Ship (LCS), a Landing Platform/Dock (LPD) 17, and a Maritime Special Operations Force (SOF) Combatant Craft Medium (CCM) with a maritime SOF platoon embarked. Further, a Submarine (SSN) is also in the area with the ability to support maritime operations. The UVC will be stationed 50 - 100 miles offshore and will be supporting the reconnaissance of, and eventual strike on, the artificial reef to eliminate the missile launch site and the secure communication capabilities of Country Red's military on the island. The duration of this mission is expected to be approximately 90 days, including all mission phases, with approximately 30 days allocated for each mission phase. Unmanned systems (UUVs, USVs, and UAVs) will be employed throughout each phase as required, but will provide 24/7 coverage preceding, during, and after the strike phase (to include ISR, targeting, and battle damage assessment).

The goal of the scenario is to exercise the way in which the UVC will operate and interact with the unmanned systems. The UVC's key overall goal is to increase and maintain UxV time on station. Having the UVC dispatched with the AFP allows all UxVs to be maintained by the UVC, without requirement to return to a more distant base of operations for maintenance, refueling, and rearming.

2. Functional Analysis

Blanchard and Frabrycky describe functional analysis as "an iterative process of translating system requirements into detailed design criteria and the subsequent identification of the resources required for system operation and support." (Blanchard and Fabrycky 2011, 86). The process seeks to obtain detailed understanding into system operations to meet demands of stakeholders. Figures 9 through 12 expand the information presented in Figure 5 and depict how information is passed through the system.

a. Functional Hierarchy

The functional hierarchy for the UVC is depicted in Figure 9. This figure shows the top-level functions of the UVC.

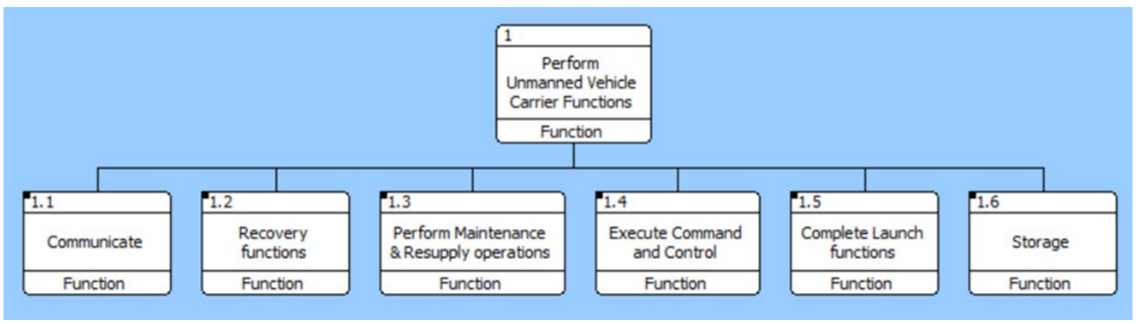

Figure 9. Functional Hierarchy

The top-level function of the UVC is decomposed into six sub-functions: communicate, recovery, perform maintenance and resupply operations, execute command and control, launch, and storage. These six functions are decomposed into lower-level functions that help to inform and refine the higher-level functions. The functions work in concert to deliver the required UVC functionality for mission success.

b. Functional Flow

Figure 10 shows the high-level enhanced functional flow block diagram (EFFBD) for the UVC. Each function is further decomposed into lower-level EFFBDs. These may be found in the Appendix A. These EFFBDs provide a visual depiction of the flow of communication within each function needed to perform the mission. The white boxes identify the functions performed, and the green ovals identify the triggers that initiate a particular function. The grey ovals are inputs, outputs, or both that apply to the functions.

The communicate function breaks down to show the flow between the Task Organization, Unmanned Operations Center (UOC), and the Theater Assets. The maintenance and resupply requests are outputs from the Theater Assets. These requests trigger the Task Organization to send orders to the UVC. At the conclusion of the maintenance operation, reports are sent to the Task Organization and the UOC. The same requests prompt the recovery of the unmanned vehicles which are slated for maintenance and resupply. Command operations are a needed input to ensure an effective vehicle recovery. The systems are then prepped for maintenance and resupply. Once maintenance, refuel, and rearm is complete, the C2 operations, along with the Launch operations, are used to launch and control the unmanned system. Control is then transferred to the unit responsible for the UxV mission execution.

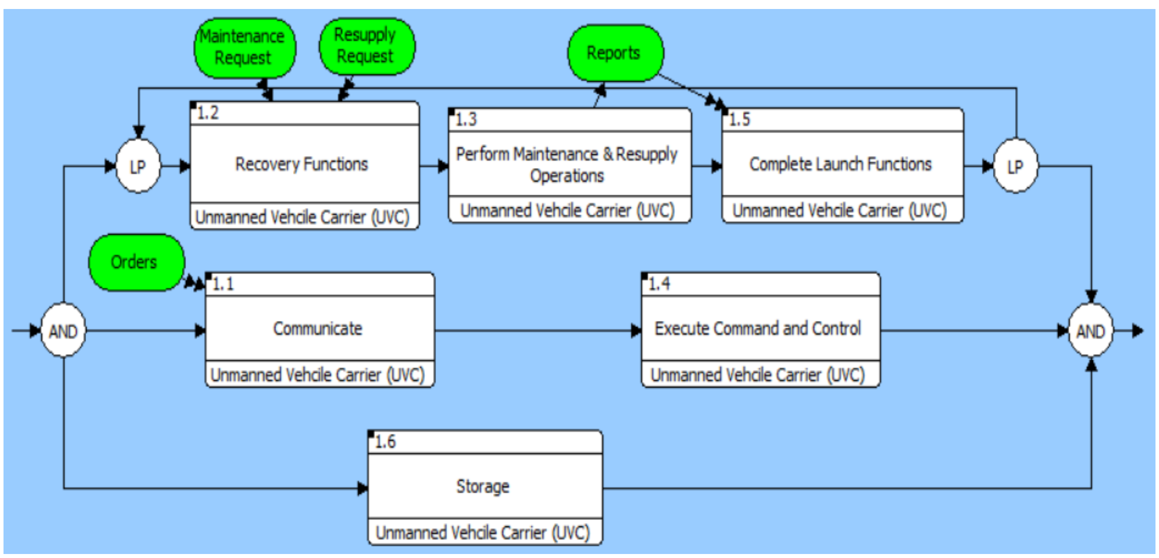

Figure 10. High-Level Functional Flow Diagram

3. Operational Activities

The operational activities for the UVC critical functions are displayed in the activity diagram shown in Figure 11. The communication activity decomposes to show how information is received from the theater assets, which leads to orders being given and a prioritization being set for the maintenance of the unmanned systems. In the recovery activity, the ship receives the request and communicates with the operator to safely recover the UxV aboard the UVC. This leads to the maintenance activity which is where corrective and preventive maintenance is performed on the recovered systems. During this activity the systems are also re-armed and refueled. After completion of maintenance, rearm, and refueling activities, the system is prepped and launched. Control of the unmanned system is returned to the AFP or unmanned control cell. The activity diagrams are used to inform the UVC functional and physical architectures.

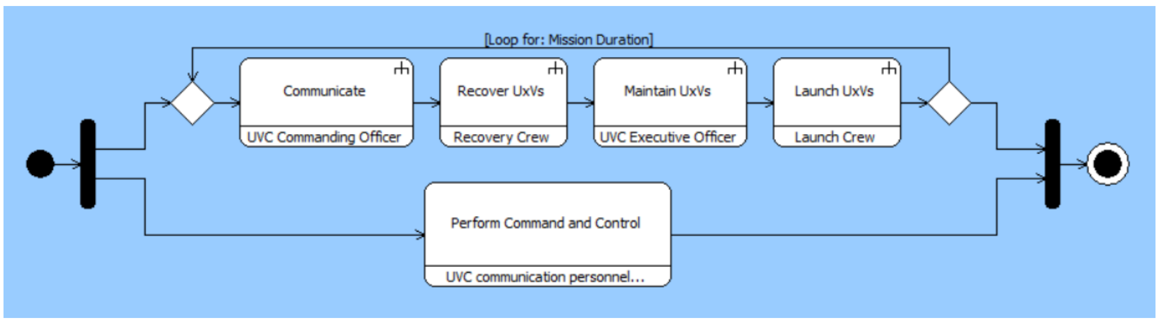

Figure 11. “Perform UVC Operations” Operational Activity Model (OV-5b)

4. UVC System Decomposition

The systems architecture was developed based on input from the stakeholders, the functional analysis, and the requirements analysis. The UVC is decomposed into two subsystems: Internal and Support. These systems are further decomposed by subsystems at level three. Within the Internal systems, the UVC contains the necessary systems to launch and recover the unmanned systems. The Control Cell operates the UxVs during the approach and terminal phases of recovery and launch. The Maintenance systems includes the equipment and facilities needed to perform afloat UxV maintenance. The Communication system consists of necessary equipment and networks to send, receive, and communicate with any external systems. The UVC contains the necessary storage equipment and areas to conduct resupply and maintenance. The overall systems decomposition of the UVC is depicted in Figure 12.

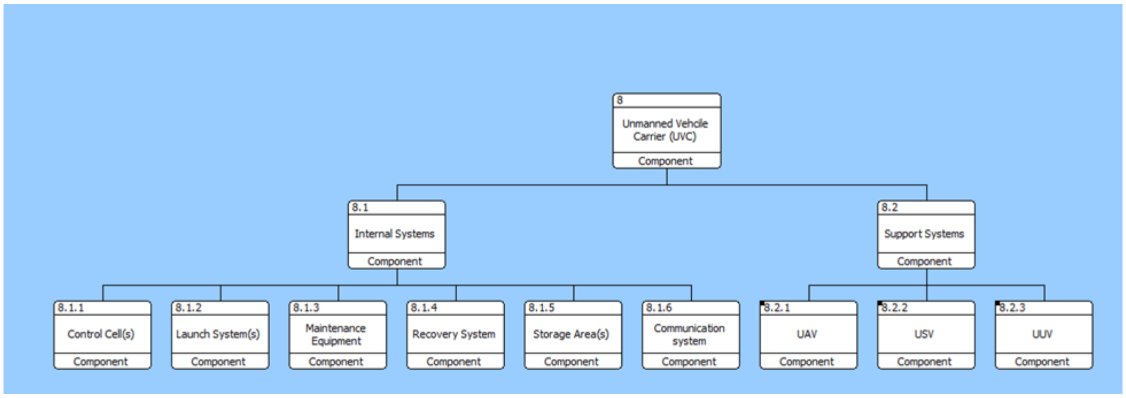

Figure 12. Systems Decomposition

The functional, operational, and systems architectures for the UVC identify and define potential design parameters for identification of promising alternatives to carry forward into the modeling and analysis phase of the project.

B. ALTERNATIVES GENERATION

The goal of this project is to identify the required system characteristics of a UVC supporting an AFP within a DMO setting. The developed discrete event simulation model allowed the project team to explore and refine design parameters to identify those ideal characteristics.

The developed systems architecture was used to inform and build a discrete event simulation model to assess the impact of changes to operational employment and design characteristics of the UVC. The aspects of the UVC design that were considered are listed in tables 2 through 5. The information in the tables is based on literature reviews and discussions with subject matter experts and stakeholders. The variability of the parameters allowed the team to assess alternative system configurations. Alternative configurations were then used to assess the best way to employ the system.

Table 2. UAV Characteristics

	MQ-8 Fire Scout	RQ-21 ScanEagle
MTBM (Planned Interval)	25 hours[1]	25 hours[2]
Mean Time Between Failure (MTBF)	30 flight hours[1]	33.5 flight hours[3]
MTTR Corrective	2.5 hours[1]	1.66 hours[3]
MTTR Preventative (Planned Maintenance Duration)	1.6 hours[1]	1.6 hours[2]
TOS (Total Endurance)	12 flight hours[1]	12 flight hours[3]
Time for Re-Arm / Refuel	0.75 hours[2]	0.75 hours[2]
Launch Time	0.5 hours[2]	0.5 hours[2]
Recovery Time	0.5 hours[2]	0.5 hours[2]
Mission Frequency	6 hours[2]	6 hours[2]

[1](Anderson 2016)
[2]The project team was unable to obtain this value, so the value entered here represents an assumption.
[3](Office of the Secretary of Defense 2015)

Table 3. USV Characteristics

	LUSV	MUSV
MTBM (Planned Interval)	30 days[1]	30 days[1]
MTBF	30 days[2]	30 days[2]
MTTR Corrective	96 hours[3]	120 hours[3]
MTTR Preventative (Planned Maintenance Duration)	96 hours[3]	120 hours[3]
TOS (Total Endurance/Range)	4500 nautical miles[4]	30-90 days / 10,000 nautical miles[4]
Time for Re-Arm / Refuel	Not Applicable[5]	Not Applicable[5]
Launch Time	3 hours[3]	3 hours[3]
Recover Time	3 hours[3]	3 hours[3]
Mission Frequency	15 days[3]	15 days[3]

[1](Burgess 2020)
[2](O'Rourke 2019)
[3]The project team was unable to obtain a value for this parameter, so the value entered here represents an assumption.
[4](Larter 2019)
[5]Included in MTTR Preventative.

Table 4. FIAC Characteristics

	FIAC
MTBM (Planned Interval)	30 days[1]
MTBF	45 days[1]
MTTR Corrective	8 hours[2]
MTTR Preventative (Planned Maintenance Duration)	8 hours[2]
TOS (Total Endurance)	30 minutes[1]
Preparation for Launch Time	30 minutes[1]
Time for Re-Arm	10 minutes[1]
Time for Refuel	10 minutes[1]
Launch Time	5 minutes[1]
Recover Time	20 minutes[1]
Mission Frequency	10 hours[2]
Swarm Size	10-20 vessels[3]
Deployment Range	12 km[4]
Estimated Range	2 km[4]
Speed	30 m/s[4]

[1]Sponsor provided.
[2]The project team was unable to obtain a value for this parameter, so the value entered here represents an assumption.
[3](Galligan, Galdorisi, and Marland 2005)
[4](Broadfoot et al. 2018)

Table 5. UUV Characteristics

	XLUUV	**LDUUV**
MTBM (Planned Interval)	>30 days	168 hours[1]
MTBF	720 hours[1]	168 hours[1]
MTTR Corrective	10 days	<5 days
MTTR Preventative	<5 days	<5 days
TOS (endurance or range)	30+ days	15 nautical miles
Preparation for Launch Time	<5 days	<8 hours
Launch Time	2 hours[1]	2 hours[1]
Recover Time	1 hour[1]	1 hour[1]
Frequency of Maintenance / Resupply request	>30 days	8 hours

[1]The project team was unable to obtain a value for this parameter, so the value entered here represents an assumption.

C. MEASURES OF EFFECTIVENESS AND MEASURES OF PERFORMANCE

After analyzing the architecture of the UVC system and the planned scenario, the team determined the MOEs and MOPs for the system as shown in Table 6 and Table 7, respectively. The MOPs and MOEs allow for the quantification of the effect the UVC support to the UxV fleet and to compare different UVC configurations. Blanchard and Fabrycky define Ao as the "probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon" (Blanchard and Fabrycky 2011, 427). Ao represents a ratio of uptime (i.e., the time during which a system is available to conduct missions) to downtime (i.e., the time during which a system is undergoing maintenance and is unavailable to conduct missions). Persistent Dwell Time represents the time during which a system is actively conducting useful missions (i.e., total uptime minus transit time to the area of operations). Based on these definitions, it was determined that Ao and Persistent Dwell Time represent the most appropriate MOEs for the UVC system. The model outputs that best indicate these MOEs are Mission Time (for each UxV), Downtime (for each UxV), and overall Maintenance Bay Utilization.

Table 6. MOEs

MOE	Description
Operational Availability (A_O), UxV	Per UxV system. Defined as $A_O = \frac{MTBM}{MTBM+MDT} = \frac{mission\ time}{mission\ time+launch\ time+maintenance\ time+refuel\ time+recovery\ time}$
Persistent Dwell Time, UxV	Per UxV system. Defined as the summation of mission time.

Table 7. MOPs

MOP	Description
Mission Time, UxV	Per UxV system. Defined as the total time the UxV is conducting a mission.
Downtime, UxV	Per UxV system. Defined as the total time that the UxV is waiting to launch, launching, waiting to recover, recovering, and being maintained.
Maintenance Bay Utilization	Per type of maintenance bay. Defined as the time used divided by the entire time used.

D. MODEL DESCRIPTION

1. Approach

A simulation model was designed and developed to aid analysis of the behavior of the UVC providing support to UxVs. M&S allows for quick examination of multiple configurations of UVC resources and supported UxV fleets where testing with physical assets is impractical due to cost, schedule, and availability of material assets. In addition, as the UVC is in the initial stages and is restricted to a proposed concept, there is no asset with which to conduct investigations, and the study is limited to a virtual model. Research and investigation of similar existing assets were implemented in the design of the model.

2. Discrete Event Simulation Model

A discrete event simulation (DES) model was developed in ExtendSim 10 to evaluate alternative system concepts. ExtendSim was selected due to its ability to model and simulate queues, which allows for the representation of UVC and UxV activities in which UxVs must wait for available resources, such as facilities for launch, recovery, and maintenance.

The modeled activities include UxVs conducting missions, the UVC facilitating support requests by UxVs, UxVs recovering to the UVC, UxVs being maintained on the UVC, UxVs being refueled on the UVC, and UxVs launching from the UVC. The structure of the model for a generic UxV is presented in Figure 13. LUSVs and MUSVs differ from other UxVs in the model as they are not initially launched from the UVC and begin in operation.

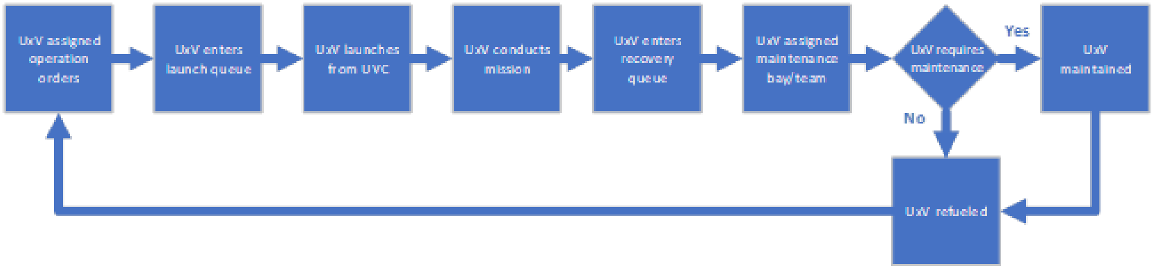

Figure 13. UxV Model Structure

The model supports UAVs, USVs, and UUVs. The simulation includes MQ-8 Fire Scout and RQ-21 Blackjack/ScanEagle in the category of UAVs; LUSV, MUSV, and FIAC in the category of USVs; and XLUUV and LDUUV in the category of UUVs. In addition, a single ScanEagle is deployed with each CCM mission. Each modeled UxV asset has its own associated parameters dictated by characteristics identified in the Alternative Generation section that affect the behavior of the simulation.

The model manages multiple resources which restrict the flow of operations. A limited number of UxVs from the AFP are assigned to receive support from the UVC at any given time. Each UxV simulated in the model is drawn from an available pool of the UxV. The model includes five separate resource pools to represent the selected UxVs; however, the LUSV and MUSV are not represented by resource pools. The model uses resource limitations based on the physical dimensions of the UVC. The deck space available on the UVC determines the available number of bays for maintenance and launch areas. There are separate maintenance bays and launch areas for UAVs and for USVs/ UUVs. Alternative system concepts will be modeled by adjusting available resources.

The simulation outputs data on the uptime and downtime of the UxVs to determine the UxV system operational availability and system dwell times. In addition, the simulation outputs data regarding the utilization of the maintenance and launch/recovery facilities and characteristics of the queues.

Launch schedules for the UxVs and the total simulation runtime are developed based on the proposed UVC CONOPS. The simulation will evaluate the system across 90 days of operations. The mission scenario is divided into three separate phases of 30 days.

The phases, in order of occurrence, are reconnaissance, action, and battle damage assessment. Each phase represents a different demand for active UxV assets, which in turn determines the quantity of mission orders to launch to be assigned at one time during the phase. The launch cycle, specific to each UxV asset type, determines how often the orders to launch are generated. By altering the launch order schedule and the duration of the simulation, the model can support other scenarios.

3. Assumptions and Limitations

The project team made a number assumptions associated with the UVC simulation model. Additionally, several limitations of the model were identified.

a. Limitations

A limitation is identified by the project team being unable to fully investigate an aspect of the study. The M&S limitations for the study are summarized in Table 8.

Table 8. M&S Limitations

Limitation	Description	Remark
L1	The impact of failures occurring during mission introduced significant complexity to the model and scenario.	See Assumption A1 in Table 9.
L2	The impact of UVC/UxV losses due to hostile action, including electronic warfare, during mission introduced significant complexity to the model and scenario.	See Assumption A9 in Table 9.
L3	Detailed data for all UxV were not available.	See Assumption A12 in Table 9.
L4	The physical dimensions of the UVC were not known.	See Assumption A13 in Table 9.
L5	The inclusion of system feedback related to the number of mission active assets introduced significant complexity to the model.	See Assumption A11 in Table 9.

b. Assumptions

An assumption is identified by the project team making a statement related to the study in the absence of information. The M&S assumptions are summarized in Table 9.

Table 9. M&S Assumptions

Assumption	Description
A1	The mission time distribution captures the effect of failures on overall mission time.
A2	The time to perform corrective maintenance is less than or equal to the time to complete preventative maintenance and is therefore included within the distribution of the preventative maintenance time.
A3	UAV, FIAC, XLUUV, LDUUV assets are initially launched from the UVC at the start of operations.
A4	LUSV and MUSV assets are not initially launched from the UVC at the start of operations
A5	UAVs use dedicated maintenance bays, and all UAV types share recovery facilities, maintenance bays, and launch facilities.
A6	USVs and UUVs share recovery facilities, maintenance bays, and launch facilities.
A7	Ship side bays are utilized to launch and recover XLUUVs, LUSVs, and MUSVs. And to perform maintenance and refueling on LUSVs and MUSVs.
A8	Ship well bays are utilized to launch and recover FIACs and LDUUVs, and to perform maintenance and refueling on FIACs, LDUUVs, and XLUUVs
A9	There will be no UVC/UxV losses during the mission.
A10	Cyber impacts on UVC/UxV will be minimal.
A11	UxV assets were launched by a schedule. Feedback on the number of UxV assets active were not used to determine when another UxV asset should be launched.
A12	UxV asset specifications and statistics were assumed as necessary, including but not limited to: MTBF, MTTR, etc.
A13	The UVC was assumed to be capable of containing any modeled configuration.

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V. ANALYSIS

This chapter is organized into two sections, a baseline analysis that quantitatively assesses the value added of a UVC compared to an AFP configuration that does not employ a UVC and a detailed analysis that assesses the design characteristics and employment decisions that have the largest impact on UVC performance, assuming it is deployed as part of an AFP.

A. BASELINE MODEL

A baseline model was developed in order to establish a measure against which any potential UVC benefits would be judged. This baseline model represents the case where the UVC is not present in the AFP, and UxVs must be rearmed, refueled, and maintained by other ships assigned to the AFP or by shore-based facilities.

1. Goal

The goal of the baseline model was to demonstrate the behavior and performance of the AFP without UVC support to compare against a standard UVC design.

2. Design

To simulate an AFP without UVC support, the inputs used in the UVC ExtendSim model were reduced to represent restricted capabilities. In comparison, a set of inputs were selected to represent a standard UVC design. The inputs for both the restricted design and standard design can be found in Appendix B.

3. Analysis Methods

Simulations were conducted for a sample of 30 runs for each of the restricted and standard UVC designs using the developed ExtendSim model and the results were collected. The mean Ao for each UxV system for each sample of data were combined to obtain the Ao statistical mean for each sample. In addition, the resulting Ao values for each UxV system for each sample of data were compared using a pooled t-test with the null hypothesis that the two samples were from the same population.

4. Results and Analysis

The Ao improves from the restricted model to the standard UVC model as identified by the mean Ao for all UxV except the LUSV. Due to the p-value determined by the t-test for all UxV except for the LUSV, we can reject the null hypothesis that both samples of data come from the same population, indicating that there is a statistically significant difference between the restricted and standard data sets. The mean Ao reveals that there is an improvement due to the presence of the UVC. The baseline comparison indicates that the LUSV does not gain a statistically significant benefit from the presence of the UVC. For each UxV, the mean Ao for the restricted model and the standard model and the p-value of the pooled t-test are shown in Table 10.

Table 10. Baseline Comparison Analysis

UxV	Mean Ao: Restricted (no UVC)	Mean Ao: Standard (UVC present)	p-Value
RQ-21 ScanEagle	0.6815	0.8127	<.0001
MQ-8 Fire Scout	0.7420	0.8212	<.0001
XLUUV	0.6078	0.9159	<.0001
LDUUV	0.1541	0.5444	<.0001
MUSV	0.8136	0.8759	<.0001
LUSV	0.6557	0.6557	0.3215
FIAC	0.0042	0.1765	<.0001

B. DETAILED ANALYSIS

The detailed analysis model represents the case in which the UVC is deployed with the AFP and is available for rearming, refueling, and maintaining UxVs.

1. Goal

The goal of the DOE effort was to demonstrate the ability of the model to determine the effectiveness of the UVC and UxV fleet conducting operations for a specified scenario.

2. Responses

From the MOPs and MOEs, the team determined that the result that would most clearly demonstrate the effectiveness of a UVC and UxV fleet configuration would be the Ao, UxV. The DoE was developed with seven responses based on the MOPs as shown in Table 11.

Table 11. DOE Responses

Response
A_O, RQ-21 ScanEagle
A_O, MQ-8 Fire Scout
A_O, LUSV
A_O, MUSV
A_O, FIAC
A_O, XLUUV
A_O, LDUUV

3. Factors

The ExtendSim model was developed to incorporate multiple input variables that can be adjusted to test different configurations of the UVC and aspects of the associated UxVs. For the initial investigation, the input variables as shown in Table 12 were used to develop the DOE.

Table 12. DOE Factors

Factor	Role	Description
Number of UAV Maintenance Bays	Discrete	The number of bays on the UVC available for maintaining on UAVs.
Number of UAV Refuel Bays	Discrete	The number of bays on the UVC assigned to refuel UAVs.
Number of UVC Well-Deck Bays	Discrete	The number of well-deck bays on the UVC assigned to support UxV recovery and relaunch operations.
Number of UVC Ship Side Bays	Discrete	The number of ship side bays on the UVC assigned to support UxV recovery, maintenance, and relaunch operations.
Number of UVC Well-Deck Maintenance Bays	Discrete	The number of well-deck bays on the UVC assigned to support UxV maintenance
Number of ScanEagles	Discrete	The number of RQ-21 ScanEagles supported by the UVC.
Number of ScanEagle Launch/ Recovery Crews	Discrete	The number of RQ-21 ScanEagle launch and recovery crews assigned to the UVC.
Maximum ScanEagle Launch Capacity	Discrete	The maximum number of RQ-21 ScanEagles that can be launched by the UVC at one time.
Maximum ScanEagle Recovery Capacity	Discrete	The maximum number of RQ-21 ScanEagles that can be recovered by the UVC at one time.
ScanEagle Mission Time	Continuous	The mean mission time of the RQ-21 ScanEagle.
Number of Fire Scouts	Discrete	The number of RQ-21 Fire Scouts supported by the UVC.
Number of Fire Scout Launch/ Recovery Crews	Discrete	The number of MQ-8 Fire Scout launch and recovery crews assigned to the UVC.
Maximum Fire Scout Launch Capacity	Discrete	The maximum number of MQ-8 Fire Scouts that can be launched by the UVC at one time.
Maximum Fire Scout Recovery Capacity	Discrete	The maximum number of MQ-8 Fire Scouts that can be recovered by the UVC at one time.

Factor	Role	Description
Fire Scout Mission Time	Continuous	The mean mission time of the MQ-8 Fire Scout.
Number of FIACs	Discrete	The number of FIACs supported by the UVC.
FIAC Mission Time	Continuous	The mean mission time of the FIAC.
Number of XLUUVs	Discrete	The number of XLUUVs supported by the UVC.
XLUUV Mission Time	Continuous	The mean mission time of the XLUUV.
Number of LDUUVs	Discrete	The number of LDUUVs supported by the UVC.
LDUUV Mission Time	Continuous	The mean mission time of the LDUUV.

4. Experimental Design

A purpose-built space-filling Latin Hypercube design was generated using the JMP software to develop the DOE. The space-filling Latin Hypercube design was selected to provide the largest amount of exploration into the experiment space while reducing the number of trials necessary to conduct. Values generated by the design for discrete factors were rounded to the nearest integer. A series of 320 trials were generated (Appendix E). Note that an appropriate experimental design will graphically fill in a large portion of the design space with minimal correlation between input variables. Assessment of the scatterplot matrix (Appendix F) and correlation matrix (Appendix G) show adequate coverage of the experimental space and minimal correlation between any of the input variables. The maximum correlation between any two variables is the X2/X3 correlation in the correlation matrix, calculated as 0.1057, which was deemed acceptable for this study.

C. ANALYSIS METHODS

Simulations were conducted for a sample of 30 runs per DOE trial using the developed ExtendSim model and the results were collected. The resulting Ao values for each UxV system for each trial were combined, respectively, to obtain the Ao statistical mean for each trial (Appendix H).

JMP was used to conduct further analysis by examining the distribution of the trial mean Ao per system. Next, JMP was used to conduct a regression to determine which factors from the DOE had the greatest effect on the response terms. The team executed a stepwise regression using a minimum Bayesian information criterion (BIC) for each response term. A second order regression model was developed, allowing the team to investigate the impact that higher order interactions may have on performance. A model was selected based on its respective R-squared and then used to develop a standard least squares regression. The summary of fit, sorted parameter estimates, prediction profiler, and interaction profiler were examined for the resulting regressions to evaluate the relationships between the factors and their effects on the response. Additional analysis was conducted using partition modeling in JMP to develop decision trees to better understand the effects of the factors on the responses.

D. RESULTS AND ANALYSIS

The team conducted a statistical simulation analysis of the UVC, and a number of significant results were identified.

1. Design of Experiments

The Ao for each UxV type was analyzed against the chosen UVC design parameters to determine the parameters with the greatest effect on Ao for each UxV type.

a. *RQ-21 ScanEagle Ao*

The distribution of the mean RQ-21 ScanEagle Ao is shown in Figure 14, which represents the full range of the Ao with the UVC providing support. With UVC support, the ScanEagle achieves a mean Ao of 0.804 (denoted as 1 in Figure 14).

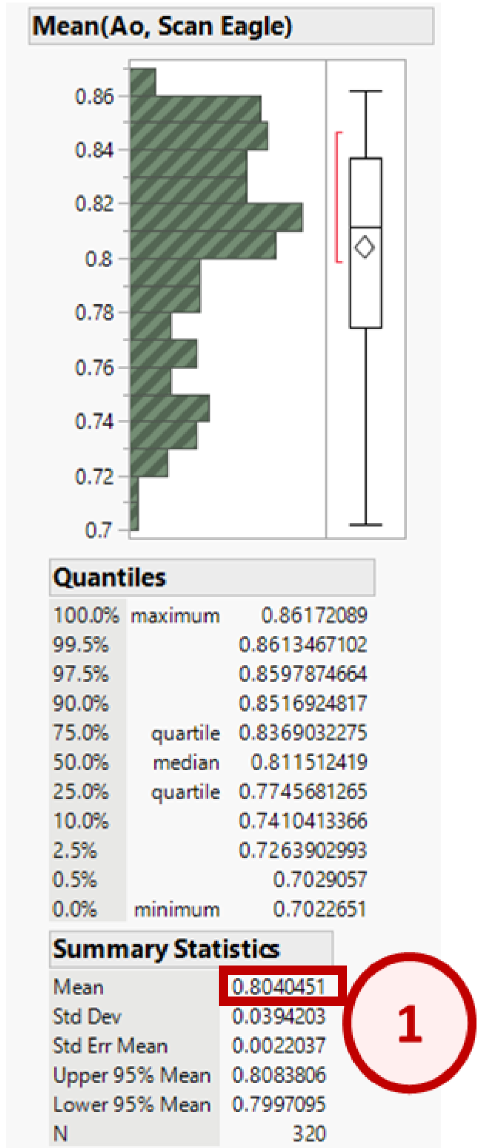
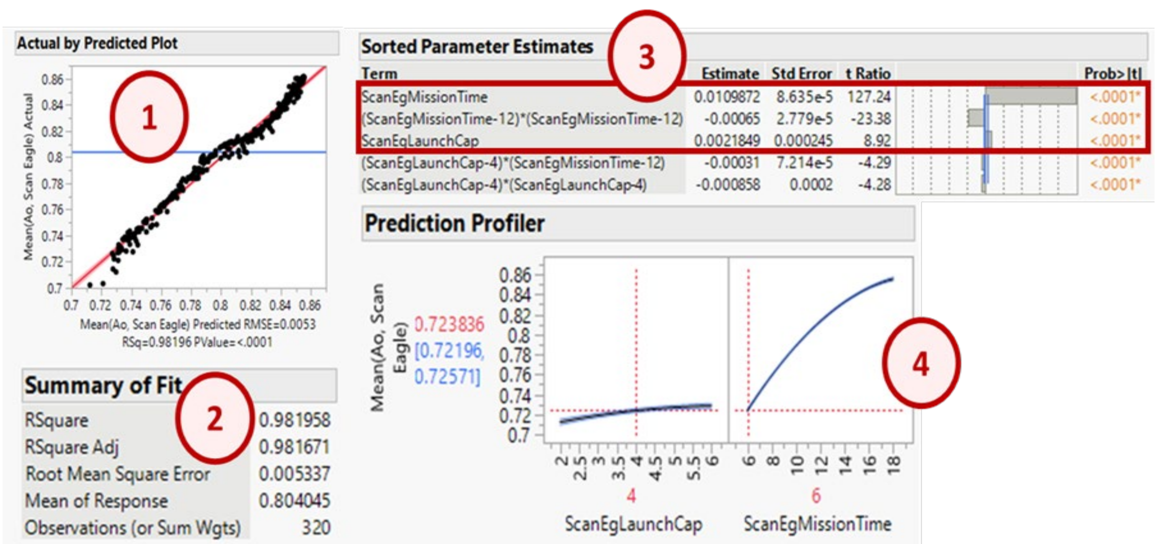


Figure 14. RQ-21 ScanEagle Ao Distribution

Regression analysis output is shown in Figure 15, showing an actual by predicted plot (top left), summary of model fit (bottom left), sorted parameter estimates (top right), and prediction profilers (bottom right) for the RQ-21 ScanEagle Ao. The figure is annotated to demonstrate model credibility and preliminary insights. The actual by predicted plot (denoted as 1 in Figure 15) demonstrates that there is no underlying pattern to the data that is not captured by the statistical model. The summary of fit (denoted as 2 in Figure 15) indicates that the statistical model is well fit to the underlying data. The sorted parameter estimates (denoted as 3 in Figure 15) indicate that operational significance can be attributed primarily to the mission time of the Fire Scout, a variable that is not associated with the design of the UVC itself, and the maximum ScanEagle launch capacity of the UVC. The prediction profile in the bottom right of Figure 15 for the maximum ScanEagle launch capacity is flatter than the profile for the ScanEagle Mission Time (denoted as 4 in Figure 15). Each prediction profile shows the isolated impact that each variable has on Ao by plotting Ao on the y-axis and each statistically significant variable on the x-axis. The flatter line for maximum ScanEagle launch capacity compared to ScanEagle Mission Time suggests a smaller change, from 0.71 to 0.73, in Ao that results from a change in ScanEagle launch capacity from 2 to 6, whereas a change from 6 hours to 18 hours in ScanEagle Mission Time increases Ao from 0.73 to 0.86. Because improvements to the UxVs themselves, such as ScanEagle Mission Time, is outside the scope of this project, it is important to identify the factors relevant to UVC design that have a statistically significant impact on Ao, despite a lack of operational significance in this specific model. Based on the full regression model, that variable is the maximum RQ-21 ScanEagle launch capacity.



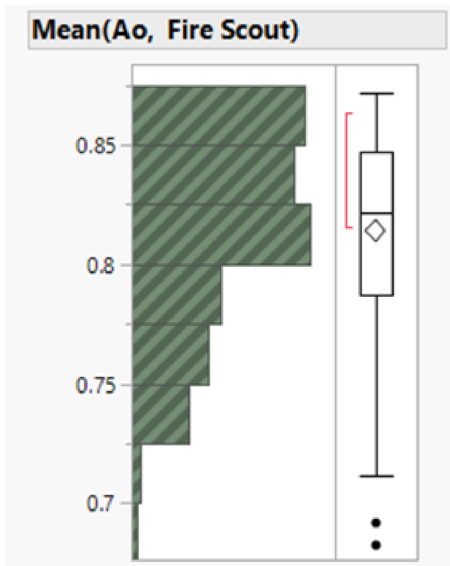
Summary of Fit	
RSquare	0.981958
RSquare Adj	0.981671
Root Mean Square Error	0.005337
Mean of Response	0.804045
Observations (or Sum Wgts)	320

Term	Estimate	Std Error	t Ratio	Prob>|t|
ScanEgMissionTime	0.0109872	8.635e-5	127.24	<.0001*
(ScanEgMissionTime-12)*(ScanEgMissionTime-12)	-0.00065	2.779e-5	-23.38	<.0001*
ScanEgLaunchCap	0.0021849	0.000245	8.92	<.0001*
(ScanEgLaunchCap-4)*(ScanEgMissionTime-12)	-0.00031	7.214e-5	-4.29	<.0001*
(ScanEgLaunchCap-4)*(ScanEgLaunchCap-4)	-0.000858	0.0002	-4.28	<.0001*

Figure 15. RQ-21 ScanEagle Ao Regression Analysis

b. MQ-8 Fire Scout Ao

The distribution of the mean MQ-8 Fire Scout Ao is shown in Figure 16, which represents the full range of the Ao with the UVC providing support. With UVC support, the Fire Scout achieves a mean Ao of 0.814 (denoted as 1 in Figure 16).



Quantiles

100.0%	maximum	0.871289166
99.5%		0.8711332648
97.5%		0.8685931526
90.0%		0.8621164143
75.0%	quartile	0.847290324
50.0%	median	0.8212012665
25.0%	quartile	0.7873101335
10.0%		0.7512729293
2.5%		0.7302383641
0.5%		0.6881287648
0.0%	minimum	0.682470391

Summary Statistics

Mean	$\boxed{0.8143751}$
Std Dev	0.0404937
Std Err Mean	0.0022637
Upper 95% Mean	0.8188287
Lower 95% Mean	0.8099215
N	320

Figure 16. MQ-8 Fire Scout Ao Distribution

Regression analysis output for the MQ-8 Fire Scout Ao is shown in Figure 17. The actual by predicted plot (denoted as 1 in Figure 17) demonstrates that there is no underlying pattern to the data that is not captured by the statistical model. The summary of fit (denoted as 2 in Figure 17) indicates that the statistical model is well fit to the underlying data. The sorted parameter estimates (denoted as 3 in Figure 17) indicate that, despite a large number of statistically significant variables, operational significance can be attributed primarily to the mission time of the Fire Scout and the total number of Fire Scouts, two variables that are not associated with the design of the UVC itself. The prediction profiles in the bottom right of Figure 17 are relatively flat, with the exception of the profile for Fire Scout Mission Time (denoted as 4 in Figure 17). Based on the full regression model, the UVC parameters which have a statistically significant impact on Ao are: the number of UAV maintenance bays, the number of UAV refuel bays, the number of MQ-8 Fire Scout launch and recovery crews, the maximum MQ-8 Fire Scout launch capacity, and the number of Fire Scouts deployed to the UVC.

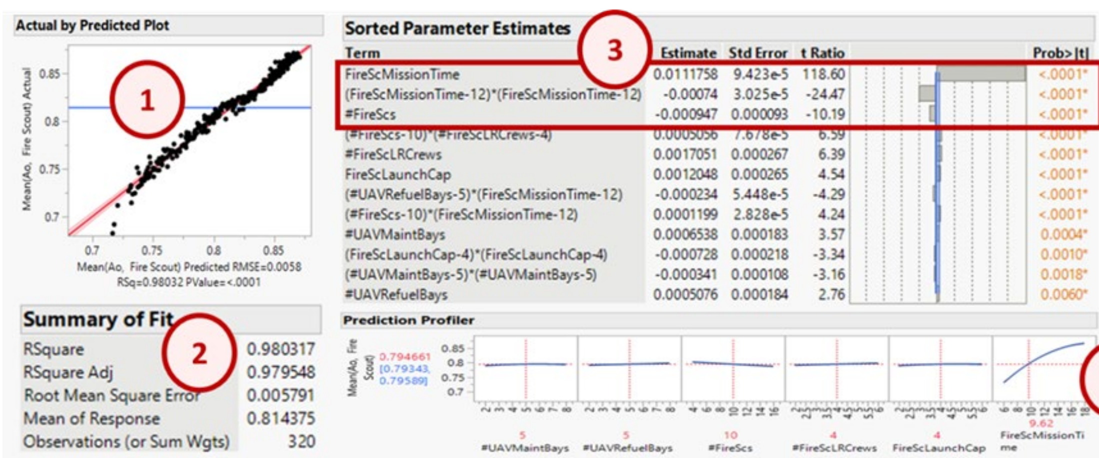
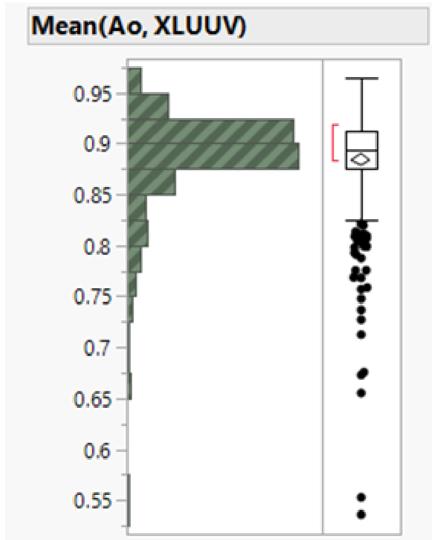


Figure 17. MQ-8 Fire Scout Ao Regression Analysis

c. XLUUV Ao

The distribution of the mean XLUUV Ao is shown in Figure 18, which represents the full range of the Ao with the UVC providing support. With UVC support, the XLUUV achieves a mean Ao of 0.884 (denoted by 1 in Figure 18).



Quantiles

100.0%	maximum	0.964778183
99.5%		0.9641834408
97.5%		0.9518523263
90.0%		0.9269288943
75.0%	quartile	0.9122978445
50.0%	median	0.894150078
25.0%	quartile	0.875968635
10.0%		0.8144192601
2.5%		0.7372229414
0.5%		0.5464108901
0.0%	minimum	0.536224032

Summary Statistics

Mean	$\boxed{0.8838519}$
Std Dev	0.0537234
Std Err Mean	0.0030032
Upper 95% Mean	0.8897606
Lower 95% Mean	0.8779433
N	320

1

Figure 18. XLUUV Ao Distribution

Regression analysis output for the XLUUV Ao is shown in Figure 19. The actual by predicted plot (denoted as 1 in Figure 19) demonstrates that much of the underlying patterns to the data are captured by the statistical model. The summary of fit (denoted as 2 in Figure 19) indicates that the statistical model is well fit to the underlying data. The sorted parameter estimates (denoted as 3 in Figure 19) indicate that, despite a large number of statistically significant variables, operational significance can be attributed primarily to the number of UVC well-deck maintenance bays and the number of UVC ship side bays. The prediction profiles in the bottom right of Figure 19 are relatively flat, with the exception of the profiles for the number of UVC well-deck maintenance bays and the number of UVC ship side bays (denoted as 4 in Figure 19). Note that the flat lines for all variables other than the number of UVC well-deck maintenance bays and the number of UVC ship side bays indicate that there is minimal change in Ao that results from a change in each of these variables, where a change in either the number of UVC well-deck maintenance bays and the number of UVC ship side bays increases the Ao from 0.86 to 0.93.

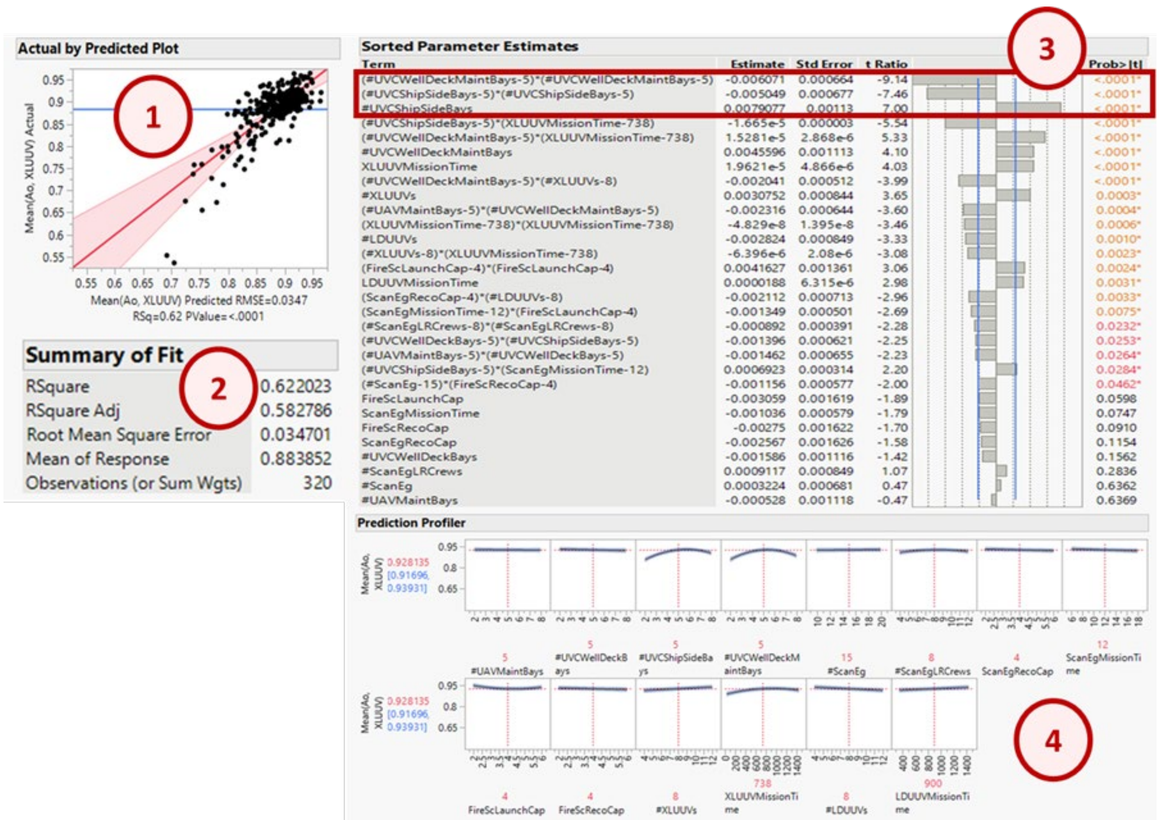


Figure 19. XLUUV Ao Regression Analysis

Due to the lower correlation of R-squared value for the regression, and to further determine which factors had the greatest impact on the response, additional analysis was conducted to further explore the factors' effect on the XLUUV Ao, as shown in Figure 20. By conducting two levels of splits within the partition decision tree, it is shown that, despite the low R-square value of 0.474 (denoted as 1 in Figure 20), the UVC ship side bays and

UVC well-deck maintenance bays are two factors that contribute towards the XLUUV Ao. The decision tree predicts that the mean Ao achieved will be as high as 0.782 with less than three ship side bays; however, with three or more ship side bays, the mean Ao achieved can be as high as 0.893, accounting for a 0.111 increase (denoted as 2 in Figure 20). Furthermore, with three or more ship side bays, and three or more well-deck maintenance bays will increase Ao from 0.82 to 0.90 (denoted as 3 in Figure 20).

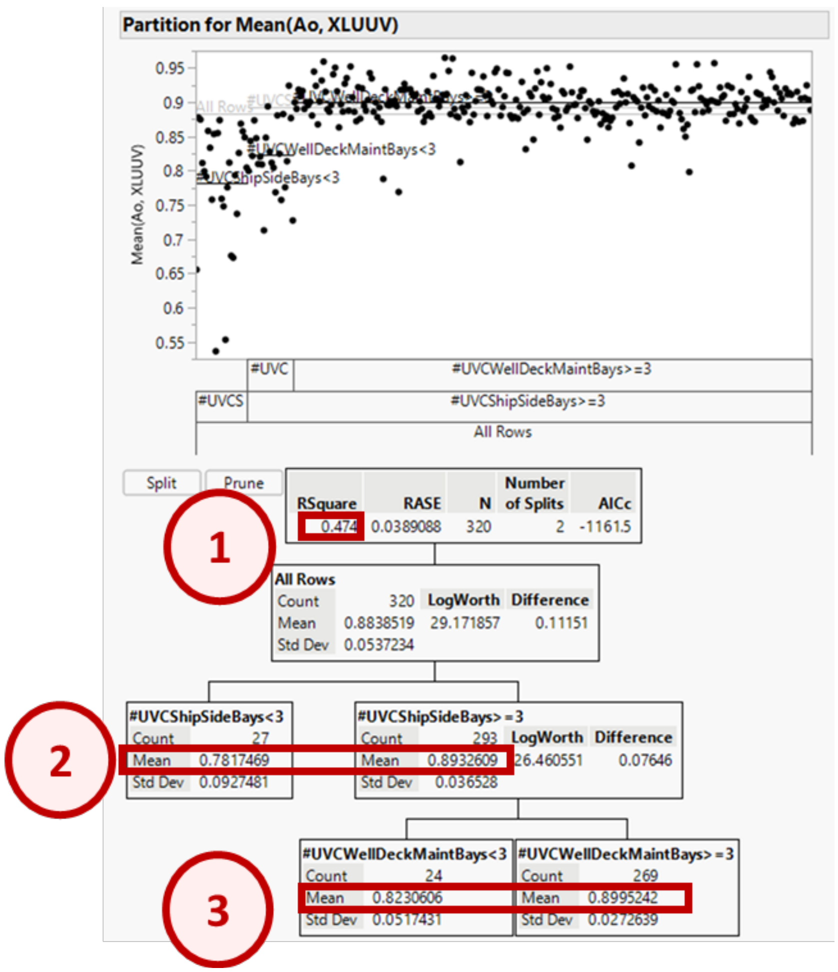


Figure 20. XLUUV Ao Partition Decision Tree

d. LDUUV Ao

The distribution of the mean LDUUV Ao is shown in Figure 21, which represents the full range of the Ao with the UVC providing support. With UVC support, the LDUUV achieves a mean Ao of 0.887 (denoted as 1 in Figure 21).

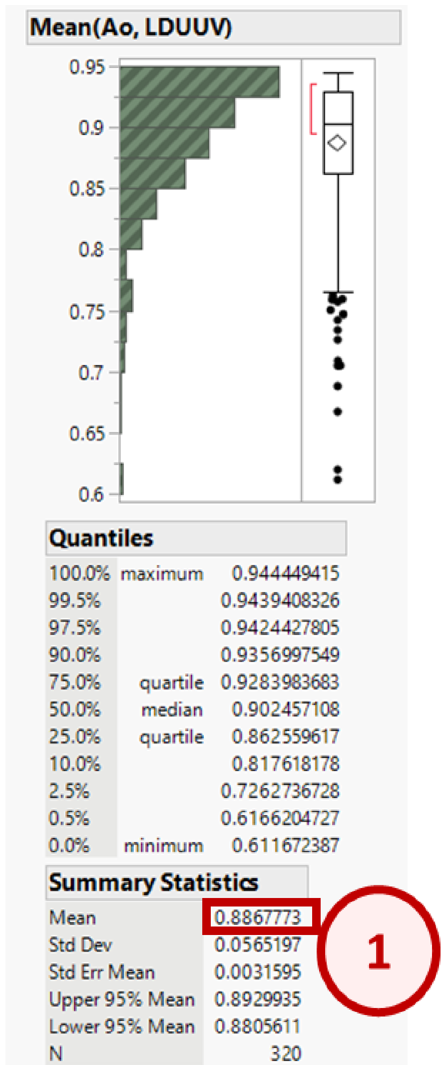


Figure 21. LDUUV Ao Distribution

Regression analysis output for the LDUUV Ao is shown in Figure 22. The actual by predicted plot (denoted as 1 in Figure 22) demonstrates that there is no underlying pattern to the data that is not captured by the statistical model. The summary of fit (denoted as 2 in Figure 22) indicates that the statistical model is well fit to the underlying data. The sorted parameter estimates (denoted as 3 in Figure 22) indicate that, despite a large number of statistically significant variables, operational significance can be attributed primarily to the mission time of the LDUUV, a variable that is not associated with the design of the UVC itself, and the number of UVC well-deck maintenance bays. The prediction profiles on the bottom right of Figure 22 are relatively flat, with the exception of the profiles for the LDUUV Mission Time and the number of UVC well-deck maintenance bays (denoted as 4 in Figure 22). Note that the flat lines for all variables other than the LDUUV Mission Time and the number of the UVC well-deck maintenance bays suggest that there is minimal change in Ao that results from a change in each of these variables, where a change from 100 hours to 1400 hours in LDUUV Mission Time increases Ao from approximately 0.81 to approximately 0.94, and a change from 2 to 8 in the number UVC well-deck maintenance bays increases Ao from approximately 0.83 to approximately 0.93. Based on the full regression model, the UVC parameter having the most statistically significant impact on Ao is the number of well-deck maintenance bays.

Figure 22. LDUUV Ao Regression Analysis

While the R-squared value was acceptable, additional analysis was conducted to further explore the factors with the greatest effect on the LDUUV Ao, as shown in Figure 23. By conducting two levels of splits within the partition decision tree, it is shown that, despite a low R-square value of 0.529 (denoted as 1 in Figure 23), the number of UVC well-deck maintenance bays contributes significantly to LDUUV Ao. The decision tree predicts that the mean Ao achieved will be as high as 0.918 with less than three well-deck maintenance bays; however, with three or more well-deck maintenance bays, the mean Ao achieved can be as high as 0.833, accounting for a 0.085 increase (denoted as 2 in Figure 23).

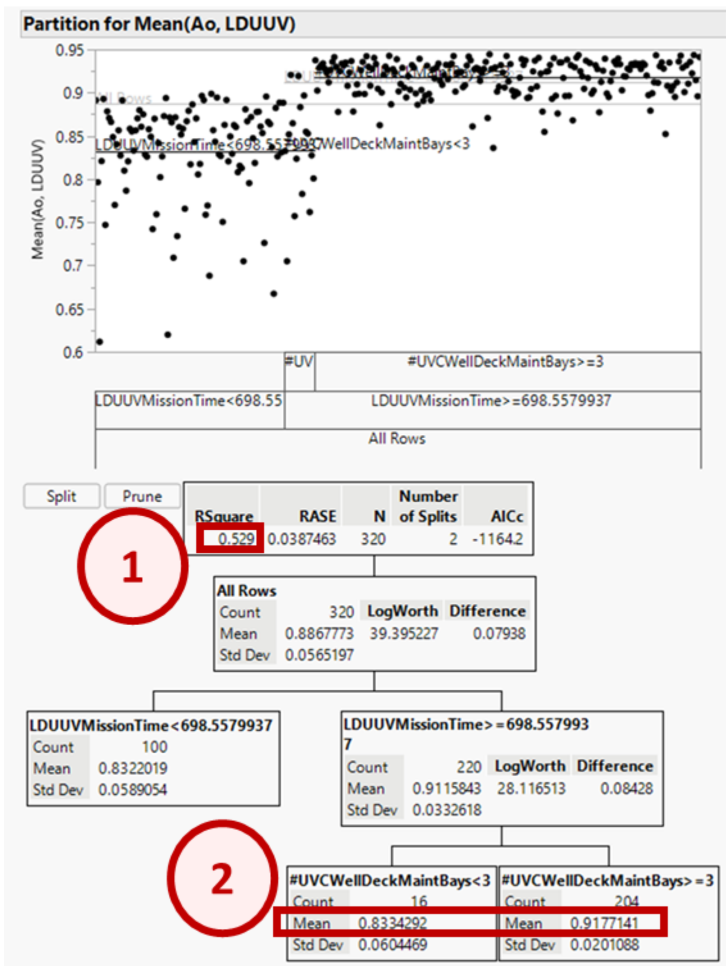
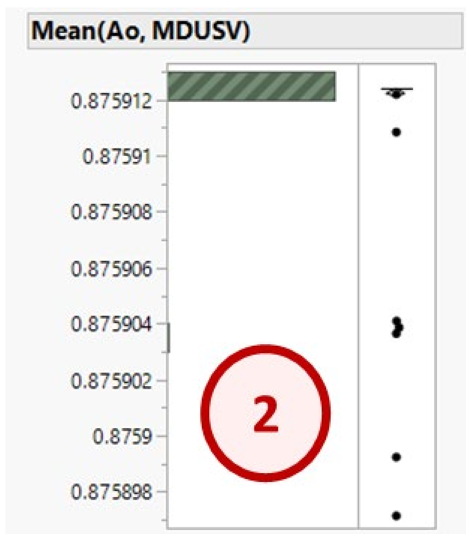


Figure 23. LDUUV Ao Partition Decision Tree

e. MUSV Ao

The distribution of the mean MUSV Ao is shown in Figure 24, which represents the full range of the Ao with the UVC providing support. With UVC support, the MUSV achieves a mean Ao of 0.876 (denoted as 1 in Figure 24). Across the various DOE configurations for the model, there was little variation in the resulting Ao (denoted as 2 in Figure 24), indicating that varying configurations of the UVC will have little effect on the Ao, beyond the inherent effect of the presence of the UVC.



Quantiles

100.0%	maximum	0.875912409
99.5%		0.875912409
97.5%		0.875912409
90.0%		0.875912409
75.0%	quartile	0.875912409
50.0%	median	0.875912409
25.0%	quartile	0.875912409
10.0%		0.875912409
2.5%		0.875912409
0.5%		0.87589841066
0.0%	minimum	0.875897145

Summary Statistics

Mean	0.8759122
Std Dev	1.3926e-6
Std Err Mean	7.7847e-8
Upper 95% Mean	0.8759124
Lower 95% Mean	0.8759121
N	320

1

Figure 24. MUSV Ao Distribution

Regression analysis output for the MUSV Ao is shown in Figure 25. The actual by predicted plot (denoted as 1 in Figure 25) demonstrates that there are likely underlying patterns to the data that are not captured by the statistical model. The summary of fit (denoted as 2 in Figure 25) indicates that the statistical model is a poor fit to the underlying data. The sorted parameter estimates (denoted as 3 in Figure 25) indicate that operational significance can be attributed primarily to the number of UVC ship side bays. The prediction profiles on the bottom right of Figure 25 are relatively flat (denoted as 4 in Figure 25). The flat lines for all variables suggest that there is minimal change in Ao that results from a change in each of these variables; however, number of UVC ship side bays has the greatest effect.

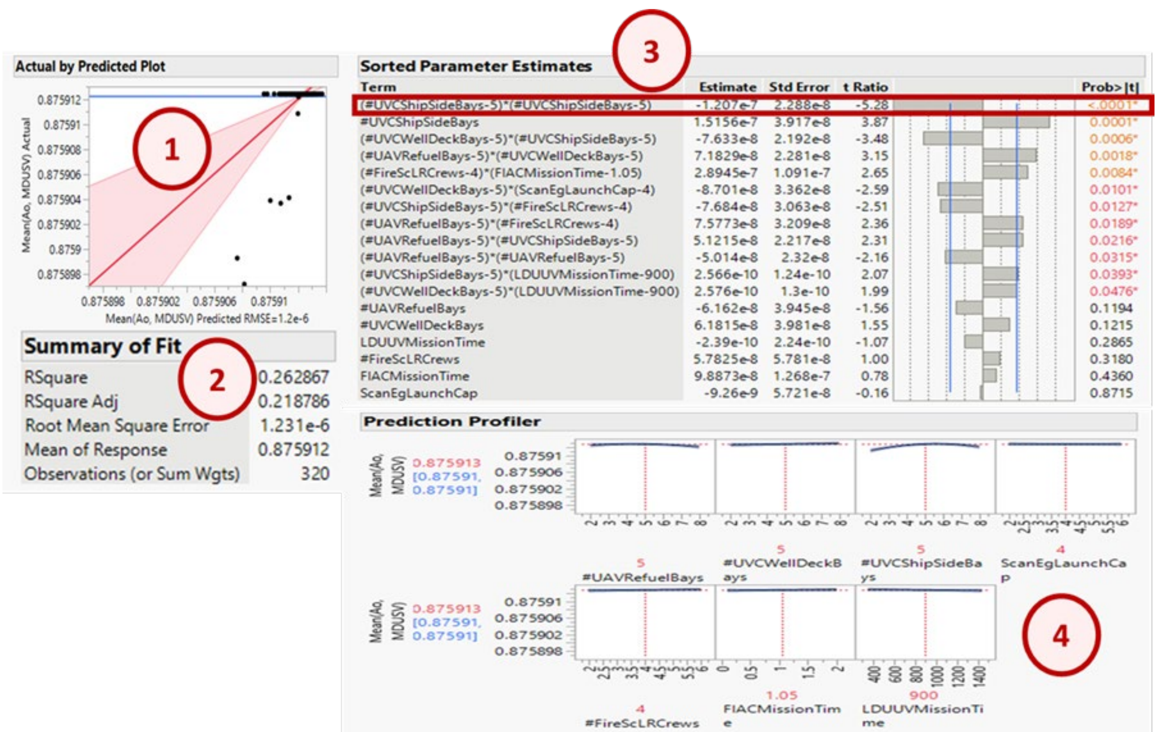


Figure 25. MUSV Ao Regression Analysis

Due to the low R-squared value associated with the generated regression, additional analysis was conducted to further explore the factors with the greatest effect on the MUSV Ao, as shown in Figure 26. By evaluating the first level of the partition decision tree, it is shown that, despite an R-squared value of 0.171 (denoted by 1 in Figure 26), the UVC ship side bays have a minimal impact on the response as indicated by the small change in the mean Ao (denoted by 2 in Figure 26). Therefore, none of the factors have a statistically significant effect on the MUSV Ao.

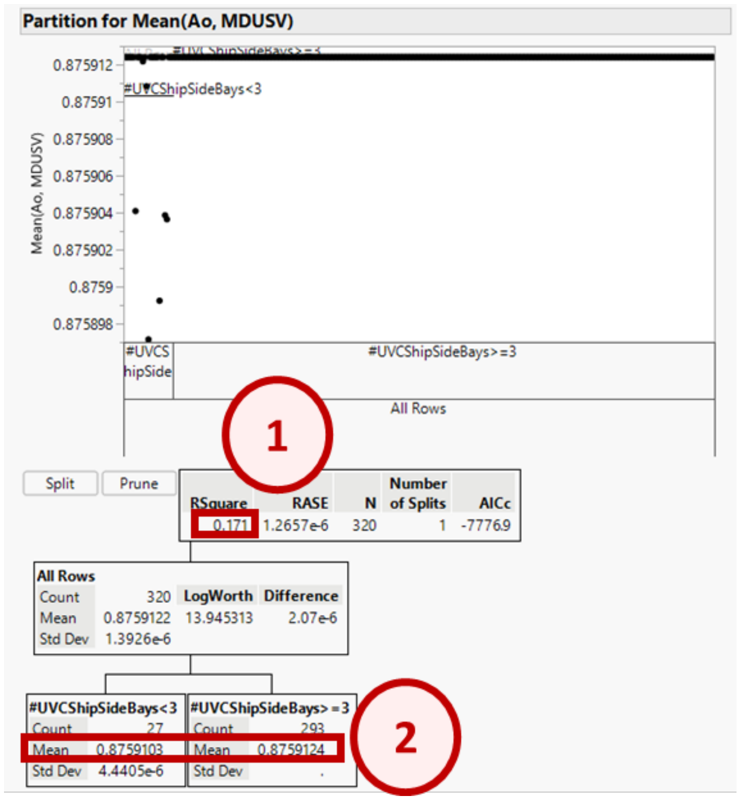


Figure 26. MUSV Ao Partition Decision Tree

f. *LUSV Ao*

The distribution of the mean LUSV Ao is shown in Figure 27. Based on the results from the developed model, the LUSV Ao response for the operational scenario and the assumed mission duration achieved was 0.656 (denoted as 1 in Figure 27). Regardless of variation of the DOE factors, the resulting Ao remained static (denoted as 2 in Figure 27). Therefore, no regression could be generated for the LUSV Ao. The results indicate that none of the factors have a statistically significant effect on LUSV Ao.

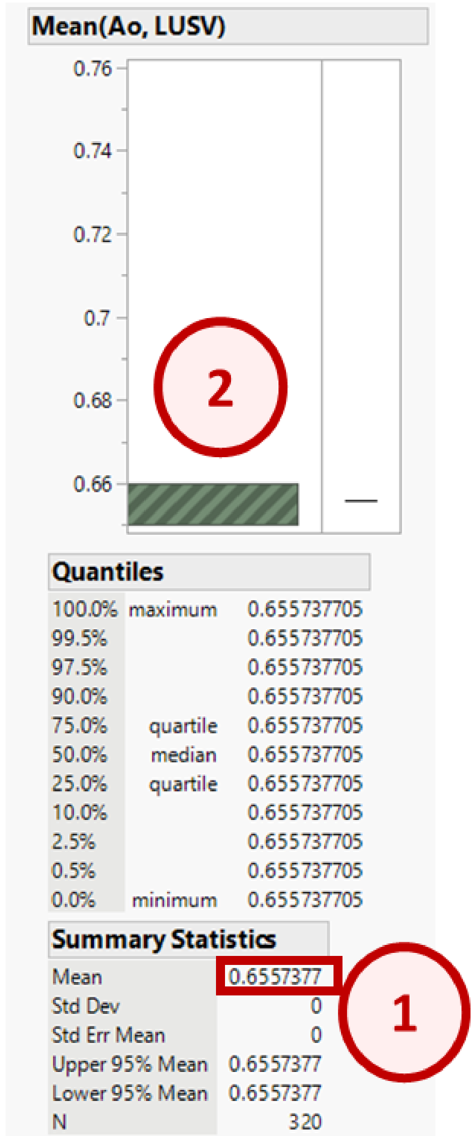


Figure 27. LUSV Ao Distribution

g. FIAC

The distribution of the mean FIAC Ao is shown in Figure 28, which represents the full range of the Ao with the UVC providing support. With UVC support, the FIAC achieves a mean Ao of 0.157 (denoted as 1 in Figure 28); however, the standard deviation is 0.102 or 64% of the mean (denoted as 2 in Figure 28), indicating a large spread of the data.

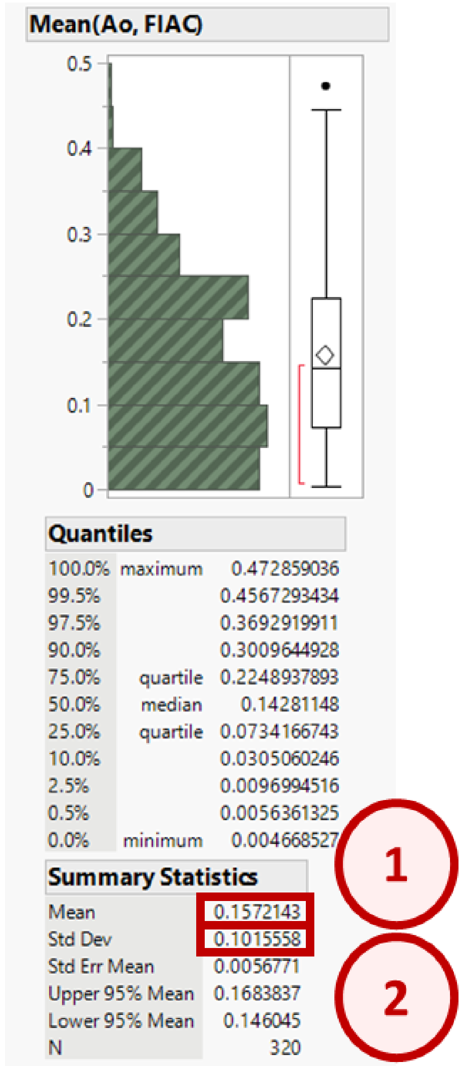


Figure 28. FIAC Ao Distribution

Regression analysis output for the FIAC Ao is shown in Figure 29. The actual by predicted plot (denoted as 1 in Figure 29) demonstrates that there is no underlying pattern to the data that is not captured by the statistical model. The summary of fit (denoted as 2 in Figure 29) indicates that the statistical model is well fit to the underlying data. The sorted parameter estimates (denoted as 3 in Figure 29) indicate that operational significance can be attributed primarily to the number of UVC well-deck maintenance bays and the mission time of the FIAC, a variable that is not associated with the design of the UVC itself. The prediction profiles in the bottom right of Figure 29 are relatively flat, with the exception of the profiles for the number of UVC well-deck maintenance bays, FIAC Mission Time, number of UVC well-deck bays, and number of FIACs (denoted as 4 in Figure 29). This suggests that there is a minimal change in Ao that results from a change in each of these variables. Based on the full regression model, that UVC parameter having the greatest effect on Ao is the number of UVC well-deck maintenance bays.

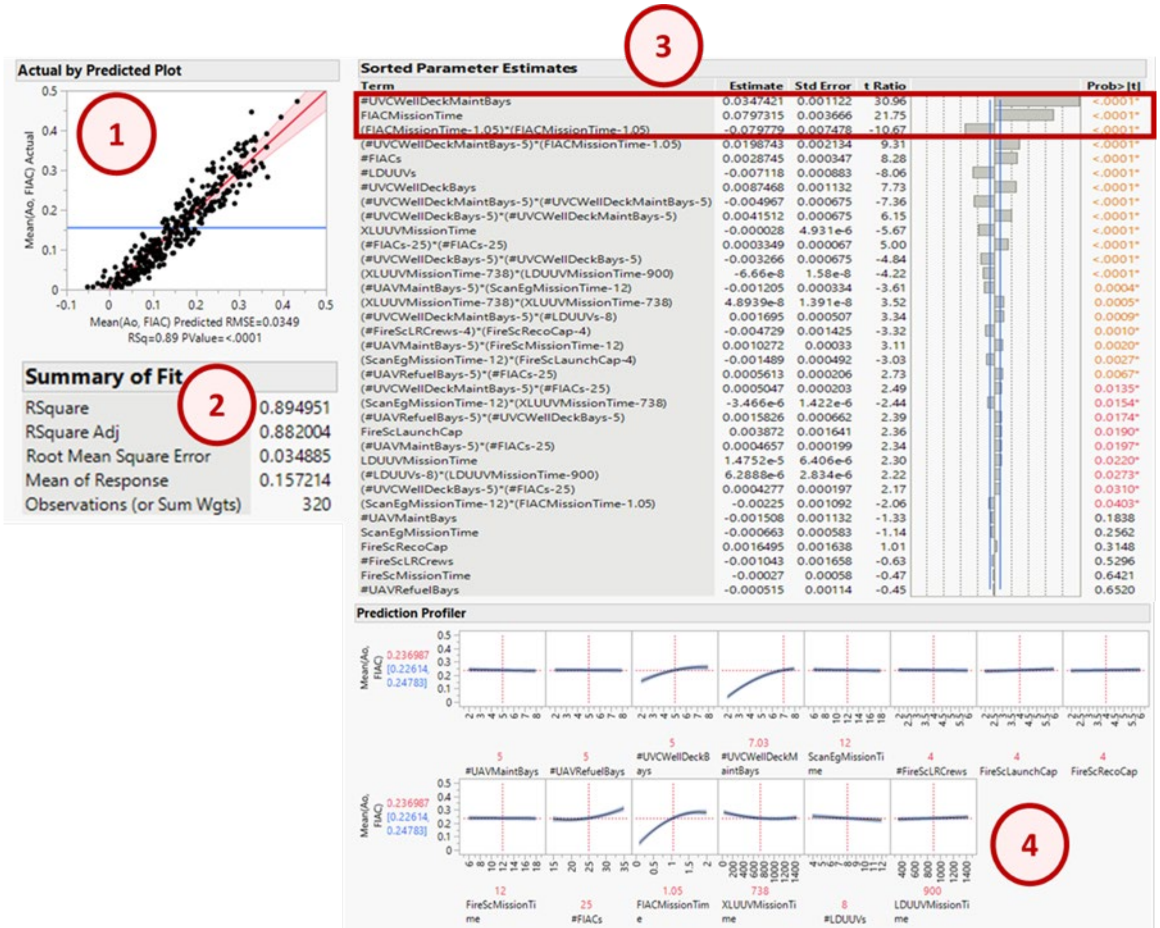


Figure 29. FIAC Ao Regression Analysis

While the R-squared value was acceptable, additional analysis was conducted to further explore the factors with the greatest effect on the FIAC Ao as shown in Figure 30. By conducting the first level split within the partition decision tree, it is shown that, despite an R-squared value of 0.324 (denoted as 1 in Figure 30), that the number of UVC well-deck maintenance bays is one of the factors that contributes most to the FIAC Ao. The decision tree predicts that the mean Ao achieved will only be 0.089 with less than five

UVC well-deck maintenance bays; however, with five or more well-deck maintenance bays, the mean Ao can be as high as 0.206, accounting for a 0.117 increase (denoted as 2 in Figure 30).

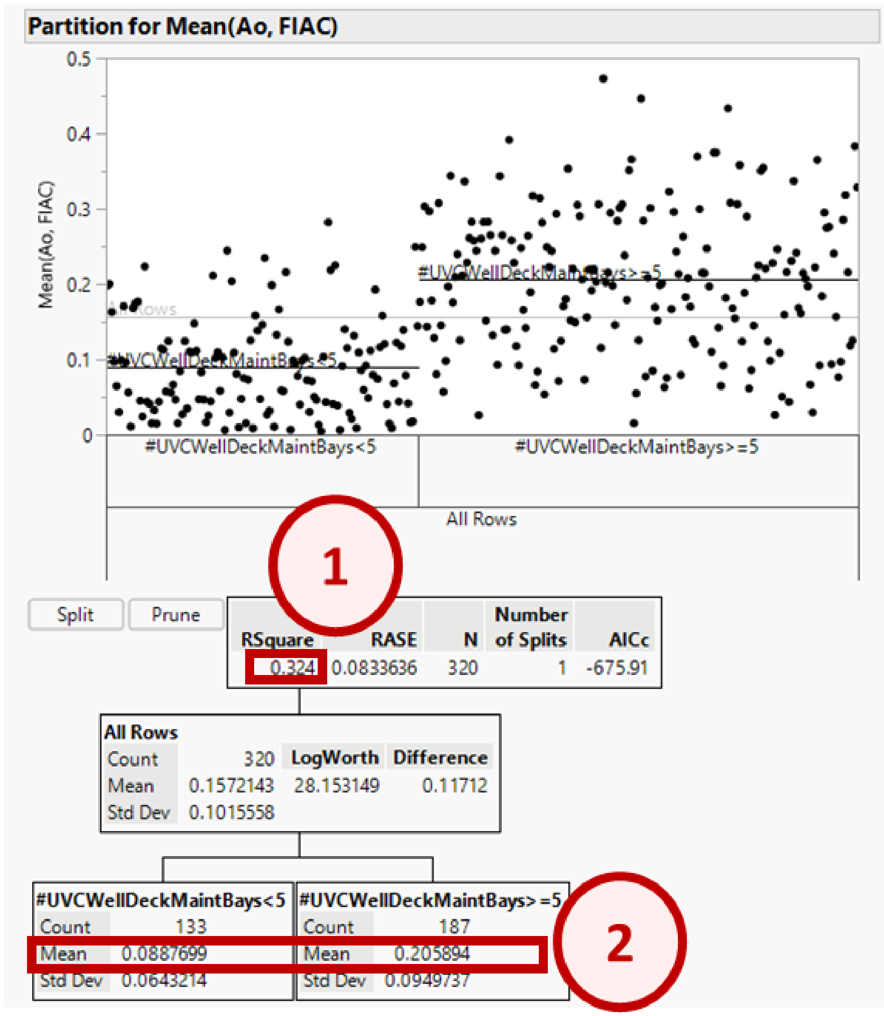


Figure 30. FIAC Ao Partition Decision Tree

2. Summary

Table 13 contains a summary of analytical findings. The key contributors to each UxV Ao are identified, as well as the conclusions drawn from the analysis for each UxV type.

Table 13. Summary of Findings

Response	Key Contributors	Conclusion
RQ-21 ScanEagle A_o	No Statistically Significant Contributor	UVC improves A_o by providing ready access to maintenance facilities without needing to leave field of operations.
MQ-8 Fire Scout A_o	Number of MQ-8 Fire Scouts supported, Number of MQ-8 Fire Scout Launch and Recovery Crews, Number of UAV Refuel Bays	UVC improves A_o by providing ready access to maintenance facilities without needing to leave field of operations. Improving UVCs maximum number of MQ-8 Fire Scouts supported, the number of MQ-8 Fire Scout Launch and Recovery Crews supported, and the number of UAV Refuel Bays will improve A_o.
XLUUV A_o	UVC Ship Side Maintenance Bays, UVC Well-Deck Maintenance Bays	UVC improves A_o by providing ready access to maintenance facilities without needing to leave field of operations. The UVC should have a minimum of three ship side bays and three well-deck maintenance bays.
LDUUV A_o	UVC Ship Side Maintenance Bays	UVC improves A_o by providing ready access to maintenance facilities without needing to leave field of operations. The UVC should have a minimum of three ship side bays.
MUSV A_o	No Statistically Significant Contributor	UVC improves A_o by providing ready access to maintenance facilities without needing to leave field of operations. The UVC should have a minimum of three ship side bays.
LUSV A_o	No Statistically Significant Contributor	UVC improves A_o by providing ready access to maintenance facilities without needing to leave field of operations. With UVC support, the A_o achieved is 0.656, regardless of UVC configurations.
FIAC A_o	UVC Well-Deck Maintenance Bays.	UVC improves A_o by providing ready access to maintenance facilities without needing to leave field of operations. The UVC should have a minimum of five well-deck maintenance bays.

VI. CONCLUSIONS AND FUTURE CONSIDERATIONS

A. CONCLUSIONS

The simulation analysis determined that the presence of the UVC improves Ao for all UxVs assigned to an AFP. The most important factor to improving UxV Ao is UxV TOS. An increase in UxV TOS can be accomplished by placing a UVC within the AFP, providing ready access to maintenance, refueling, rearming, and storage functions without the longer transit times associated with ferry to a shore-based facility.

UxV Ao is improved by increasing the number of UVC launch, refuel, and maintenance stations, thereby reducing or eliminating UxV queuing time for those stations and services. The simulation analysis indicates that the UVC should be designed with at least eight launch/recovery stations (for each UAV type), at least three ship side bays, and at least five well-deck bays.

Interestingly, while the presence of the UVC improves LUSV Ao, the actual design of the UVC has no statistically relevant impact on LUSV Ao. This likely is due to the long mission time and assumed maintenance intervals for the LUSV, eliminating the likelihood of any queuing activity. A single ship side bay appears to be sufficient to service a number of LUSVs, but the availability of that single ship side bay improves Ao by eliminating the transit time to shore-based maintenance facilities.

B. FUTURE CONSIDERATIONS

The team identified several potential areas for future research. These areas represent research aspects that were either outside the current scope of the project, or those which would provide further refinement of the analysis.

1. Refinement of Key Contributors to Ao

The key contributors to optimization of Ao should be refined to provide further insight to UVC design requirements. For instance, the analysis defined the lower bound for ship side bays and well-deck bays, but additional analysis is required to determine the point at which additional bays provides only marginal improvement in Ao.

2. Failure Rates and Maintenance Intervals

The analysis did not consider UxV failure rates, as this information was not readily available to the team and was considered out of scope for this project. Likewise, the model currently considers maintenance schedules on a very simple, evenly distributed scale by assuming a single, standard maintenance interval for each UxV type. More realistic failure rates (i.e., unscheduled maintenance) and scheduled maintenance intervals would provide greater fidelity to the analysis.

3. Combat Losses

Likewise, the model does not currently consider UxV combat losses, by either direct hostile action or cybersecurity intrusions. Modeling of varying combat loss rates would allow planners, designers, and decision makers to assess the effectiveness of the UVC in different operational scenarios.

4. Mission Tasking

The model currently implements a simple, evenly distributed schedule for launch and recovery of UxV assets. Greater fidelity could be gained by implementing more realistic launch and recovery rates based on mission tasking.

5. UxV Physical Parameters

The simulation model used the best data available to the project team at the time. Some of the UxV input parameters were provided by the project sponsor, but several were identified through research of public records (i.e., internet search). Some of the UxVs, such as LUSV, MUSV, and XLUUV, have yet to be designed; therefore, assumptions were made regarding the likely design parameters, based on discussions with the project sponsor and other subject matter experts. As these design parameters become available, they should be included allow for further refinement of the model and greater fidelity in the analysis and definition of the UVC design.

6. UVC Design Parameters

Likewise, the UVC architecture defined in this report currently represents only a notional ship. The U.S. Navy could choose to develop the UVC by repurposing an existing ship, such as the LHD, or to design a new, purpose-built ship for the UVC role. This project assumes that the LHD will be repurposed as a UVC. However, LHD physical design data was not readily available to the project team, so the appropriateness of the design recommendations is unknown.

7. UVC Self Defense

The project team did not consider any required self-defense capabilities of the UVC, nor were battle damage effects considered. Future research should examine the criticality of losing all or part of the UVC functionality to hostile fire, especially with respect to recovery of deployed UxV assets after loss of the UVC.

8. UVC Design for LUSV

The analysis was unable to determine any UVC design parameters with a statistically significant impact on LUSV Ao. Further consideration and study to determine UVC design parameters having a beneficial effect on LUSV Ao is warranted.

C. SUMMARY

This project examined the integration of USVs, UUVs, and UAVs aboard a UVC supporting an AFP conducting DMO. The goal of this project was to evaluate the use of a UVC for UxV launch, recovery, rearming, refueling, storage, and maintenance to increase UxV TOS and Ao. The project team developed a systems architecture for the UVC, identifying the functions and operational activities critical to UVC mission success. The team then constructed a discrete event simulation model and conducted an evaluation of the UVC, focusing on its impact to UxV Ao. The analysis showed that a UVC has the potential to provide significant improvements in Ao for UxVs supporting AFPs conducting DMO by reducing queuing times for maintenance activities and by reducing transit time, thereby increasing persistent dwell times.

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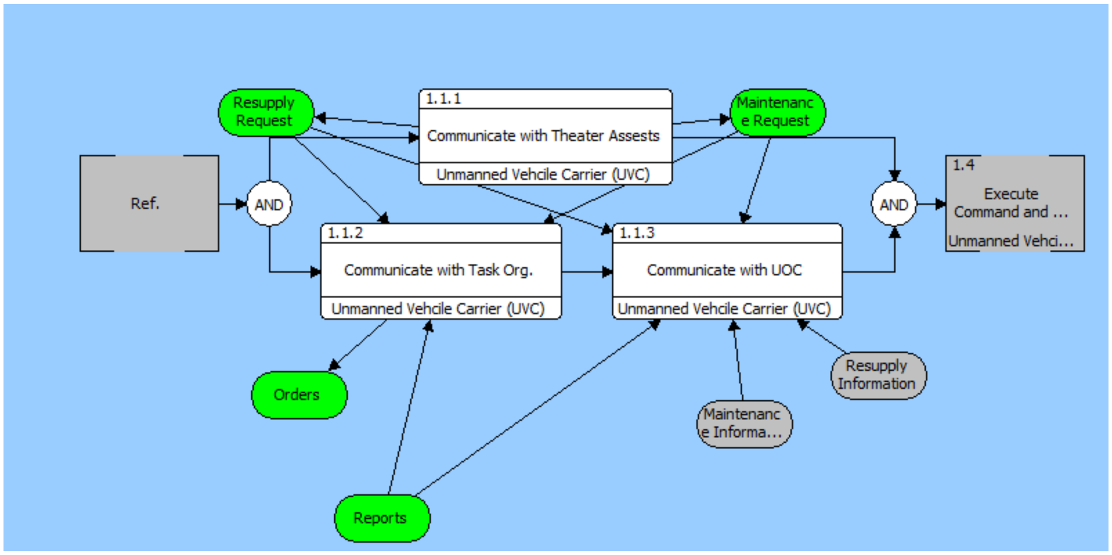
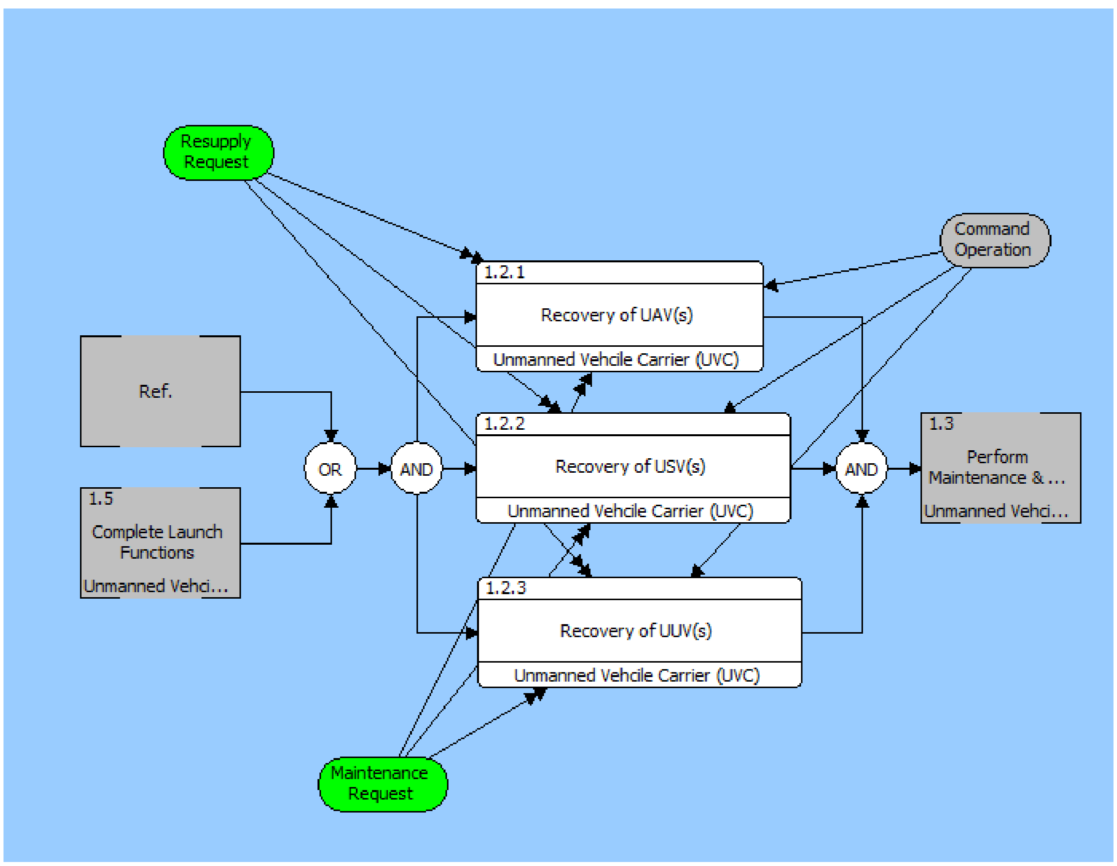
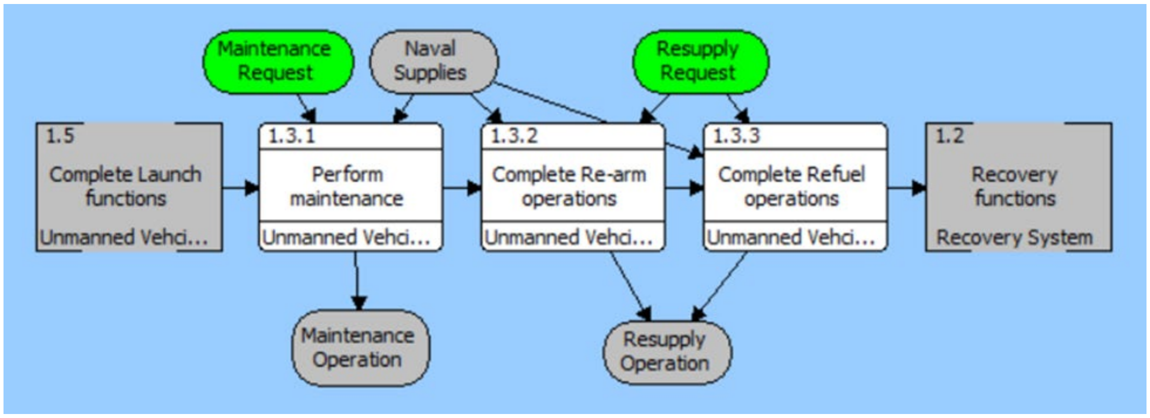
APPENDIX A. FUNCTIONAL FLOW BLOCK DIAGRAMS



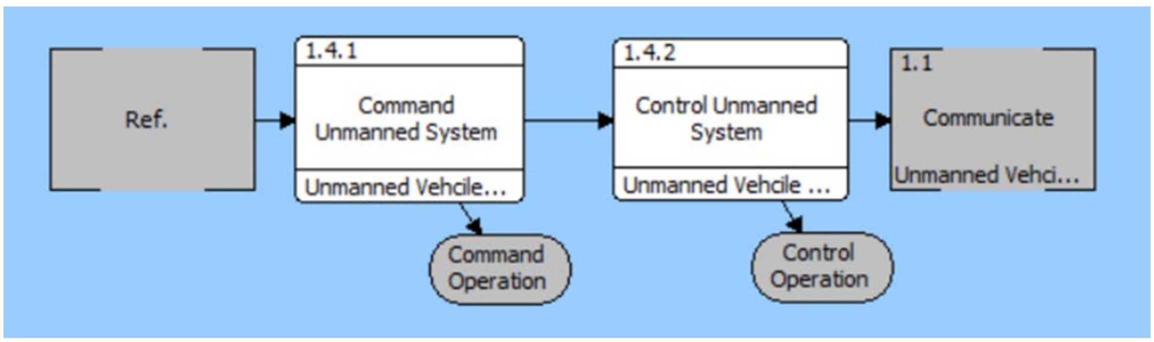
"Communicate" Functional Flow



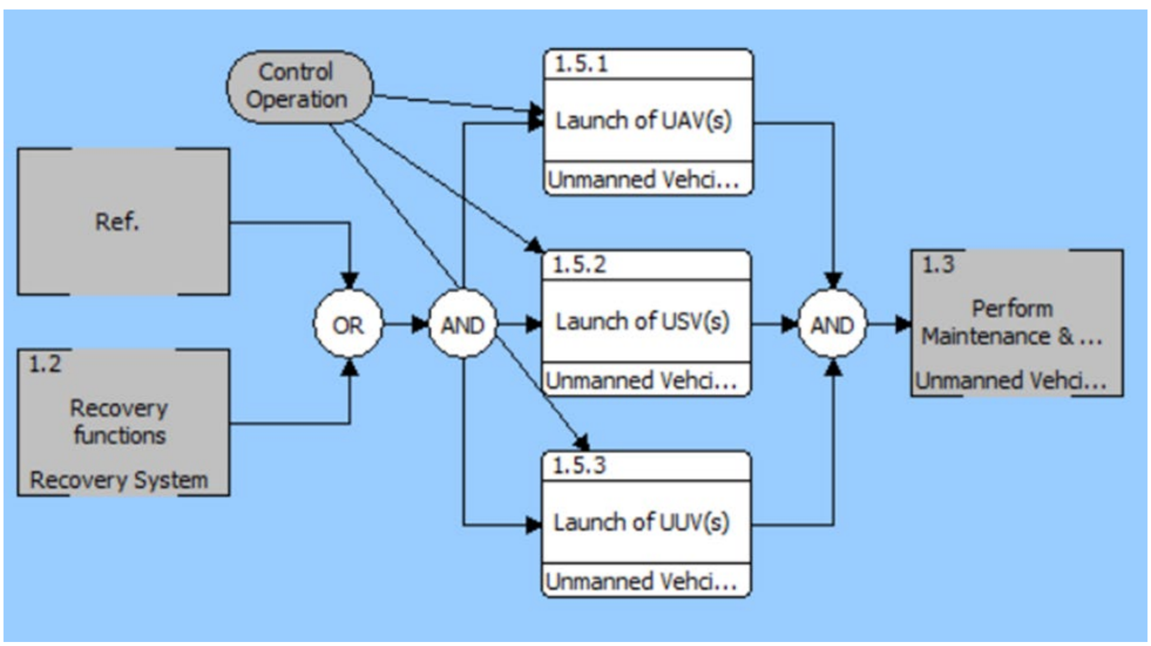
"Recovery" Functional Flow



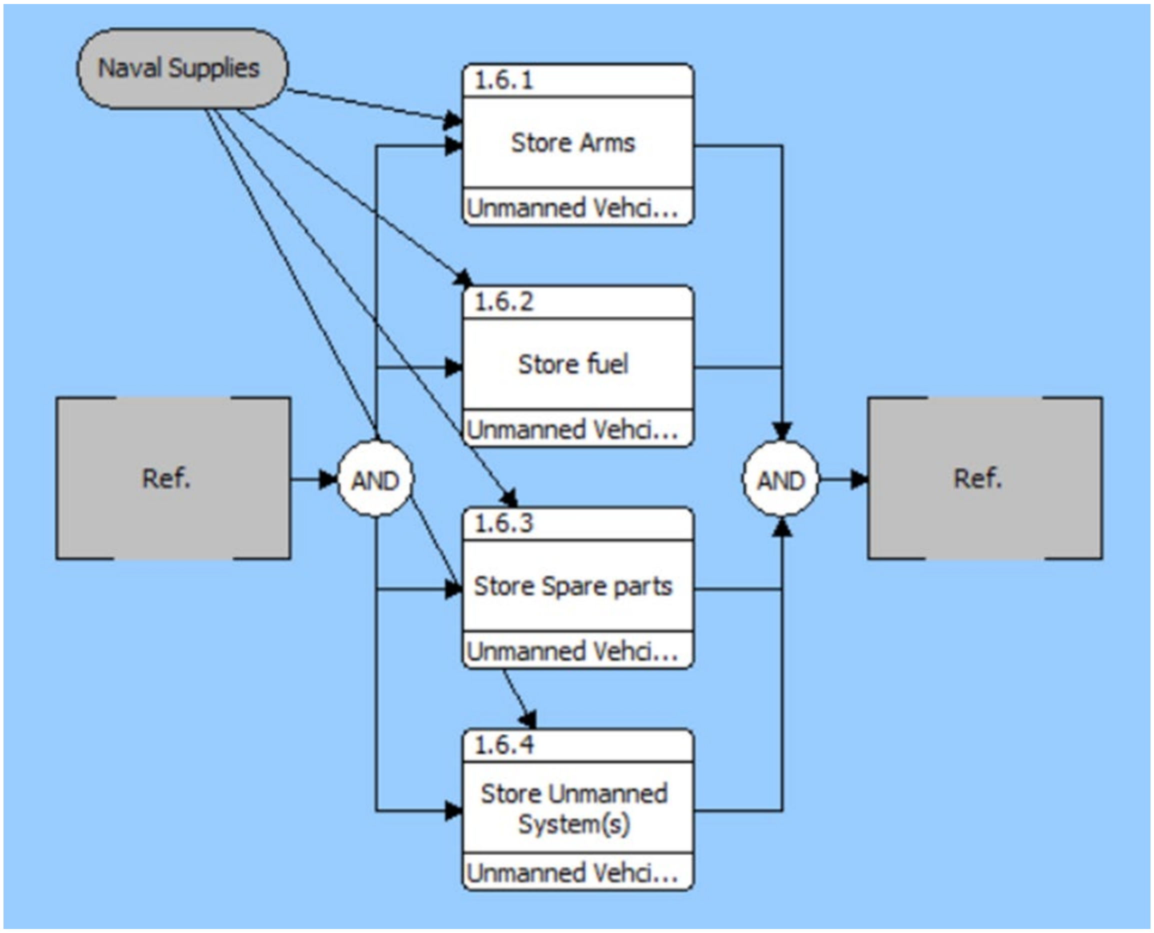
"Maintenance and Resupply" Functional Flow



"Command and Control" Functional Flow



"Launch" Functional Flow



"Storage" Functional Flow

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APPENDIX B. BASELINE MODEL TRIALS

Variable	Restricted Model	Standard UVC Model
#UAVMaintBays	2	8
#UAVRefuelBays	1	4
#UVCWellDeckBays	1	8
#UVCShipSideBays	1	4
#UVCWellDeckMaintBays	1	8
#ScanEg	20	20
#ScanEgLRCrews	1	5
ScanEgLaunchCap	1	5
ScanEgRecoCap	1	2
ScanEgMissionTime	12	12
#FireScs	10	10
#FireScLRCrews	1	2
FireScLaunchCap	1	2
FireScRecoCap	1	2
FireScMissionTime	12	12
#FIACs	18	18
FIACMissionTime	0.58	0.58
#XLUUVs	8	8
XLUUVMissionTime	720	720
#LDUUVs	8	8
LDUUVMissionTime	24	24

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APPENDIX C. BASELINE MEAN AO

	Scan Eagle		Fire Scout		XLUUV		LDUUV		MUSV		LUSV		FIACs	
Run	**Restricted**	**Standard**	**Restricted**	**Standard**	**Restricted**	**Standard**	**Restricted**	**Standard**	**Restricted**	**Standard**	**Restricted**	**Standard**	**Restricted**	**Standard**
1	0.6798	0.8121	0.7421	0.8227	0.6696	0.9026	0.1627	0.5363	0.8136	0.8759	0.6557	0.6557	0.0046	0.1890
2	0.6802	0.8126	0.7447	0.8221	0.5200	0.9027	0.1343	0.5458	0.8136	0.8759	0.6557	0.6557	0.0032	0.1599
3	0.6808	0.8118	0.7405	0.8216	0.6343	0.9342	0.1586	0.5508	0.8136	0.8759	0.6557	0.6557	0.0040	0.1712
4	0.6820	0.8128	0.7375	0.8217	0.6521	0.9238	0.1529	0.5385	0.8136	0.8759	0.6557	0.6557	0.0045	0.1738
5	0.6806	0.8128	0.7424	0.8217	0.6365	0.9123	0.1585	0.5452	0.8136	0.8759	0.6557	0.6557	0.0040	0.1883
6	0.6822	0.8141	0.7424	0.8218	0.6612	0.9221	0.1635	0.5480	0.8136	0.8759	0.6557	0.6557	0.0044	0.1702
7	0.6858	0.8129	0.7436	0.8225	0.7189	0.9157	0.1740	0.5444	0.8136	0.8759	0.6557	0.6557	0.0052	0.1861
8	0.6824	0.8131	0.7435	0.8215	0.5937	0.9253	0.1385	0.5521	0.8136	0.8759	0.6557	0.6557	0.0031	0.1850
9	0.6796	0.8119	0.7421	0.8228	0.5495	0.9291	0.1586	0.5393	0.8136	0.8759	0.6557	0.6557	0.0046	0.1470
10	0.6782	0.8112	0.7409	0.8231	0.6082	0.9135	0.1696	0.5493	0.8136	0.8759	0.6557	0.6557	0.0050	0.1659
11	0.6824	0.8125	0.7418	0.8230	0.6353	0.8972	0.1641	0.5447	0.8136	0.8759	0.6557	0.6557	0.0050	0.1384
12	0.6815	0.8121	0.7401	0.8215	0.6458	0.9064	0.1527	0.5598	0.8136	0.8759	0.6557	0.6557	0.0043	0.1924
13	0.6836	0.8130	0.7427	0.8218	0.5646	0.9190	0.1495	0.5414	0.8135	0.8759	0.6556	0.6557	0.0038	0.1715
14	0.6849	0.8109	0.7472	0.8210	0.5341	0.9324	0.1174	0.5397	0.8136	0.8759	0.6557	0.6557	0.0025	0.1916
15	0.6822	0.8129	0.7402	0.8218	0.5343	0.9050	0.1452	0.5430	0.8136	0.8759	0.6557	0.6557	0.0041	0.1750
16	0.6834	0.8123	0.7421	0.8211	0.6355	0.9152	0.1530	0.5449	0.8136	0.8759	0.6557	0.6557	0.0040	0.1670
17	0.6781	0.8118	0.7398	0.8220	0.6193	0.8976	0.1826	0.5544	0.8136	0.8759	0.6557	0.6557	0.0066	0.1478
18	0.6783	0.8140	0.7410	0.8222	0.5465	0.9102	0.1522	0.5514	0.8136	0.8759	0.6557	0.6557	0.0043	0.1924
19	0.6816	0.8128	0.7406	0.8225	0.7158	0.8986	0.1804	0.5454	0.8136	0.8759	0.6557	0.6557	0.0063	0.1960
20	0.6793	0.8126	0.7391	0.8224	0.4835	0.9438	0.1503	0.5586	0.8136	0.8759	0.6557	0.6557	0.0043	0.1882
21	0.6840	0.8133	0.7440	0.8217	0.6069	0.9259	0.1659	0.5302	0.8136	0.8759	0.6557	0.6557	0.0052	0.1913
22	0.6811	0.8129	0.7412	0.8211	0.5849	0.9248	0.1561	0.5430	0.8136	0.8759	0.6557	0.6557	0.0043	0.1535
23	0.6832	0.8128	0.7448	0.8209	0.6322	0.8928	0.1517	0.5380	0.8136	0.8759	0.6557	0.6557	0.0036	0.1899
24	0.6814	0.8142	0.7415	0.8218	0.6066	0.9338	0.1533	0.5439	0.8134	0.8759	0.6557	0.6557	0.0045	0.1948
25	0.6771	0.8131	0.7392	0.8216	0.6541	0.9117	0.1549	0.5320	0.8136	0.8759	0.6557	0.6557	0.0041	0.1823
26	0.6832	0.8138	0.7403	0.8215	0.5851	0.9225	0.1440	0.5427	0.8136	0.8759	0.6557	0.6557	0.0037	0.1807
27	0.6826	0.8137	0.7437	0.8224	0.5049	0.9247	0.1167	0.5447	0.8136	0.8759	0.6557	0.6557	0.0021	0.1915
28	0.6795	0.8106	0.7419	0.8228	0.6389	0.9115	0.1489	0.5425	0.8136	0.8759	0.6557	0.6557	0.0039	0.1619
29	0.6840	0.8125	0.7448	0.8209	0.6608	0.9126	0.1638	0.5429	0.8136	0.8759	0.6557	0.6557	0.0050	0.1852
30	0.6837	0.8139	0.7452	0.8225	0.6021	0.9089	0.1491	0.5383	0.8136	0.8759	0.6557	0.6557	0.0030	0.1658
Average	0.6815	0.8127	0.7420	0.8219	0.6078	0.9159	0.1541	0.5444	0.8136	0.8759	0.6557	0.6557	0.0042	0.1765
Standard Deviation	0.0022	0.0009	0.0021	0.0006	0.0583	0.0126	0.0148	0.0068	0.0000	0.0000	0.0000	0.0000	0.0010	0.0159

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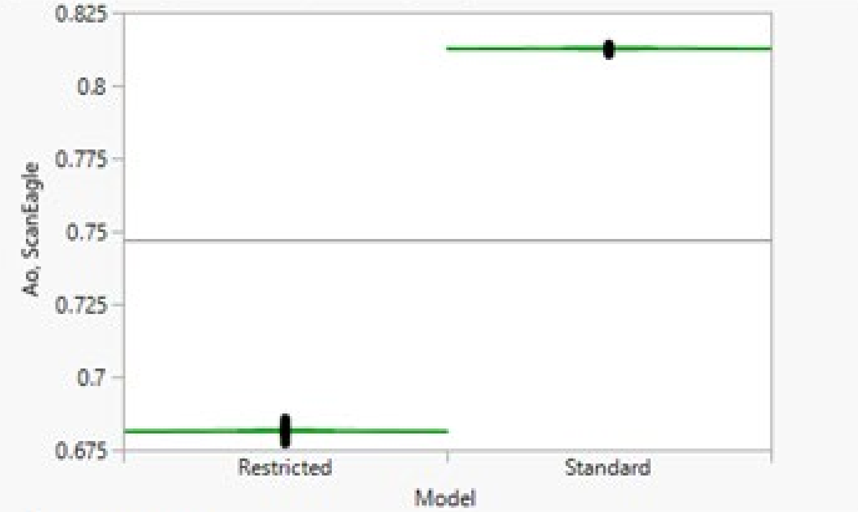
APPENDIX D. BASELINE POOLED T-TESTS

Oneway Analysis of Ao, ScanEagle By Model



Oneway Anova

Summary of Fit

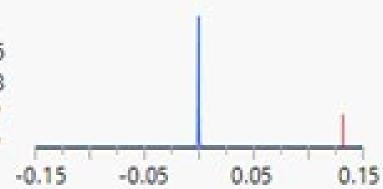
Rsquare	0.999384
Adj Rsquare	0.999374
Root Mean Square Error	0.001655
Mean of Response	0.747123
Observations (or Sum Wgts)	60

Pooled t Test

Standard-Restricted

Assuming equal variances

Difference	0.131148	t Ratio	306.8736
Std Err Dif	0.000427	DF	58
Upper CL Dif	0.132003	Prob > |t|	<.0001*
Lower CL Dif	0.130292	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

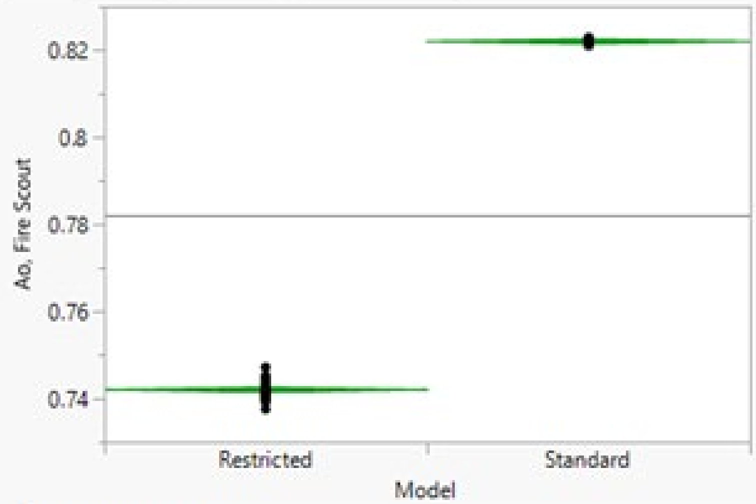
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	1	0.25799675	0.257997	94171.39	<.0001*
Error	58	0.00015890	2.74e-6		
C. Total	59	0.25815565			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Restricted	30	0.681549	0.00030	0.68094	0.68215
Standard	30	0.812697	0.00030	0.81209	0.81330

Std Error uses a pooled estimate of error variance

Oneway Analysis of Ao, Fire Scout By Model



Oneway Anova

Summary of Fit

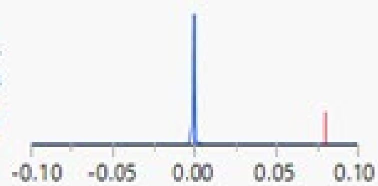
Rsquare	0.998514
Adj Rsquare	0.998488
Root Mean Square Error	0.001568
Mean of Response	0.781982
Observations (or Sum Wgts)	60

Pooled t Test

Standard-Restricted

Assuming equal variances

Difference	0.079910	t Ratio	197.3988
Std Err Dif	0.000405	DF	58
Upper CL Dif	0.080720	Prob > |t|	<.0001*
Lower CL Dif	0.079099	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

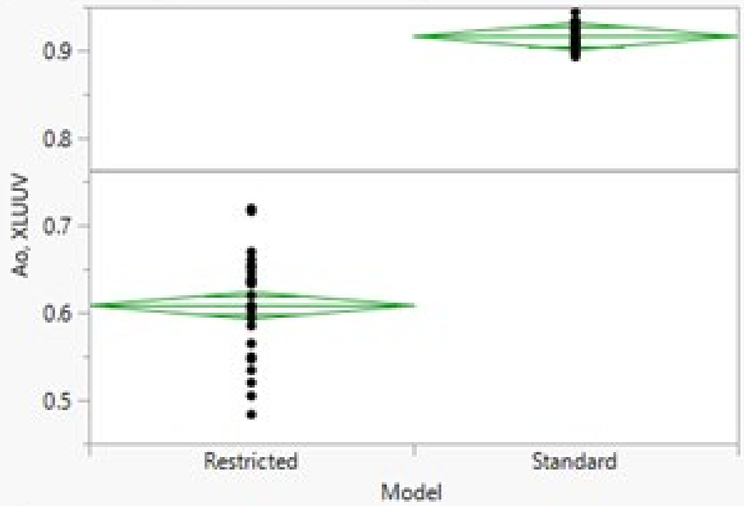
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	1	0.09578322	0.095783	38966.27	<.0001*
Error	58	0.00014257	2.458e-6		
C. Total	59	0.09592579			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Restricted	30	0.742027	0.00029	0.74145	0.74260
Standard	30	0.821937	0.00029	0.82136	0.82251

Std Error uses a pooled estimate of error variance

Oneway Analysis of Ao, XLUUV By Model



Oneway Anova

Summary of Fit

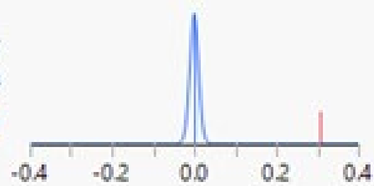
Rsquare	0.932342
Adj Rsquare	0.931176
Root Mean Square Error	0.042197
Mean of Response	0.76185
Observations (or Sum Wgts)	60

Pooled t Test

Standard-Restricted

Assuming equal variances

Difference	0.308019	t Ratio	28.27117
Std Err Dif	0.010895	DF	58
Upper CL Dif	0.329828	Prob > |t|	<.0001*
Lower CL Dif	0.286210	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

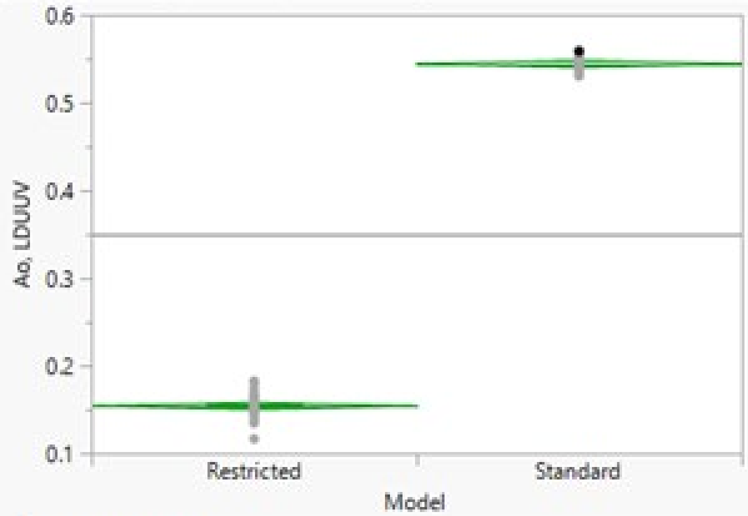
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	1	1.4231377	1.42314	799.2588	<.0001*
Error	58	0.1032732	0.00178		
C. Total	59	1.5264109			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Restricted	30	0.607840	0.00770	0.59242	0.62326
Standard	30	0.915859	0.00770	0.90044	0.93128

Std Error uses a pooled estimate of error variance

Oneway Analysis of Ao, LDUUV By Model



Oneway Anova

Summary of Fit

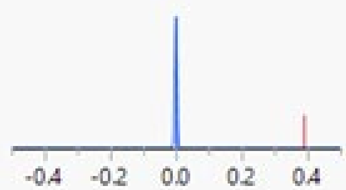
Rsquare	0.996642
Adj Rsquare	0.996584
Root Mean Square Error	0.01152
Mean of Response	0.349233
Observations (or Sum Wgts)	60

Pooled t Test

Standard-Restricted

Assuming equal variances

Difference	0.390274	t Ratio	131.2037
Std Err Dif	0.002975	DF	58
Upper CL Dif	0.396228	Prob > |t|	<.0001*
Lower CL Dif	0.384319	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

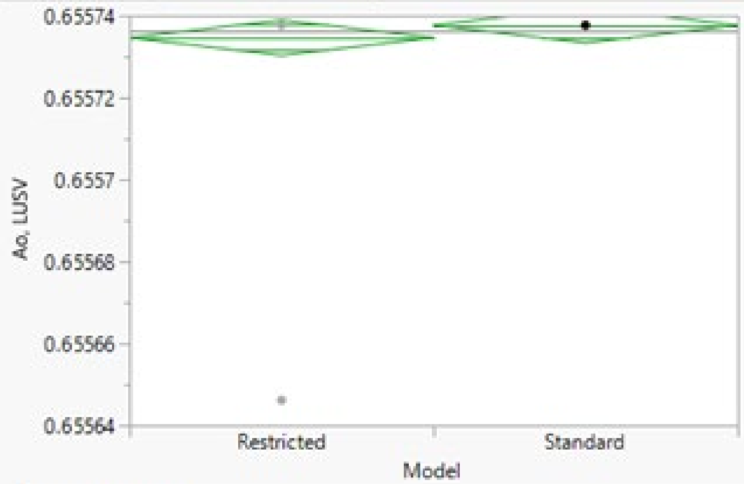
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	1	2.2847027	2.28470	17214.40	<.0001*
Error	58	0.0076978	0.00013		
C. Total	59	2.2924005			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Restricted	30	0.154096	0.00210	0.14989	0.15831
Standard	30	0.544370	0.00210	0.54016	0.54858

Std Error uses a pooled estimate of error variance

Oneway Analysis of Ao, LUSV By Model



Oneway Anova

Summary of Fit

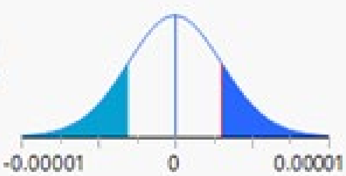
Rsquare	0.016949
Adj Rsquare	7.95e-13
Root Mean Square Error	1.182e-5
Mean of Response	0.655736
Observations (or Sum Wgts)	60

Pooled t Test

Standard-Restricted

Assuming equal variances

Difference	3.0508e-6	t Ratio	1
Std Err Dif	3.0508e-6	DF	58
Upper CL Dif	9.1575e-6	Prob > |t|	0.3215
Lower CL Dif	-3.056e-6	Prob > t	0.1607
Confidence	0.95	Prob < t	0.8393



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	1	1.3961e-10	1.396e-10	1.0000	0.3215
Error	58	8.09724e-9	1.396e-10		
C. Total	59	8.23685e-9			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Restricted	30	0.655735	2.1572e-6	0.65573	0.65574
Standard	30	0.655738	2.1572e-6	0.65573	0.65574

Std Error uses a pooled estimate of error variance

Oneway Analysis of Ao, MUSV By Model

Oneway Anova

Summary of Fit

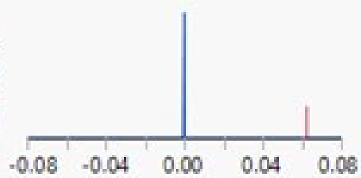
Rsquare	1
Adj Rsquare	1
Root Mean Square Error	1.72e-5
Mean of Response	0.844733
Observations (or Sum Wgts)	60

Pooled t Test

Standard-Restricted

Assuming equal variances

Difference	0.062359	t Ratio	14039.73
Std Err Dif	4.442e-6	DF	58
Upper CL Dif	0.062367	Prob > |t|	<.0001*
Lower CL Dif	0.062350	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	1	0.05832890	0.058329	1.971e+8	<.0001*
Error	58	1.71631e-8	2.96e-10		
C. Total	59	0.05832891			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Restricted	30	0.813554	3.1407e-6	0.81355	0.81356
Standard	30	0.875912	3.1407e-6	0.87591	0.87592

Std Error uses a pooled estimate of error variance

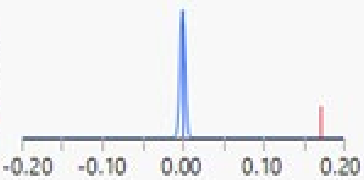
Root Mean Square Error	0.011298
Mean of Response	0.090346
Observations (or Sum Wgts)	60

Pooled t Test

Standard-Restricted

Assuming equal variances

Difference	0.172209	t Ratio	59.03353
Std Err Dif	0.002917	DF	58
Upper CL Dif	0.178048	Prob > |t|	<.0001*
Lower CL Dif	0.166370	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	1	0.44483889	0.444839	3484.957	<.0001*
Error	58	0.00740343	0.000128		
C. Total	59	0.45224233			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Restricted	30	0.004242	0.00206	0.00011	0.00837
Standard	30	0.176451	0.00206	0.17232	0.18058

Std Error uses a pooled estimate of error variance

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APPENDIX E. DOE TRIALS

Trial	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
1	8	7	6	6	5	12	5	6	2	11.68025	10	3	5	4	16.68339	35	0.826646	4	1356.376	10	1341.818
2	6	3	5	4	3	19	7	6	3	9.874608	14	3	5	2	15.2163	28	0.159561	11	344.0878	10	661.3166
3	8	7	4	6	5	13	11	2	5	7.617555	11	3	4	5	6.639498	18	1.047022	7	379.2978	11	620.6897
4	3	5	3	3	3	14	5	3	4	14.91536	8	2	5	5	12.05643	34	0.326332	10	542.1442	12	481.8809
5	3	4	4	8	6	14	12	3	5	9.423197	12	3	4	4	7.768025	29	0.761129	5	1175.925	11	1026.959
6	6	3	7	8	8	11	11	5	3	6.940439	15	3	3	6	15.44201	19	0.868339	7	850.232	8	641.0031
7	3	2	5	3	3	10	6	3	4	11.30408	4	3	3	4	11.22884	25	1.606897	4	1426.796	8	1233.48
8	4	8	5	4	2	20	11	4	5	15.59248	8	3	5	2	15.14107	28	0.272727	7	1004.276	5	525.8934
9	2	8	7	5	5	15	9	4	2	9.724138	10	5	5	2	8.332288	33	1.845141	11	1109.906	7	549.5925
10	4	4	5	6	4	14	5	2	3	17.88715	12	5	4	4	8.670846	32	1.803448	9	568.5517	10	1182.696
11	7	5	8	7	3	20	10	4	2	8.181818	8	4	3	5	9.084639	19	1.398433	9	577.3542	8	1382.445
12	6	5	6	5	8	11	10	4	6	17.58621	8	4	5	5	16.38245	28	1.648589	10	40.40125	6	583.4483
13	6	2	6	5	2	20	7	3	6	15.81818	14	6	5	5	7.504702	20	0.546708	11	713.7931	7	972.79
14	2	3	7	5	8	17	9	6	4	12.28213	12	4	6	5	15.59248	20	1.380564	11	1321.166	6	1118.37
15	7	3	8	4	5	15	5	5	5	11.41693	15	4	5	3	6.827586	23	0.42163	12	313.279	5	1179.31
16	4	5	2	7	6	19	8	3	5	8.595611	6	5	4	5	16.00627	17	0.1	12	951.4608	8	732.4138
17	4	5	2	2	7	19	12	4	3	13.89969	10	5	5	3	16.4953	32	0.892163	5	181.2414	10	1064.201
18	6	7	3	4	8	19	7	2	5	11.75549	9	5	2	3	9.498433	28	0.493103	11	889.8433	10	1114.984
19	7	4	6	5	4	20	4	6	2	6.451411	6	3	4	4	16.34483	32	1.344828	11	964.6646	5	722.2571
20	7	5	4	7	5	12	6	5	6	10.66458	13	5	2	5	11.60502	34	0.671787	5	256.0627	12	867.837
21	6	3	7	6	7	12	11	5	4	6.263323	9	6	3	5	11.75549	30	1.624765	11	969.0658	7	813.6677
22	5	6	6	3	6	15	6	3	6	14.46395	7	3	3	2	7.655172	19	0.111912	5	731.3981	7	1094.671
23	6	2	6	4	2	15	12	5	5	7.54232	7	3	5	4	8.031348	31	0.612226	9	700.5893	11	898.3072
24	2	6	7	7	5	17	6	4	2	11.83072	13	3	2	5	16.79624	19	1.03511	11	124.0251	8	1426.458
25	6	3	7	7	6	11	6	2	3	10.51411	11	5	6	5	13.74922	24	1.815361	10	150.4326	7	955.8621
26	4	5	3	2	4	11	8	3	3	8.407524	7	6	5	3	12.58307	29	0.749216	7	594.9592	6	387.0846
27	3	4	6	7	5	12	7	2	5	11.90596	10	5	2	4	15.36677	29	1.577116	4	625.768	5	1240.251
28	5	7	3	5	3	14	12	3	5	12.35737	15	2	4	3	10.32602	25	0.695611	5	251.6614	6	1291.034
29	8	8	6	4	3	15	9	3	2	16.26959	8	5	3	3	8.633229	30	0.653918	5	361.6928	10	431.0972
30	3	3	4	2	3	20	9	5	5	13.82445	14	3	6	4	11.11599	29	1.136364	8	110.8213	7	1284.263
31	8	7	7	6	4	18	6	4	2	16.0815	6	3	6	3	8.407524	30	0.213166	7	458.5204	6	969.4044
32	7	5	7	3	3	14	11	5	3	12.31975	9	5	2	3	9.122257	26	1.452038	8	590.558	12	1216.552
33	3	3	8	3	7	11	12	4	3	14.76489	4	5	4	5	6.564263	34	0.808777	8	484.9279	10	840.7524
34	5	5	3	5	2	10	9	4	3	17.32288	11	4	5	4	13.33542	16	1.237618	5	766.6082	7	363.3856
35	4	5	8	2	7	19	7	4	4	12.77116	9	5	5	4	6.338558	34	1.06489	9	533.3417	11	1433.229
36	6	8	6	4	7	18	9	4	2	12.99687	7	4	6	5	12.01881	27	1.851097	12	726.9969	11	735.7994
37	5	4	4	3	2	16	10	4	3	8.821317	5	3	6	2	16.11912	32	1.154232	10	418.9091	7	915.2351
38	4	7	3	6	6	18	5	6	2	9.799373	4	5	3	3	14.38871	29	0.266771	6	75.61129	6	1318.119
39	3	8	4	6	6	10	5	3	4	10.17555	16	6	5	3	8.482759	33	0.60627	6	581.7555	8	823.8245
40	4	3	4	3	4	15	4	3	2	10.02508	8	4	2	4	6.413793	33	0.278683	8	176.8401	11	1043.887
41	6	6	2	5	3	13	11	4	6	6.564263	11	5	4	3	14.05016	17	1.446082	6	1338.771	10	1429.843
42	5	2	7	2	5	17	10	5	3	6.15047	14	4	3	5	15.89342	21	0.921944	8	317.6803	8	949.0909
43	4	2	7	3	4	12	10	2	3	16.38245	7	4	3	3	14.72727	31	0.260815	10	559.7492	11	857.6803
44	3	3	7	5	3	18	6	3	4	7.504702	13	3	2	5	10.62696	30	0.320376	8	352.8903	5	1345.204

Trial	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
45	8	6	3	6	6	20	12	5	4	7.316614	13	5	6	3	10.9279	17	1.291223	12	207.6489	11	942.3197
46	7	2	3	4	7	18	10	3	5	7.39185	8	5	4	4	6.376176	32	1.863009	10	793.0157	8	881.3793
47	8	3	8	3	7	10	7	4	3	10.36364	9	5	5	3	17.84953	26	0.201254	10	920.652	8	820.4389
48	6	4	2	3	3	11	5	4	5	8.934169	5	2	6	3	9.047022	27	0.731348	9	898.6458	6	979.5611
49	7	8	8	3	5	13	9	5	4	17.73668	6	4	5	5	6.489028	22	1.654545	7	881.0408	7	613.9185
50	5	5	3	2	7	13	7	3	3	15.78056	10	5	2	5	9.724138	31	0.397806	7	1017.48	9	742.5705
51	3	3	7	4	6	16	6	6	3	11.64263	4	3	5	6	15.93103	32	0.290596	9	1233.141	11	451.4107
52	6	7	5	4	6	10	4	4	5	12.2069	6	6	5	3	10.58934	17	1.35674	6	1189.129	10	1257.179
53	6	6	3	3	5	17	12	5	3	17.43574	10	6	4	4	7.467085	26	1.422257	6	1413.592	6	1324.89
54	4	7	5	7	5	18	9	4	6	15.70533	5	4	5	5	14.95298	35	1.868966	8	907.4483	11	847.5235
55	7	8	3	5	6	12	6	6	3	9.047022	10	4	4	4	15.74295	25	1.553292	6	146.0313	4	566.5204
56	5	6	6	5	5	14	12	5	2	11.49216	5	5	5	2	7.203762	18	0.189342	8	392.5016	10	884.7649
57	8	7	7	6	6	16	5	4	3	13.18495	7	5	5	6	6.601881	27	1.833229	8	410.1066	10	1409.53
58	6	3	5	4	4	12	11	5	3	10.13793	14	2	2	2	16.721	28	1.714107	11	269.2665	10	458.1818
59	5	6	7	7	5	18	10	5	6	14.42633	8	4	3	3	11.07837	24	1.326959	4	859.0345	12	1213.166
60	5	5	6	3	2	16	7	6	5	11.34169	6	2	3	5	17.77429	32	1.374608	7	867.837	6	437.8683
61	5	7	8	5	4	11	9	4	5	14.3511	13	4	5	4	15.81818	26	0.844514	10	1193.53	4	390.4702
62	3	5	4	3	3	17	5	4	5	14.9906	7	4	6	3	6.752351	22	1.940439	9	88.81505	12	803.511
63	8	6	4	7	6	11	10	5	3	16.87147	14	6	3	4	17.54859	28	0.755172	9	1118.708	6	380.3135
64	3	7	6	3	4	14	11	5	3	11.19122	15	3	3	5	10.36364	28	0.379937	5	1281.555	7	1013.417
65	6	7	4	7	3	18	7	5	4	8.369906	10	5	3	5	7.166144	32	0.790909	5	1215.536	9	1152.226
66	8	7	7	3	4	18	4	4	4	12.4326	14	3	3	4	14.42633	21	0.945768	7	1052.69	12	1274.107
67	5	5	6	8	4	14	10	3	5	16.83386	4	4	3	5	9.460815	29	0.975549	11	621.3668	7	1054.044
68	3	6	5	8	8	12	7	6	4	6.30094	7	5	3	6	9.68652	32	1.857053	4	903.047	10	610.5329
69	7	7	4	7	6	13	9	3	5	7.730408	9	5	5	4	15.8558	33	1.368652	6	1440	7	749.3417
70	2	6	7	3	5	14	11	5	2	17.3605	10	3	5	5	9.648903	24	2	6	115.2226	4	1209.781
71	5	7	7	2	6	17	6	3	5	10.77743	7	6	4	6	16.0815	16	0.85047	6	977.8683	5	651.1599
72	5	2	5	6	5	18	6	2	5	12.92163	7	4	4	5	7.429467	16	1.60094	4	449.7179	7	559.7492
73	8	7	2	4	6	11	8	2	4	17.54859	14	4	3	4	14.61442	35	1.642633	12	669.7806	8	850.9091
74	4	5	3	2	5	14	12	3	4	7.956113	15	5	3	6	14.9906	29	1.761755	8	955.8621	4	1074.357
75	6	3	3	7	2	13	10	4	4	14.38871	7	5	4	3	10.25078	18	0.171473	10	1351.975	5	596.9906
76	7	8	8	8	3	18	8	3	6	8.971787	13	4	3	3	10.13793	23	1.106583	11	938.2571	5	769.6552
77	6	5	3	3	3	17	8	5	4	7.278997	15	3	5	3	14.68966	29	0.951724	7	1431.197	4	1412.915
78	3	4	4	6	6	10	12	5	4	8.670846	7	2	5	2	6.940439	19	0.522884	9	599.3605	7	1162.382
79	6	6	5	8	3	20	11	3	2	13.26019	13	3	2	5	12.80878	31	1.916614	5	1162.721	12	685.0157
80	6	8	6	5	4	11	10	2	4	12.50784	11	5	2	5	14.12539	18	0.332288	9	1092.301	8	901.6928
81	5	4	3	3	6	19	10	6	4	16.42006	13	5	3	4	6.188088	23	0.451411	7	916.2508	12	701.9436
82	6	5	6	7	6	16	6	2	3	7.467085	14	5	3	2	11.90596	23	0.588401	10	405.7053	8	681.6301
83	4	6	6	6	4	14	4	4	5	12.73354	6	6	5	5	7.805643	32	0.981505	12	999.8746	6	759.4984
84	7	8	7	8	7	12	11	4	3	15.74295	11	6	4	2	9.310345	26	1.499687	11	1105.505	7	1060.815
85	5	7	8	7	4	14	5	3	5	15.66771	12	4	2	6	10.73981	31	0.409718	6	1197.931	8	1175.925
86	7	4	2	6	4	16	11	4	3	14.16301	15	5	4	3	13.97492	16	0.886207	9	1369.58	11	789.9687
87	2	5	3	3	4	12	5	4	3	7.166144	12	3	2	4	7.617555	21	1.946395	9	722.5956	12	1006.646
88	3	7	3	6	3	14	8	2	5	11.98119	14	4	4	3	12.4326	18	1.440125	8	1285.956	6	989.7179
89	7	5	7	5	2	13	11	6	2	14.80251	13	4	6	3	15.32915	30	1.130408	6	691.7868	7	888.1505
90	4	4	7	3	5	14	10	4	3	7.84326	6	2	3	5	8.557994	33	1.731975	9	1325.567	5	488.652
91	3	2	4	8	5	17	9	2	3	10.58934	11	2	4	6	12.88401	29	1.321003	6	423.3103	7	556.3636
92	4	5	2	4	4	14	8	5	4	6.075235	10	3	4	4	16.57053	22	1.24953	5	1237.542	12	522.5078
93	2	6	6	2	2	15	9	2	5	8.257053	7	2	5	5	8.445141	17	0.248903	8	225.2539	9	1436.614
94	6	7	5	3	7	16	10	6	6	15.44201	12	5	6	3	14.01254	15	1.243574	8	586.1567	7	1338.433

Trial	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
95	2	2	5	5	4	18	12	4	4	11.86834	16	5	2	6	8.257053	21	1.964263	6	718.1944	11	756.1129
96	5	6	3	7	6	13	10	3	3	14.50157	6	4	3	2	6.865204	17	1.309091	7	304.4765	11	444.6395
97	3	6	6	4	4	12	10	4	6	12.95925	6	3	5	4	6.112853	31	1.14232	12	1167.122	12	1003.26
98	6	4	7	6	3	19	5	3	3	16.90909	12	4	3	5	8.896552	25	0.558621	11	749.0031	9	475.1097
99	3	5	4	6	4	18	9	4	2	11.07837	13	4	5	6	16.87147	24	0.39185	12	1307.962	11	766.2696
100	6	6	5	3	8	15	8	3	3	14.05016	10	2	3	3	15.25392	24	0.153605	7	374.8966	4	752.7273
101	7	4	5	5	6	18	12	3	4	10.47649	6	5	4	6	10.70219	31	0.219122	9	1048.288	10	1379.06
102	5	3	5	5	6	11	6	5	6	13.74922	8	4	5	2	13.86207	34	0.231034	7	942.6583	8	1101.442
103	4	3	6	7	4	13	10	5	3	10.10031	14	2	6	3	16.04389	20	1.67837	8	1290.357	11	830.5956
104	4	4	2	7	3	15	10	6	4	8.332288	11	5	3	5	16.94671	21	0.481191	10	229.6552	5	1355.361
105	2	2	3	7	7	18	8	6	3	7.241379	9	5	4	5	9.987461	27	1.124451	11	489.3292	10	471.7241
106	6	4	7	6	6	18	11	4	2	16.75862	11	2	3	6	9.912226	17	0.796865	5	1391.586	10	1189.467
107	5	5	4	5	8	14	12	5	6	14.01254	13	5	2	4	13.22257	25	1.636677	5	198.8464	5	1067.586
108	6	2	7	4	6	18	10	5	4	8.858934	14	6	4	3	6.225705	22	1.749843	5	498.1317	10	1128.527
109	4	6	7	7	4	11	6	6	5	15.10345	16	3	4	3	11.34169	16	1.46395	12	234.0564	10	708.7147
110	4	3	3	6	7	12	8	4	6	13.97492	13	2	6	5	6.15047	27	1.38652	8	339.6865	6	1030.345
111	2	5	5	6	5	17	6	6	4	8.106583	5	6	5	6	11.30408	20	0.362069	7	1074.696	8	1070.972
112	7	8	5	2	4	18	8	3	4	17.84953	7	4	5	6	14.87774	27	0.487147	11	1079.097	7	1419.687
113	5	8	6	6	5	17	7	6	4	12.01881	15	3	3	5	10.66458	34	1.559248	11	238.4577	5	512.3511
114	7	8	4	2	6	16	5	4	3	9.836991	7	2	5	5	11.7931	19	1.737931	7	753.4044	7	1389.216
115	7	5	4	4	6	11	5	5	5	6.601881	11	5	4	6	15.51724	30	1.201881	11	71.21003	5	1267.335
116	3	3	3	7	7	17	9	4	5	13.48589	12	4	5	2	16.23197	31	0.95768	11	1259.549	6	407.3981
117	5	7	5	6	4	15	5	6	5	12.05643	8	5	6	3	9.347962	24	0.969592	5	652.1755	5	373.5423
118	4	6	3	3	5	14	5	2	3	17.24765	13	6	4	6	17.32288	19	0.344201	10	603.7618	5	739.185
119	5	5	4	3	6	20	8	3	4	12.39498	13	4	4	2	11.26646	23	0.647962	7	1422.395	7	441.2539
120	2	7	5	5	5	12	11	5	5	10.9279	12	5	5	5	18	21	1.303135	9	471.7241	8	532.6646
121	6	6	5	4	5	12	6	6	3	6.526646	14	5	2	2	7.015674	30	0.707524	9	1409.191	4	922.0063
122	4	8	3	8	7	15	6	6	6	11.15361	9	5	3	6	10.51411	26	1.821317	12	1096.702	9	1145.455
123	6	4	5	6	3	17	6	6	2	11.94357	8	5	4	5	6.978056	22	1.958307	8	647.7743	11	502.1944
124	5	3	6	4	6	13	11	4	3	13.7116	13	3	5	2	6.037618	26	1.702194	11	837.0282	5	1280.878
125	7	5	3	6	8	16	7	5	3	6.338558	15	4	4	4	11.15361	21	0.475235	6	436.5141	11	1243.636
126	8	4	4	8	3	14	9	3	3	17.92476	9	2	6	4	17.28527	24	0.594357	9	326.4828	6	999.8746
127	5	6	6	2	8	17	10	5	4	13.03448	9	4	4	6	9.53605	24	0.195298	10	62.40752	9	827.21
128	5	6	3	5	7	13	10	6	4	9.122257	13	3	4	5	13.41066	18	1.630721	10	53.60502	9	1023.574
129	5	6	7	2	6	13	6	5	4	13.63636	5	3	3	4	7.54232	16	0.814734	10	216.4514	6	959.2476
130	5	3	7	2	3	11	7	5	6	6.677116	5	5	4	3	8.971787	18	0.659875	8	220.8527	9	536.0502
131	4	6	5	6	7	17	7	5	2	17.77429	13	2	4	4	7.918495	25	1.523511	10	1277.154	5	1111.599
132	7	4	2	7	7	19	8	5	3	10.73981	9	3	3	4	7.128527	33	1.184013	6	995.4734	4	945.7053
133	5	8	3	3	2	13	4	5	5	17.39812	9	6	4	2	17.96238	22	1.791536	8	414.5078	9	637.6176
134	8	6	8	4	5	16	8	6	5	13.37304	5	6	3	3	8.708464	23	1.112539	11	1382.784	8	580.0627
135	6	7	5	4	3	20	8	4	3	16.30721	10	3	3	2	17.58621	30	0.963636	9	203.2476	9	1294.42
136	6	5	4	7	2	18	9	5	6	15.63009	15	3	5	6	8.520376	20	1.011285	11	1387.185	8	600.3762
137	2	5	4	4	7	12	8	4	4	16.94671	11	2	3	4	17.92476	16	1.315047	10	1140.715	10	400.627
138	7	5	6	5	8	19	5	4	6	6.413793	10	3	5	4	17.1348	26	1.225705	9	36	5	779.8119
139	6	4	4	6	4	17	6	5	5	10.96552	15	5	6	6	12.84639	32	1.809404	5	1043.887	11	918.6207
140	6	6	6	6	5	14	10	4	5	6.752351	12	4	4	4	8.595611	34	1.261442	12	49.20376	12	837.3668
141	4	7	7	3	4	19	10	4	2	12.84639	16	4	5	4	14.31348	17	1.660502	11	1294.759	8	505.5799
142	6	2	6	7	7	13	9	4	3	16.60815	14	4	4	2	10.85266	26	1.797492	5	58.00627	10	576.6771
143	5	3	8	8	4	10	8	4	4	16.53292	4	5	6	4	17.17241	19	1.195925	9	854.6332	10	1372.288
144	4	7	6	3	5	15	4	4	4	6.376176	10	3	6	4	13.7116	30	1.428213	4	1206.734	7	485.2665

Trial	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
145	3	5	5	3	6	12	4	3	3	13.22257	10	3	6	2	15.55486	20	0.71348	6	894.2445	11	854.2947
146	3	7	4	4	6	13	6	5	5	18	12	4	6	5	16.26959	28	1.928527	8	1013.078	9	1108.213
147	3	8	8	7	5	14	6	4	3	14.87774	6	4	4	4	13.9373	20	0.665831	4	612.5643	5	817.0533
148	5	2	8	5	3	17	7	4	4	8.520376	6	5	3	3	17.81191	22	1.535423	6	1417.994	10	644.3887
149	5	4	5	7	5	19	5	3	4	16.15674	11	3	3	4	16.64577	19	0.236991	5	282.4702	11	552.9781
150	5	5	2	5	6	16	5	3	6	10.81505	4	3	6	5	9.38558	29	0.183386	6	947.0596	12	1121.755
151	7	6	3	6	3	12	7	3	4	16.79624	6	4	6	5	11.00313	16	1.148276	4	273.6677	8	1368.903
152	8	4	5	5	2	11	4	2	2	9.197492	12	4	2	4	14.53918	16	0.683699	9	788.6144	6	1081.129
153	4	7	8	5	5	12	5	3	4	8.557994	4	3	3	5	9.611285	16	0.242947	12	1435.599	6	718.8715
154	5	2	2	4	4	11	9	3	5	7.090909	11	5	3	5	8.144201	20	0.534796	11	1400.389	8	935.5486
155	5	4	5	4	4	16	8	3	4	13.59875	8	3	3	6	13.67398	22	1.922571	12	1241.944	8	1158.997
156	7	6	4	6	6	19	11	6	5	16.19436	8	5	3	3	15.06583	20	0.254859	10	630.1693	7	932.163
157	7	2	2	4	6	17	5	6	6	15.02821	8	2	3	4	7.880878	24	0.570533	8	454.1191	9	1392.602
158	2	6	4	4	3	20	5	4	4	14.20063	15	4	2	3	15.47962	29	1.267398	7	616.9655	11	492.0376
159	7	7	6	7	4	16	7	5	3	17.1348	7	4	4	3	17.21003	15	1.404389	7	1026.282	11	654.5455
160	2	5	8	3	4	12	6	3	5	13.67398	16	2	3	5	13.37304	23	0.510972	7	445.3166	10	1050.658
161	4	2	5	4	7	15	11	3	3	10.21317	12	3	5	4	16.42006	29	1.005329	11	93.2163	6	1375.674
162	8	4	6	6	2	19	11	3	5	10.55172	8	4	5	5	16.75862	24	0.689655	6	810.6207	7	461.5674
163	3	7	5	4	3	19	5	6	4	8.783699	7	3	2	2	10.2884	30	0.904075	4	1312.364	8	1037.116
164	6	4	3	3	3	16	6	3	4	14.08777	7	3	2	3	16.15674	15	1.505643	7	278.069	5	1098.056
165	3	4	6	6	3	12	8	4	2	14.12539	15	4	5	6	13.18495	21	0.49906	8	506.9342	4	1203.009
166	2	5	6	7	7	16	4	5	3	11.7931	12	3	4	2	12.77116	21	1.541379	5	1057.091	9	542.8213
167	8	6	4	5	7	18	5	2	3	14.72727	9	6	6	4	6.451411	22	1.392476	12	911.8495	9	464.953
168	7	5	3	2	8	10	6	3	3	13.14734	11	6	5	5	10.0627	17	1.755799	7	66.80878	8	569.906
169	6	5	3	3	3	16	5	6	4	10.89028	8	5	5	6	12.39498	32	0.20721	11	608.163	7	874.6082
170	7	4	7	3	4	12	11	2	6	7.429467	5	5	2	4	9.197492	19	0.677743	5	735.7994	6	1226.708
171	3	3	5	6	6	11	4	3	3	9.648903	8	2	5	4	8.783699	27	0.177429	8	1061.492	7	1223.323
172	8	6	7	8	3	11	5	4	4	12.65831	10	6	4	4	16.19436	26	1.517555	7	194.4451	6	1077.743
173	6	4	5	7	7	15	7	4	5	9.987461	12	2	3	4	7.241379	34	0.582445	11	819.4232	6	1331.661
174	7	4	8	5	5	18	7	4	6	13.78683	13	4	4	2	16.53292	25	1.767712	9	480.5266	12	657.931
175	7	6	4	7	4	16	8	5	2	8.445141	6	2	5	5	16.83386	21	1.487774	10	260.4639	8	434.4828
176	4	6	7	6	4	14	4	5	3	6.225705	11	3	5	5	6.30094	25	0.802821	7	97.61755	9	586.8339
177	5	4	4	5	3	19	9	3	4	14.65204	9	4	3	5	17.05956	18	1.082759	6	467.3229	11	1399.373
178	3	6	4	5	3	19	12	2	3	13.44828	6	3	2	3	6.714734	24	1.052978	6	401.3041	5	624.0752
179	7	7	5	2	4	12	8	6	5	11.5674	15	2	5	3	13.48589	26	0.987461	5	638.9718	9	617.3041
180	7	4	4	3	3	19	7	5	5	15.17868	12	4	4	3	7.84326	23	1.207837	10	1365.179	10	1311.348
181	4	7	3	5	5	15	9	5	3	16.57053	5	5	3	5	13.59875	17	0.82069	11	1246.345	10	1138.683
182	4	2	6	4	2	14	4	5	2	13.86207	11	6	3	5	7.090909	17	1.475862	8	1373.981	7	1297.806
183	2	3	5	5	8	14	5	5	6	6.037618	4	3	3	2	10.17555	21	1.058934	8	1395.987	8	1263.95
184	6	8	8	6	8	15	9	3	3	15.89342	14	4	5	4	10.21317	34	1.696238	4	1211.135	5	729.0282
185	4	6	8	2	5	17	6	5	4	16.98433	9	2	6	5	11.41693	23	0.308464	8	709.3918	8	515.7367
186	8	3	4	8	5	13	7	3	5	13.10972	14	3	4	2	15.70533	22	1.547335	10	784.2132	4	1328.276
187	6	5	3	3	5	18	6	3	6	7.354232	9	6	2	3	6.075235	25	1.178056	5	524.5392	9	698.558
188	8	4	4	4	7	18	8	5	4	13.33542	14	3	6	2	9.836991	33	0.225078	7	933.8558	7	745.9561
189	3	7	6	6	7	17	8	2	3	17.62382	7	3	4	6	8.068966	28	1.27931	5	247.2602	11	668.0878
190	2	8	5	5	7	16	10	2	4	9.38558	9	5	3	2	14.76489	27	1.017241	6	80.01254	10	1040.502
191	5	3	2	5	2	16	6	2	6	12.88401	13	3	4	3	11.83072	27	0.296552	7	1114.307	9	671.4734
192	4	7	4	4	4	18	9	6	5	12.09404	12	3	3	2	6.902821	25	1.898746	9	1136.313	11	410.7837
193	7	3	4	8	4	15	9	5	3	9.310345	13	6	5	3	8.934169	35	1.332915	10	841.4295	6	1301.191
194	7	7	6	8	6	20	10	3	6	15.51724	6	5	4	3	16.45768	26	1.297179	4	462.9216	6	393.8558

Trial	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
195	4	8	4	7	2	19	4	4	5	8.068966	10	2	4	5	9.761755	21	1.618809	8	832.627	9	1406.144
196	4	2	3	5	3	17	8	5	5	11.11599	14	2	3	4	12.95925	22	1.934483	10	308.8777	12	725.6426
197	2	6	4	5	5	11	9	5	4	6.865204	12	3	5	2	13.0721	35	0.457367	10	1149.517	10	1362.132
198	6	7	4	4	3	15	10	5	5	8.294671	5	4	2	6	7.99373	16	1.160188	7	322.0815	7	864.4514
199	3	8	5	5	7	18	7	3	6	9.761755	15	5	3	6	12.2069	22	1.362696	9	1329.969	9	986.3323
200	6	4	4	7	3	10	8	5	3	7.768025	10	4	3	5	13.56113	34	0.123824	9	1347.574	10	908.4639
201	5	2	5	7	5	13	9	3	2	9.68652	6	4	2	3	15.40439	24	0.630094	4	172.4389	9	962.6332
202	7	3	3	3	5	15	9	2	5	14.53918	6	6	4	4	15.17868	27	1.469906	5	801.8182	9	1131.912
203	3	2	6	3	7	15	6	2	5	7.69279	15	4	4	4	15.66771	28	1.988088	12	1035.085	7	1335.047
204	7	4	6	7	4	18	9	4	5	6.188088	14	6	4	4	13.78683	16	0.832602	5	744.6019	6	1260.564
205	4	3	3	6	4	17	6	2	5	7.805643	15	5	4	4	10.81505	18	1.743887	9	185.6426	10	1423.072
206	8	4	6	2	3	18	7	6	3	15.36677	7	3	3	5	12.54545	30	1.219749	11	973.4671	11	420.9404
207	4	5	6	7	6	17	11	5	6	8.031348	13	5	4	6	13.29781	30	0.373981	6	757.8056	8	627.4608
208	3	3	6	2	2	15	9	3	2	15.32915	6	2	4	6	9.23511	17	0.105956	6	291.2727	8	695.1724
209	8	4	5	3	5	14	10	2	5	8.896552	15	6	6	5	12.62069	27	0.463323	4	84.41379	7	563.1348
210	8	6	7	4	4	17	6	3	5	6.902821	5	4	2	4	13.63636	32	0.52884	11	1145.116	6	1020.188
211	6	8	8	3	6	15	12	2	5	7.918495	5	2	2	5	12.16928	35	1.273354	8	546.5455	11	607.1473
212	6	5	2	4	7	14	11	5	3	12.58307	7	5	2	4	17.43574	23	1.910658	10	674.1818	8	664.7022
213	2	4	3	8	4	10	6	4	5	10.32602	5	4	6	4	12.69592	17	1.684326	10	300.0752	4	966.0188
214	7	7	7	3	5	19	9	6	5	7.128527	15	5	3	3	16.90909	31	0.856426	9	815.0219	6	938.9342
215	7	6	7	4	8	12	7	3	2	8.708464	8	4	2	3	8.106583	25	1.690282	11	797.4169	5	1155.611
216	3	6	4	6	2	11	8	5	4	9.498433	14	6	4	3	9.874608	20	0.784953	5	106.4201	11	1186.082
217	6	7	4	8	2	13	5	6	5	11.71787	11	5	4	2	11.68025	27	0.576489	10	634.5705	11	928.7774
218	7	3	7	5	5	19	8	4	2	15.29154	12	6	3	4	15.02821	20	1.982132	11	1123.11	5	448.0251
219	5	2	5	7	7	13	11	5	3	9.460815	11	4	6	6	11.37931	33	1.166144	7	1250.746	7	976.1755
220	2	7	5	7	8	16	4	5	5	9.573668	9	5	3	2	8.294671	31	1.088715	11	1039.486	5	495.4232
221	6	3	4	7	6	10	7	4	4	11.37931	13	2	4	4	6	30	1.434169	10	929.4545	12	454.7962
222	8	4	4	4	3	17	8	4	4	16.45768	4	3	5	5	15.10345	35	1.255486	6	740.2006	12	1402.759
223	5	3	3	8	8	11	5	3	3	16.4953	16	3	3	5	13.52351	29	0.725392	5	696.1881	10	1250.408
224	7	4	5	6	3	16	6	5	4	10.43887	5	6	3	6	15.63009	33	1.880878	7	1070.295	4	1125.141
225	3	5	3	3	7	13	9	3	5	6.489028	6	3	3	4	11.49216	19	0.642006	7	330.884	8	366.7712
226	7	3	3	3	5	16	4	5	2	6.978056	11	6	5	3	11.86834	21	1.904702	8	1334.37	5	590.2194
227	5	7	3	7	7	19	11	5	3	17.02194	14	3	5	3	13.82445	25	1.231661	5	388.1003	7	498.8088
228	3	6	7	2	3	16	9	3	4	10.85266	11	3	4	3	14.91536	33	1.410345	6	1171.524	10	1358.746
229	4	3	2	3	5	14	9	4	4	9.949843	12	3	4	3	12.50784	34	1.511599	6	335.2853	5	1010.031
230	5	3	6	5	2	13	10	4	6	16.00627	5	3	2	3	7.730408	31	0.284639	5	1360.777	7	1199.624
231	6	6	5	4	2	11	11	4	3	6.827586	8	3	6	4	14.5768	24	0.147649	5	1087.9	4	871.2226
232	3	3	4	7	7	17	6	3	5	9.159875	5	4	3	3	13.26019	33	0.624138	9	154.8339	9	705.3292
233	3	4	8	2	8	16	5	3	4	15.96865	13	5	4	4	8.821317	22	1.666458	10	168.0376	8	546.2069
234	7	5	2	5	3	13	5	3	4	9.912226	5	4	4	5	8.369906	18	0.385893	11	141.6301	11	1084.514
235	7	4	3	4	6	15	9	6	2	12.54545	5	3	5	5	11.71787	21	0.505016	11	704.9906	6	1314.734
236	4	7	5	7	7	14	11	2	2	12.16928	5	3	6	5	9.799373	28	1.1721	10	163.6364	5	861.0658
237	7	3	7	7	6	13	10	6	2	11.45455	6	3	4	6	12.47022	30	1.594984	8	44.80251	9	1148.84
238	5	2	4	8	7	15	11	5	3	15.25392	10	6	4	4	17.62382	26	1.076803	7	762.2069	9	1351.975
239	4	7	7	4	5	19	11	4	6	17.28527	7	2	3	6	13.89969	23	0.63605	6	128.4263	6	1087.9
240	4	5	7	2	6	11	6	2	5	7.015674	15	3	4	6	11.64263	32	1.874922	8	502.5329	11	691.7868
241	6	7	5	4	8	13	5	5	5	16.11912	5	4	4	4	12.24451	34	1.481818	5	264.8652	8	1033.73
242	7	6	2	6	7	17	12	5	5	13.41066	4	3	5	5	9.272727	25	1.779624	11	1219.937	6	404.0125
243	5	6	4	3	5	19	7	2	4	9.084639	16	3	5	5	13.44828	18	0.862382	10	555.348	5	1321.505
244	5	7	2	8	3	11	5	2	3	10.62696	9	2	5	5	10.89028	32	1.070846	7	537.7429	8	793.3542

Trial	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
245	4	6	6	6	3	15	8	3	5	8.746082	12	3	2	4	16.60815	19	0.719436	4	476.1254	6	468.3386
246	4	8	2	7	7	13	8	3	6	13.9373	14	4	2	2	13.14734	23	1.338871	7	572.953	8	424.326
247	5	5	2	7	7	13	11	4	3	7.99373	6	4	4	2	12.92163	35	0.469279	7	528.9404	6	508.9655
248	7	5	3	5	7	15	6	4	5	9.53605	16	4	6	5	7.316614	15	0.129781	10	1180.326	11	529.279
249	7	8	4	4	7	20	8	4	3	12.47022	11	2	3	6	8.746082	18	1.029154	6	1228.74	10	360
250	2	8	5	6	8	11	10	5	4	10.0627	6	6	5	4	14.23824	28	0.165517	10	925.0533	5	1047.273
251	2	4	2	6	6	11	12	5	4	14.68966	4	3	4	3	17.66144	19	1.49373	5	1101.103	12	993.1034
252	5	3	7	4	7	16	6	4	4	15.14107	10	6	2	3	7.053292	33	0.939812	4	1158.32	6	806.8966
253	3	8	3	6	2	18	10	6	4	13.0721	9	3	4	2	10.02508	28	0.880251	11	678.5831	5	1287.649
254	4	7	3	5	3	20	7	3	3	7.053292	6	4	3	5	13.03448	28	1.041066	6	564.1505	11	800.1254
255	3	4	5	6	7	12	4	4	3	10.2884	5	6	3	4	14.08777	18	0.915987	9	427.7116	4	1172.539
256	5	5	4	6	8	14	8	3	3	11.60502	7	4	3	6	7.69279	22	0.898119	6	1202.332	4	397.2414
257	4	3	7	3	8	16	10	5	5	14.27586	12	2	3	4	9.573668	24	1.457994	11	823.8245	9	905.0784
258	6	3	3	8	2	11	8	4	5	17.81191	9	4	5	4	10.47649	32	1.023197	9	986.6708	9	1247.022
259	3	7	6	8	7	17	12	4	5	11.26646	5	4	2	2	12.13166	19	0.433542	9	991.0721	9	427.7116
260	2	3	8	4	5	14	8	3	3	10.40125	14	5	5	2	17.69906	34	0.415674	5	357.2915	6	911.8495
261	5	6	2	5	8	12	8	2	5	11.22884	12	3	6	2	6.677116	26	1.672414	8	1021.881	7	573.2915
262	6	4	7	7	4	11	11	3	5	8.633229	10	4	4	3	10.43887	17	0.141693	10	348.489	11	1416.301
263	4	5	6	4	8	10	7	6	3	12.13166	14	6	5	6	11.04075	25	1.118495	7	370.4953	7	1206.395
264	3	3	2	6	4	19	9	2	4	11.52978	11	3	5	3	9.159875	33	0.618182	8	132.8276	9	1307.962
265	3	4	4	8	6	10	7	2	4	8.482759	5	6	4	4	10.40125	34	1.350784	9	779.8119	10	833.9812
266	3	2	7	7	3	18	8	4	6	7.655172	10	4	5	3	7.956113	25	1.720063	8	643.373	6	1091.285
267	7	5	4	3	3	19	5	5	2	9.009404	10	5	4	3	7.278997	28	0.999373	5	295.674	4	1236.865
268	4	7	7	7	4	13	5	5	3	9.23511	8	5	4	5	14.65204	34	1.583072	12	665.3793	11	674.8589
269	6	6	6	5	3	10	5	5	2	17.47335	9	4	2	5	11.94357	19	0.701567	9	190.0439	12	894.9216
270	4	3	5	7	5	15	11	6	4	6.789969	7	2	4	3	12.35737	24	0.600313	6	1343.172	4	630.8464
271	6	7	8	3	6	17	11	4	4	14.61442	7	3	4	3	15.78056	26	1.976176	6	960.2633	5	1016.803
272	7	6	2	3	6	16	5	2	4	6	10	5	5	4	14.84013	16	1.189969	10	511.3354	9	688.4013
273	4	4	3	2	6	13	5	5	2	17.05956	10	5	2	4	9.423197	26	1.612853	8	515.7367	4	1192.853
274	3	6	4	5	6	11	10	3	5	14.5768	13	4	4	5	12.73354	18	1.970219	5	242.8589	10	1169.154
275	3	3	7	7	6	18	9	2	5	15.40439	15	6	3	3	9.949843	23	1.70815	5	1263.95	8	925.3918
276	4	3	5	5	5	16	11	2	3	16.34483	16	2	5	5	12.09404	16	1.89279	11	119.6238	5	383.6991
277	7	7	7	5	3	14	11	2	6	15.55486	11	5	5	4	14.16301	28	1.57116	10	1030.683	9	1219.937
278	3	4	6	5	5	18	10	2	5	7.579937	14	5	5	4	17.39812	30	1.589028	5	1268.351	11	539.4357
279	2	6	3	6	5	17	10	3	3	8.144201	11	5	2	3	6.789969	29	0.135737	9	159.2351	7	844.1379
280	2	5	7	5	2	12	6	4	5	16.721	8	4	3	5	14.80251	19	1.827273	8	493.7304	9	603.7618
281	4	7	5	6	2	16	9	4	2	11.04075	12	6	6	3	17.24765	21	1.213793	8	1299.16	5	1348.589
282	3	4	6	8	7	13	11	3	3	17.66144	9	3	5	4	17.02194	18	0.427586	8	775.4107	10	593.605
283	2	4	8	5	4	16	10	3	3	16.64577	8	5	6	6	12.28213	27	1.529467	10	1184.727	4	417.5549
284	3	7	2	2	4	17	11	2	4	9.347962	6	4	4	4	17.3605	23	0.552665	9	383.6991	5	1230.094
285	4	4	8	2	5	15	7	4	6	16.23197	9	5	3	4	14.20063	17	0.445455	10	876.6395	11	1057.429
286	3	3	8	4	3	19	7	3	2	13.56113	8	5	5	2	11.98119	18	0.516928	11	660.9781	7	1253.793
287	5	4	3	6	4	19	10	3	4	12.80878	6	3	6	3	14.46395	24	1.994044	4	1404.79	5	370.1567
288	5	5	3	8	4	20	8	4	4	6.639498	13	4	3	3	8.858934	20	0.368025	9	1224.339	10	1142.069
289	4	5	5	5	2	15	7	4	5	17.96238	15	3	6	5	9.009404	16	0.338245	6	982.2696	12	952.4765
290	2	4	7	3	7	20	7	4	4	9.611285	11	3	6	5	16.98433	21	1.773668	6	137.2288	11	715.4859
291	6	5	2	6	4	19	11	5	6	11.00313	15	5	3	3	11.45455	33	1.726019	5	1272.752	6	982.9467
292	5	3	6	4	6	16	4	6	4	17.51097	8	4	6	3	10.77743	20	0.838558	4	863.4357	4	1385.831
293	6	4	7	3	7	14	7	4	3	15.93103	7	6	4	4	16.30721	27	0.910031	4	396.9028	5	1196.238
294	3	6	7	7	3	18	10	5	6	17.17241	15	3	4	4	8.219436	31	0.773041	10	520.1379	10	1304.577

Trial	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
295	6	7	5	4	7	12	7	3	2	15.8558	12	4	3	2	12.65831	15	0.540752	12	550.9467	10	1104.828
296	7	4	5	8	6	17	9	5	4	12.24451	5	2	4	3	10.55172	31	1.100627	12	440.9154	9	647.7743
297	8	3	7	6	6	13	7	3	4	10.25078	9	2	2	4	12.31975	15	1.285266	6	845.8307	9	634.232
298	4	7	5	3	8	11	8	3	2	8.219436	9	5	6	5	10.96552	15	1.839185	12	432.1129	9	1365.517
299	7	6	4	7	7	14	5	5	4	13.52351	4	5	3	5	14.50157	27	0.439498	8	1255.147	10	773.0408
300	8	5	6	3	3	15	7	6	6	6.714734	14	2	2	3	7.39185	20	0.767085	7	885.442	8	1277.492
301	8	7	6	6	7	12	6	3	3	12.62069	14	4	6	6	15.96865	22	0.737304	9	1316.765	9	1395.987
302	7	3	6	5	7	11	12	4	4	12.69592	12	3	3	5	17.73668	33	1.565204	6	872.2382	11	776.4263
303	2	2	6	3	5	12	9	3	5	7.203762	16	6	3	5	7.579937	20	0.933856	6	682.9843	5	678.2445
304	5	5	8	7	4	10	11	3	4	9.272727	8	6	5	6	6.526646	23	1.78558	4	828.2257	8	1135.298
305	7	5	4	5	4	19	5	4	2	14.23824	15	5	5	3	17.88715	31	0.874295	5	286.8715	6	762.884
306	3	7	7	5	8	15	6	5	6	7.880878	11	4	3	4	15.29154	29	0.350157	9	806.2194	11	996.489
307	5	6	2	4	5	12	11	4	6	14.95298	9	3	4	3	17.51097	22	0.74326	11	1083.498	9	1165.768
308	4	2	6	7	5	19	8	3	4	14.31348	16	4	5	3	8.181818	27	0.403762	5	366.094	6	376.9279
309	7	3	6	4	7	17	9	3	5	17.09718	7	2	3	3	17.47335	23	1.094671	10	687.3856	10	1440
310	3	6	3	6	3	15	12	4	5	17.69906	16	5	5	5	6.263323	31	1.886834	7	656.5768	5	810.2821
311	3	2	5	4	7	12	7	5	2	15.2163	5	5	4	3	7.354232	20	0.564577	7	1008.677	7	712.1003
312	3	3	3	6	4	19	7	6	3	16.04389	8	4	5	4	13.10972	34	0.117868	7	1303.561	9	1270.721
313	4	8	5	8	6	12	8	5	4	15.47962	13	2	5	3	10.10031	15	0.302508	8	1378.382	8	783.1975
314	8	3	7	4	7	16	11	3	5	10.70219	13	5	2	2	14.27586	29	0.31442	8	1065.893	9	786.5831
315	6	6	3	4	8	19	9	3	5	17.21003	16	4	3	6	17.09718	17	0.9279	6	771.0094	7	891.5361
316	8	2	8	7	8	20	7	3	4	6.112853	10	4	5	4	11.5674	25	0.993417	9	1153.918	8	877.9937
317	5	4	6	2	2	10	4	2	6	16.68339	16	6	5	3	12.99687	33	1.416301	9	1131.912	9	414.1693
318	5	5	4	4	4	13	10	5	5	14.84013	15	5	3	3	11.52978	31	0.778997	12	212.0502	6	796.7398
319	3	8	3	2	5	13	10	5	3	15.06583	4	4	5	3	14.3511	16	0.356113	6	102.0188	5	519.1223
320	3	3	7	5	6	11	4	5	6	13.29781	11	5	4	5	11.19122	30	1.952351	7	1127.511	6	478.4953

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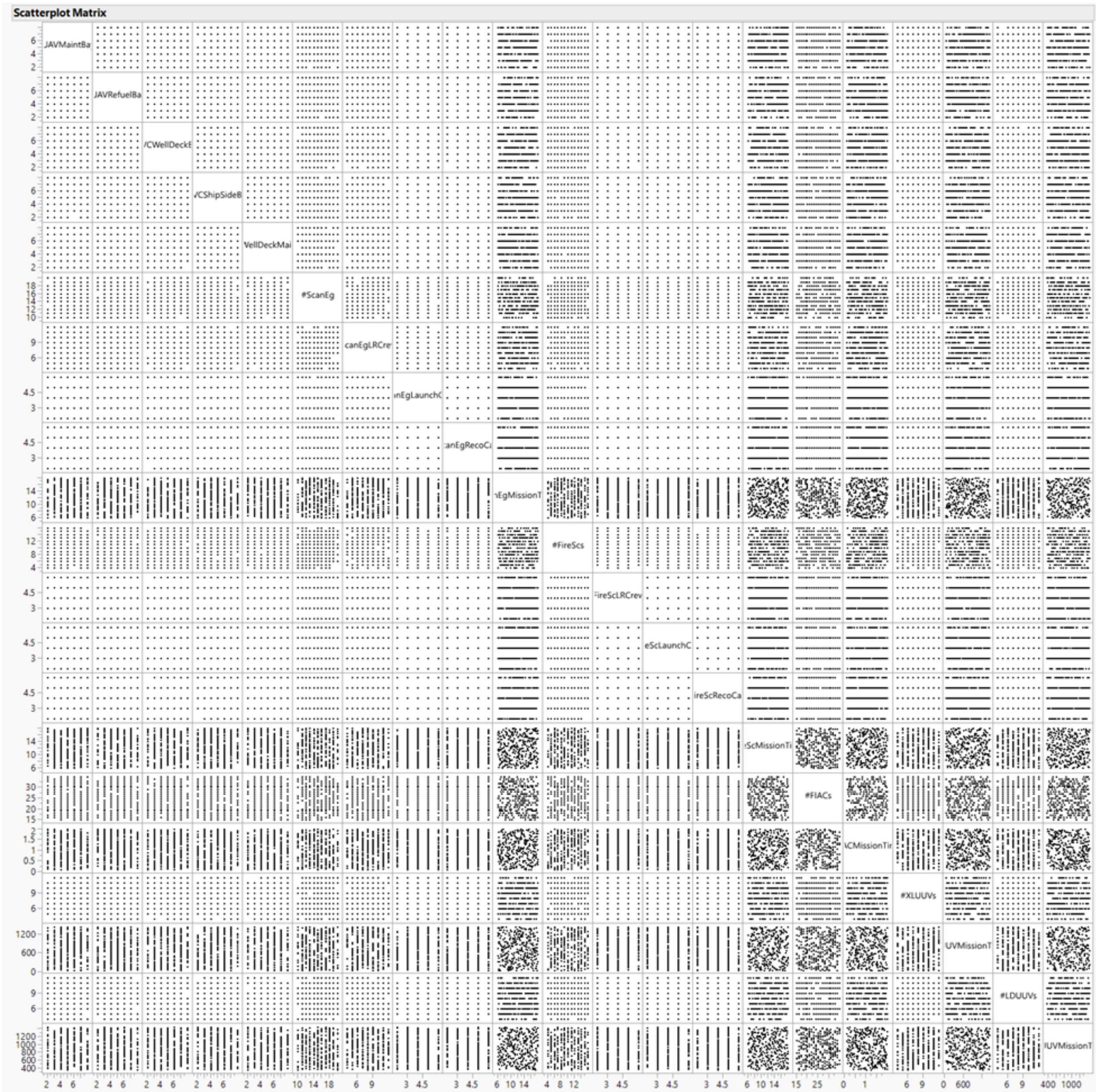
APPENDIX F. DOE SCATTERPLOT MATRIX



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APPENDIX G. DOE CORRELATION MATRIX

	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
#UAV MaintBays	1	0.0413	0.001	0.0167	-0.0187	0.065	-0.009	0.0501	-0.0272	0.0157	-0.0085	0.073	-0.0172	-0.02	0.0383	0.0188	-0.0084	0.0456	0.0369	-0.012	0.0389
#UAV RefuelBays	0.0413	1	-0.0305	-0.0128	0.0167	0.015	-0.0254	0.0415	0.0243	0.087	-0.0586	0.0057	0	-0.0014	0.0427	-0.0376	0.0038	0.0015	0.0124	-0.0247	-0.0596
#UVC WellDeck Bays	0.001	-0.0305	1	-0.0551	0.0167	-0.0108	-0.0292	-0.0014	-0.043	0.0631	-0.0145	0.0229	-0.0358	0.0788	-0.0008	0.0136	0.0358	0.0187	0.0268	-0.0157	-0.0108
#UVC ShipSide Bays	0.0167	-0.0128	-0.0551	1	0.0354	-0.0331	0.0748	0.0272	0	-0.0268	0.0281	0.0229	0.0057	0.0057	-0.0002	0.05	0.0261	-0.0022	0.0756	0.0299	-0.0341
#UVC WellDeck MaintBays	-0.0187	0.0167	0.0167	0.0354	1	-0.0806	0.0419	-0.0057	-0.0286	-0.0226	-0.005	0.0659	-0.0115	0.0358	-0.0025	0.037	0.0789	0.0419	-0.0347	-0.0344	-0.0807
#ScanEg	0.065	0.015	-0.0108	-0.0331	-0.0806	1	0.0544	0.0446	0.0219	0.0134	0.0616	-0.0648	-0.0455	-0.0219	-0.0028	0.0328	-0.0138	-0.0087	0.0339	0.0201	-0.021
#ScanEg LRCrews	-0.009	-0.0254	-0.0292	0.0748	0.0419	0.0544	1	-0.0207	0.0239	0.0422	0.0289	-0.0598	-0.0098	-0.0272	0.0509	0.0041	0.0339	-0.0307	0.0063	-0.021	-0.0278
ScanEg LaunchCap	0.0501	0.0415	-0.0014	0.0272	-0.0057	0.0446	-0.0207	1	-0.0604	-0.0229	-0.0386	-0.0187	0.0438	-0.0542	-0.0067	0.0683	0.0098	0.0555	0.0873	-0.0131	0.0179
ScanEg RecoCap	-0.0272	0.0243	-0.043	0	-0.0286	0.0219	0.0239	-0.0604	1	-0.0565	0.0714	0.0021	-0.0563	-0.05	-0.0496	0.0256	0.0103	-0.0207	0.0718	0.0794	0.0205
ScanEg Mission Time	0.0157	0.087	0.0631	-0.0268	-0.0226	0.0134	0.0422	-0.0229	-0.0565	1	-0.0028	-0.0357	0.0866	0.0027	0.056	-0.0651	0.0389	-0.0323	-0.012	0.0334	-0.029
#FireScs	-0.0085	-0.0586	-0.0145	0.0281	-0.005	0.0616	0.0289	-0.0386	0.0714	-0.0028	1	0.0233	0.0131	-0.0401	0.0319	-0.0123	0.1057	0.0046	-0.0004	0.0152	-0.0087
#FireSc LR Crews	0.073	0.0057	0.0229	0.0229	0.0659	-0.0648	-0.0598	-0.0187	0.0021	-0.0357	0.0233	1	-0.0292	-0.0062	-0.0081	0.015	0.0745	-0.0054	0.0471	-0.086	0.0242
FireSc LaunchCap	-0.0172	0	-0.0358	0.0057	-0.0115	-0.0455	-0.0098	0.0438	-0.0563	0.0866	0.0131	-0.0292	1	0.025	0.0491	0.0097	0.0412	0.0533	-0.0043	-0.0751	-0.0006
FireSc RecoCap	-0.02	-0.0014	0.0788	0.0057	0.0358	-0.0219	-0.0272	-0.0542	-0.05	0.0027	-0.0401	-0.0062	0.025	1	-0.0065	-0.0388	0.0864	0.0228	-0.0124	0.049	0.0283
FireSc Mission Time	0.0383	0.0427	-0.0008	-0.0002	-0.0025	-0.0028	0.0509	-0.0067	-0.0496	0.056	0.0319	-0.0081	0.0491	-0.0065	1	-0.0278	0.011	-0.0283	-0.0077	-0.0442	-0.0378
#FIACs	0.0188	-0.0376	0.0136	0.05	0.037	0.0328	0.0041	0.0683	0.0256	-0.0651	-0.0123	0.015	0.0097	-0.0388	-0.0278	1	0.0285	-0.0311	0.0539	-0.0131	-0.0086
FIAC Mission Time	-0.0084	0.0038	0.0358	0.0261	0.0789	-0.0138	0.0339	0.0098	0.0103	0.0389	0.1057	0.0745	0.0412	0.0864	0.011	0.0285	1	-0.0071	0.0035	0.0066	-0.0799

	#UAV MaintBays	#UAV RefuelBays	#UVC WellDeck Bays	#UVC ShipSide Bays	#UVC WellDeck MaintBays	#ScanEg	#ScanEg LRCrews	ScanEg LaunchCap	ScanEg RecoCap	ScanEg Mission Time	#FireScs	#FireSc LRCrews	FireSc LaunchCap	FireSc RecoCap	FireSc Mission Time	#FIACs	FIAC Mission Time	#XLUUVs	XLUUV Mission Time	#LDUUVs	LDUUV Mission Time
#XLUUVs	0.0456	0.0015	0.0187	-0.0022	0.0419	-0.0087	-0.0307	0.0555	-0.0207	-0.0323	0.0046	-0.0054	0.0533	0.0228	-0.0283	-0.0311	-0.0071	1	0.0084	0.0142	0.0218
XLUUV Mission Time	0.0369	0.0124	0.0268	0.0756	-0.0347	0.0339	0.0063	0.0873	0.0718	-0.012	-0.0004	0.0471	-0.0043	-0.0124	-0.0077	0.0539	0.0035	0.0084	1	-0.013	-0.0388
#LDUUVs	-0.012	-0.0247	-0.0157	0.0299	-0.0344	0.0201	-0.021	-0.0131	0.0794	0.0334	0.0152	-0.086	-0.0751	0.049	-0.0442	-0.0131	0.0066	0.0142	-0.013	1	-0.013
LDUUV Mission Time	0.0389	-0.0596	-0.0108	-0.0341	-0.0807	-0.021	-0.0278	0.0179	0.0205	-0.029	-0.0087	0.0242	-0.0006	0.0283	-0.0378	-0.0086	-0.0799	0.0218	-0.0388	-0.013	1

APPENDIX H. MEAN AO PER TRIAL

Trial	Ao, ScanEagle	Ao, Fire Scout	Ao, XLUUV	Ao, LDUUV	Ao, MUSV	Ao, LUSV	Ao, FIAC
1	0.812	0.863	0.915	0.937	0.876	0.656	0.231
2	0.796	0.846	0.917	0.843	0.876	0.656	0.010
3	0.740	0.738	0.863	0.878	0.876	0.656	0.114
4	0.835	0.823	0.871	0.750	0.876	0.656	0.015
5	0.782	0.761	0.902	0.929	0.876	0.656	0.184
6	0.745	0.847	0.885	0.891	0.876	0.656	0.198
7	0.809	0.820	0.875	0.877	0.876	0.656	0.057
8	0.843	0.851	0.825	0.766	0.876	0.656	0.006
9	0.788	0.776	0.900	0.866	0.876	0.656	0.284
10	0.860	0.785	0.916	0.927	0.876	0.656	0.198
11	0.765	0.793	0.917	0.925	0.876	0.656	0.138
12	0.861	0.861	0.788	0.875	0.876	0.656	0.283
13	0.837	0.761	0.877	0.855	0.876	0.656	0.016
14	0.804	0.844	0.919	0.934	0.876	0.656	0.295
15	0.811	0.751	0.964	0.934	0.876	0.656	0.176
16	0.767	0.858	0.892	0.898	0.876	0.656	0.015
17	0.828	0.861	0.759	0.932	0.876	0.656	0.142
18	0.801	0.794	0.884	0.932	0.876	0.656	0.110
19	0.728	0.861	0.893	0.895	0.876	0.656	0.282
20	0.807	0.811	0.873	0.907	0.876	0.656	0.126
21	0.727	0.823	0.892	0.908	0.876	0.656	0.263
22	0.829	0.769	0.904	0.934	0.876	0.656	0.043
23	0.748	0.769	0.821	0.757	0.876	0.656	0.008
24	0.804	0.854	0.921	0.942	0.876	0.656	0.201
25	0.799	0.838	0.932	0.927	0.876	0.656	0.307
26	0.763	0.829	0.869	0.810	0.876	0.656	0.109
27	0.807	0.852	0.920	0.929	0.876	0.656	0.219
28	0.810	0.790	0.869	0.933	0.876	0.656	0.111
29	0.848	0.782	0.841	0.742	0.876	0.656	0.032
30	0.826	0.809	0.673	0.935	0.876	0.656	0.235
31	0.848	0.782	0.888	0.927	0.876	0.656	0.065
32	0.815	0.784	0.885	0.868	0.876	0.656	0.042
33	0.835	0.748	0.881	0.910	0.876	0.656	0.314
34	0.859	0.835	0.809	0.620	0.876	0.656	0.030
35	0.818	0.739	0.833	0.944	0.876	0.656	0.392
36	0.819	0.826	0.912	0.899	0.876	0.656	0.283
37	0.778	0.860	0.848	0.883	0.876	0.656	0.071
38	0.795	0.845	0.876	0.939	0.876	0.656	0.061
39	0.800	0.781	0.916	0.908	0.876	0.656	0.170

Trial	Ao, ScanEagle	Ao, Fire Scout	Ao, XLUUV	Ao, LDUUV	Ao, MUSV	Ao, LUSV	Ao, FIAC
40	0.791	0.724	0.935	0.925	0.876	0.656	0.050
41	0.737	0.842	0.893	0.910	0.876	0.656	0.102
42	0.712	0.851	0.811	0.925	0.876	0.656	0.168
43	0.847	0.846	0.917	0.895	0.876	0.656	0.044
44	0.746	0.802	0.915	0.935	0.876	0.656	0.097
45	0.753	0.819	0.950	0.922	0.876	0.656	0.202
46	0.733	0.731	0.883	0.917	0.876	0.656	0.297
47	0.801	0.866	0.890	0.908	0.876	0.656	0.092
48	0.781	0.796	0.869	0.901	0.876	0.656	0.041
49	0.857	0.749	0.882	0.879	0.876	0.656	0.207
50	0.846	0.792	0.874	0.896	0.876	0.656	0.092
51	0.813	0.855	0.907	0.849	0.876	0.656	0.086
52	0.814	0.818	0.905	0.931	0.876	0.656	0.222
53	0.857	0.767	0.919	0.929	0.876	0.656	0.118
54	0.845	0.847	0.877	0.899	0.876	0.656	0.209
55	0.784	0.856	0.929	0.873	0.876	0.656	0.223
56	0.810	0.765	0.863	0.908	0.876	0.656	0.066
57	0.821	0.750	0.868	0.940	0.876	0.656	0.248
58	0.801	0.852	0.943	0.829	0.876	0.656	0.125
59	0.832	0.822	0.883	0.924	0.876	0.656	0.152
60	0.812	0.869	0.820	0.709	0.876	0.656	0.029
61	0.831	0.857	0.903	0.818	0.876	0.656	0.193
62	0.837	0.756	0.798	0.855	0.876	0.656	0.079
63	0.855	0.865	0.896	0.827	0.876	0.656	0.197
64	0.811	0.806	0.905	0.927	0.876	0.656	0.103
65	0.771	0.754	0.874	0.894	0.876	0.656	0.047
66	0.812	0.836	0.873	0.895	0.876	0.656	0.046
67	0.852	0.803	0.952	0.929	0.876	0.656	0.249
68	0.729	0.804	0.887	0.886	0.876	0.656	0.323
69	0.750	0.857	0.921	0.901	0.876	0.656	0.375
70	0.850	0.789	0.900	0.932	0.876	0.656	0.294
71	0.802	0.859	0.875	0.893	0.876	0.656	0.203
72	0.804	0.760	0.876	0.870	0.876	0.656	0.246
73	0.860	0.842	0.945	0.912	0.876	0.656	0.261
74	0.753	0.845	0.858	0.932	0.876	0.656	0.143
75	0.833	0.812	0.881	0.805	0.876	0.656	0.009
76	0.774	0.804	0.880	0.878	0.876	0.656	0.058
77	0.752	0.841	0.918	0.937	0.876	0.656	0.175
78	0.775	0.749	0.927	0.932	0.876	0.656	0.151
79	0.817	0.819	0.882	0.796	0.876	0.656	0.047
80	0.816	0.842	0.901	0.914	0.876	0.656	0.066
81	0.850	0.727	0.892	0.893	0.876	0.656	0.080

Trial	Ao, ScanEagle	Ao, Fire Scout	Ao, XLUUV	Ao, LDUUV	Ao, MUSV	Ao, LUSV	Ao, FIAC
82	0.738	0.819	0.890	0.899	0.876	0.656	0.215
83	0.816	0.770	0.898	0.896	0.876	0.656	0.223
84	0.845	0.798	0.903	0.936	0.876	0.656	0.244
85	0.844	0.805	0.902	0.923	0.876	0.656	0.074
86	0.831	0.841	0.912	0.879	0.876	0.656	0.075
87	0.746	0.743	0.887	0.897	0.876	0.656	0.081
88	0.800	0.823	0.906	0.912	0.876	0.656	0.096
89	0.837	0.853	0.873	0.853	0.876	0.656	0.035
90	0.759	0.783	0.914	0.860	0.876	0.656	0.365
91	0.789	0.823	0.889	0.867	0.876	0.656	0.301
92	0.722	0.862	0.868	0.802	0.876	0.656	0.045
93	0.747	0.775	0.791	0.919	0.876	0.656	0.048
94	0.842	0.841	0.912	0.940	0.876	0.656	0.265
95	0.805	0.749	0.885	0.861	0.876	0.656	0.116
96	0.833	0.756	0.927	0.843	0.876	0.656	0.161
97	0.819	0.734	0.901	0.913	0.876	0.656	0.110
98	0.849	0.783	0.876	0.770	0.876	0.656	0.029
99	0.809	0.863	0.909	0.876	0.876	0.656	0.059
100	0.825	0.851	0.880	0.902	0.876	0.656	0.054
101	0.799	0.818	0.901	0.943	0.876	0.656	0.066
102	0.826	0.840	0.894	0.931	0.876	0.656	0.063
103	0.799	0.848	0.906	0.887	0.876	0.656	0.163
104	0.768	0.864	0.955	0.941	0.876	0.656	0.073
105	0.743	0.804	0.917	0.858	0.876	0.656	0.244
106	0.853	0.788	0.914	0.928	0.876	0.656	0.140
107	0.829	0.823	0.867	0.934	0.876	0.656	0.293
108	0.775	0.733	0.908	0.925	0.876	0.656	0.213
109	0.839	0.811	0.952	0.886	0.876	0.656	0.166
110	0.828	0.692	0.944	0.934	0.876	0.656	0.216
111	0.758	0.819	0.900	0.924	0.876	0.656	0.073
112	0.857	0.849	0.849	0.939	0.876	0.656	0.133
113	0.814	0.807	0.957	0.861	0.876	0.656	0.446
114	0.796	0.824	0.857	0.942	0.876	0.656	0.296
115	0.738	0.854	0.863	0.937	0.876	0.656	0.344
116	0.822	0.857	0.914	0.833	0.876	0.656	0.215
117	0.813	0.799	0.912	0.815	0.876	0.656	0.158
118	0.856	0.867	0.938	0.899	0.876	0.656	0.077
119	0.810	0.818	0.920	0.849	0.876	0.656	0.183
120	0.803	0.865	0.886	0.852	0.876	0.656	0.156
121	0.736	0.740	0.921	0.919	0.876	0.656	0.228
122	0.810	0.816	0.902	0.930	0.876	0.656	0.221
123	0.813	0.757	0.879	0.759	0.876	0.656	0.056

Trial	Ao, ScanEagle	Ao, Fire Scout	Ao, XLUUV	Ao, LDUUV	Ao, MUSV	Ao, LUSV	Ao, FIAC
124	0.826	0.712	0.880	0.934	0.876	0.656	0.209
125	0.731	0.817	0.892	0.937	0.876	0.656	0.109
126	0.861	0.867	0.959	0.928	0.876	0.656	0.109
127	0.820	0.802	0.536	0.907	0.876	0.656	0.079
128	0.784	0.829	0.831	0.929	0.876	0.656	0.249
129	0.826	0.767	0.799	0.927	0.876	0.656	0.211
130	0.739	0.792	0.776	0.817	0.876	0.656	0.043
131	0.860	0.755	0.917	0.932	0.876	0.656	0.244
132	0.808	0.751	0.903	0.924	0.876	0.656	0.188
133	0.857	0.871	0.727	0.726	0.876	0.656	0.033
134	0.823	0.788	0.918	0.870	0.876	0.656	0.125
135	0.850	0.869	0.946	0.929	0.876	0.656	0.171
136	0.844	0.776	0.800	0.667	0.876	0.656	0.016
137	0.846	0.862	0.901	0.827	0.876	0.656	0.242
138	0.733	0.866	0.769	0.903	0.876	0.656	0.358
139	0.810	0.830	0.881	0.904	0.876	0.656	0.092
140	0.742	0.784	0.812	0.903	0.876	0.656	0.306
141	0.818	0.843	0.908	0.826	0.876	0.656	0.140
142	0.848	0.811	0.845	0.871	0.876	0.656	0.243
143	0.853	0.867	0.871	0.919	0.876	0.656	0.084
144	0.727	0.838	0.905	0.857	0.876	0.656	0.354
145	0.821	0.852	0.887	0.904	0.876	0.656	0.139
146	0.860	0.858	0.897	0.927	0.876	0.656	0.215
147	0.836	0.840	0.923	0.906	0.876	0.656	0.228
148	0.769	0.869	0.876	0.795	0.876	0.656	0.060
149	0.844	0.862	0.872	0.853	0.876	0.656	0.050
150	0.802	0.800	0.900	0.932	0.876	0.656	0.026
151	0.853	0.821	0.880	0.921	0.876	0.656	0.083
152	0.772	0.843	0.814	0.824	0.876	0.656	0.015
153	0.766	0.804	0.921	0.895	0.876	0.656	0.097
154	0.733	0.761	0.924	0.920	0.876	0.656	0.073
155	0.820	0.838	0.906	0.903	0.876	0.656	0.124
156	0.849	0.851	0.944	0.923	0.876	0.656	0.071
157	0.834	0.752	0.873	0.944	0.876	0.656	0.092
158	0.820	0.834	0.861	0.759	0.876	0.656	0.049
159	0.856	0.867	0.890	0.856	0.876	0.656	0.099
160	0.815	0.808	0.877	0.923	0.876	0.656	0.094
161	0.790	0.858	0.893	0.942	0.876	0.656	0.337
162	0.800	0.864	0.811	0.705	0.876	0.656	0.015
163	0.777	0.812	0.910	0.919	0.876	0.656	0.099
164	0.825	0.860	0.920	0.909	0.876	0.656	0.139
165	0.828	0.830	0.887	0.930	0.876	0.656	0.118

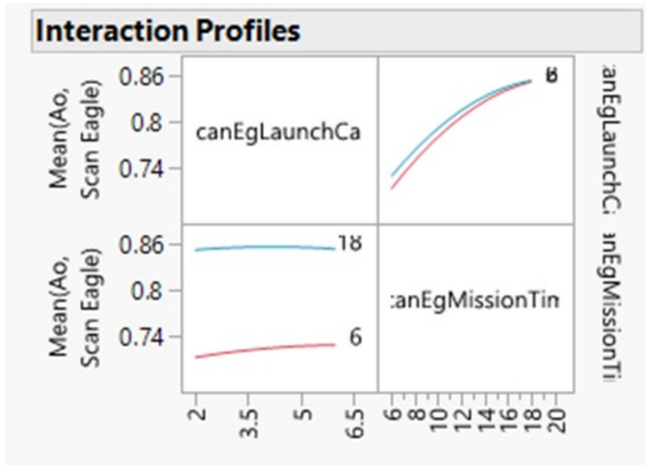
Trial	Ao, ScanEagle	Ao, Fire Scout	Ao, XLUUV	Ao, LDUUV	Ao, MUSV	Ao, LUSV	Ao, FIAC
166	0.800	0.812	0.900	0.864	0.876	0.656	0.225
167	0.826	0.744	0.891	0.858	0.876	0.656	0.218
168	0.821	0.810	0.553	0.871	0.876	0.656	0.305
169	0.808	0.828	0.941	0.899	0.876	0.656	0.027
170	0.738	0.797	0.902	0.932	0.876	0.656	0.124
171	0.786	0.779	0.901	0.936	0.876	0.656	0.055
172	0.817	0.859	0.935	0.926	0.876	0.656	0.113
173	0.799	0.742	0.884	0.940	0.876	0.656	0.197
174	0.827	0.862	0.886	0.882	0.876	0.656	0.171
175	0.770	0.864	0.955	0.829	0.876	0.656	0.132
176	0.721	0.725	0.897	0.870	0.876	0.656	0.177
177	0.830	0.866	0.878	0.901	0.876	0.656	0.058
178	0.812	0.751	0.884	0.880	0.876	0.656	0.146
179	0.812	0.822	0.878	0.866	0.876	0.656	0.104
180	0.840	0.770	0.877	0.862	0.876	0.656	0.041
181	0.852	0.838	0.909	0.923	0.876	0.656	0.084
182	0.823	0.745	0.828	0.833	0.876	0.656	0.044
183	0.715	0.810	0.918	0.935	0.876	0.656	0.198
184	0.844	0.810	0.911	0.899	0.876	0.656	0.473
185	0.854	0.820	0.853	0.855	0.876	0.656	0.094
186	0.817	0.851	0.888	0.937	0.876	0.656	0.197
187	0.745	0.714	0.911	0.891	0.876	0.656	0.145
188	0.823	0.798	0.897	0.901	0.876	0.656	0.065
189	0.850	0.774	0.878	0.894	0.876	0.656	0.351
190	0.769	0.842	0.880	0.932	0.876	0.656	0.328
191	0.807	0.814	0.843	0.747	0.876	0.656	0.006
192	0.814	0.745	0.871	0.769	0.876	0.656	0.068
193	0.786	0.790	0.883	0.933	0.876	0.656	0.244
194	0.838	0.862	0.890	0.826	0.876	0.656	0.241
195	0.763	0.790	0.776	0.783	0.876	0.656	0.024
196	0.807	0.812	0.942	0.836	0.876	0.656	0.078
197	0.738	0.821	0.903	0.935	0.876	0.656	0.098
198	0.768	0.774	0.913	0.896	0.876	0.656	0.121
199	0.788	0.820	0.919	0.928	0.876	0.656	0.258
200	0.758	0.837	0.911	0.891	0.876	0.656	0.011
201	0.784	0.852	0.845	0.923	0.876	0.656	0.180
202	0.825	0.851	0.888	0.932	0.876	0.656	0.168
203	0.736	0.851	0.894	0.939	0.876	0.656	0.290
204	0.726	0.839	0.900	0.928	0.876	0.656	0.110
205	0.743	0.818	0.945	0.944	0.876	0.656	0.225
206	0.842	0.828	0.793	0.688	0.876	0.656	0.027
207	0.762	0.834	0.895	0.888	0.876	0.656	0.129

Trial	Ao, ScanEagle	Ao, Fire Scout	Ao, XLUUV	Ao, LDUUV	Ao, MUSV	Ao, LUSV	Ao, FIAC
208	0.837	0.795	0.676	0.787	0.876	0.656	0.005
209	0.765	0.829	0.873	0.872	0.876	0.656	0.146
210	0.737	0.838	0.901	0.927	0.876	0.656	0.124
211	0.746	0.826	0.899	0.878	0.876	0.656	0.300
212	0.816	0.869	0.927	0.896	0.876	0.656	0.238
213	0.801	0.827	0.965	0.923	0.876	0.656	0.199
214	0.750	0.862	0.880	0.922	0.876	0.656	0.249
215	0.769	0.763	0.886	0.933	0.876	0.656	0.290
216	0.790	0.806	0.757	0.852	0.876	0.656	0.021
217	0.812	0.824	0.894	0.828	0.876	0.656	0.013
218	0.840	0.850	0.897	0.847	0.876	0.656	0.208
219	0.785	0.817	0.911	0.927	0.876	0.656	0.369
220	0.784	0.768	0.897	0.858	0.876	0.656	0.353
221	0.811	0.682	0.884	0.842	0.876	0.656	0.206
222	0.851	0.851	0.880	0.906	0.876	0.656	0.168
223	0.852	0.830	0.907	0.936	0.876	0.656	0.166
224	0.805	0.856	0.886	0.914	0.876	0.656	0.122
225	0.725	0.822	0.917	0.821	0.876	0.656	0.124
226	0.743	0.824	0.916	0.878	0.876	0.656	0.265
227	0.855	0.833	0.888	0.863	0.876	0.656	0.216
228	0.802	0.848	0.855	0.903	0.876	0.656	0.112
229	0.798	0.820	0.894	0.932	0.876	0.656	0.240
230	0.847	0.769	0.847	0.865	0.876	0.656	0.011
231	0.744	0.847	0.883	0.897	0.876	0.656	0.009
232	0.776	0.834	0.935	0.899	0.876	0.656	0.178
233	0.842	0.788	0.758	0.867	0.876	0.656	0.308
234	0.791	0.781	0.911	0.912	0.876	0.656	0.030
235	0.816	0.825	0.930	0.938	0.876	0.656	0.115
236	0.803	0.807	0.938	0.912	0.876	0.656	0.375
237	0.811	0.828	0.807	0.932	0.876	0.656	0.317
238	0.838	0.867	0.894	0.940	0.876	0.656	0.301
239	0.857	0.839	0.920	0.936	0.876	0.656	0.247
240	0.731	0.813	0.804	0.892	0.876	0.656	0.264
241	0.848	0.827	0.872	0.932	0.876	0.656	0.433
242	0.823	0.798	0.909	0.831	0.876	0.656	0.192
243	0.770	0.830	0.922	0.939	0.876	0.656	0.151
244	0.801	0.817	0.893	0.878	0.876	0.656	0.099
245	0.770	0.862	0.869	0.808	0.876	0.656	0.041
246	0.827	0.822	0.911	0.837	0.876	0.656	0.157
247	0.762	0.831	0.901	0.860	0.876	0.656	0.075
248	0.792	0.762	0.907	0.861	0.876	0.656	0.026
249	0.816	0.772	0.905	0.813	0.876	0.656	0.142

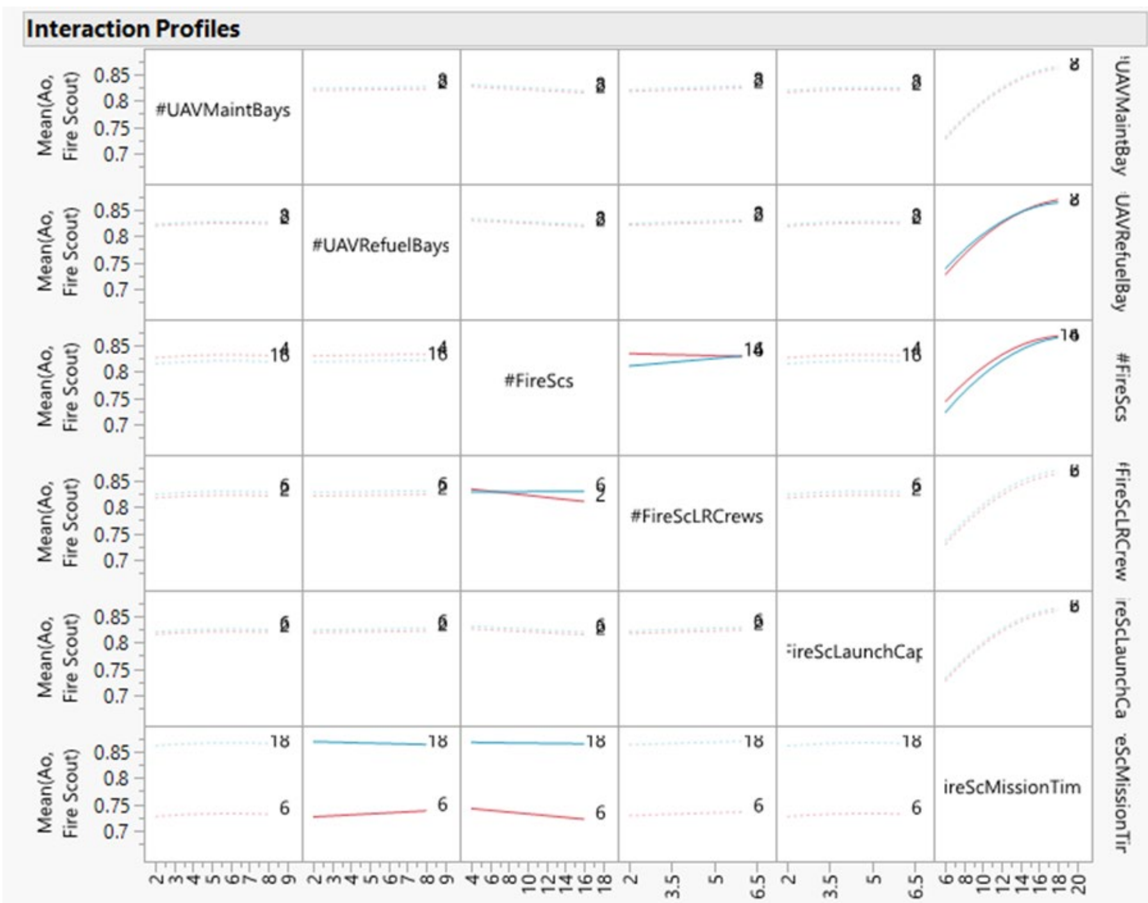
Trial	Ao, ScanEagle	Ao, Fire Scout	Ao, XLUUV	Ao, LDUUV	Ao, MUSV	Ao, LUSV	Ao, FIAC
250	0.797	0.840	0.890	0.935	0.876	0.656	0.057
251	0.831	0.866	0.899	0.921	0.876	0.656	0.125
252	0.839	0.741	0.902	0.910	0.876	0.656	0.350
253	0.820	0.807	0.924	0.921	0.876	0.656	0.079
254	0.740	0.833	0.890	0.852	0.876	0.656	0.056
255	0.800	0.842	0.879	0.936	0.876	0.656	0.209
256	0.806	0.769	0.907	0.829	0.876	0.656	0.228
257	0.831	0.784	0.885	0.917	0.876	0.656	0.284
258	0.862	0.816	0.768	0.762	0.876	0.656	0.015
259	0.811	0.826	0.896	0.840	0.876	0.656	0.125
260	0.790	0.863	0.892	0.917	0.876	0.656	0.159
261	0.803	0.738	0.897	0.871	0.876	0.656	0.179
262	0.767	0.814	0.943	0.942	0.876	0.656	0.047
263	0.814	0.821	0.889	0.934	0.876	0.656	0.303
264	0.799	0.787	0.925	0.937	0.876	0.656	0.091
265	0.759	0.815	0.888	0.905	0.876	0.656	0.283
266	0.747	0.762	0.922	0.917	0.876	0.656	0.115
267	0.782	0.762	0.880	0.933	0.876	0.656	0.211
268	0.786	0.847	0.937	0.866	0.876	0.656	0.148
269	0.859	0.825	0.909	0.878	0.876	0.656	0.039
270	0.742	0.826	0.914	0.891	0.876	0.656	0.176
271	0.835	0.856	0.896	0.929	0.876	0.656	0.282
272	0.702	0.848	0.908	0.896	0.876	0.656	0.149
273	0.854	0.787	0.812	0.930	0.876	0.656	0.215
274	0.833	0.826	0.878	0.932	0.876	0.656	0.306
275	0.831	0.799	0.913	0.919	0.876	0.656	0.276
276	0.841	0.802	0.916	0.826	0.876	0.656	0.285
277	0.841	0.842	0.850	0.871	0.876	0.656	0.044
278	0.739	0.867	0.896	0.849	0.876	0.656	0.167
279	0.749	0.732	0.937	0.909	0.876	0.656	0.030
280	0.845	0.840	0.810	0.734	0.876	0.656	0.047
281	0.810	0.867	0.804	0.801	0.876	0.656	0.025
282	0.858	0.864	0.891	0.881	0.876	0.656	0.155
283	0.842	0.819	0.898	0.821	0.876	0.656	0.115
284	0.773	0.867	0.748	0.933	0.876	0.656	0.086
285	0.848	0.843	0.826	0.926	0.876	0.656	0.085
286	0.818	0.823	0.942	0.931	0.876	0.656	0.109
287	0.813	0.846	0.918	0.819	0.876	0.656	0.216
288	0.739	0.783	0.903	0.915	0.876	0.656	0.040
289	0.861	0.785	0.713	0.705	0.876	0.656	0.007
290	0.784	0.858	0.919	0.899	0.876	0.656	0.336
291	0.810	0.817	0.911	0.928	0.876	0.656	0.204

Trial	Ao, ScanEagle	Ao, Fire Scout	Ao, XLUUV	Ao, LDUUV	Ao, MUSV	Ao, LUSV	Ao, FIAC
292	0.857	0.818	0.888	0.941	0.876	0.656	0.182
293	0.847	0.861	0.863	0.936	0.876	0.656	0.343
294	0.855	0.768	0.910	0.925	0.876	0.656	0.158
295	0.845	0.824	0.949	0.933	0.876	0.656	0.118
296	0.815	0.816	0.918	0.894	0.876	0.656	0.318
297	0.795	0.825	0.885	0.891	0.876	0.656	0.258
298	0.758	0.820	0.913	0.941	0.876	0.656	0.306
299	0.824	0.846	0.911	0.902	0.876	0.656	0.125
300	0.741	0.746	0.871	0.897	0.876	0.656	0.044
301	0.817	0.857	0.915	0.943	0.876	0.656	0.275
302	0.817	0.870	0.890	0.900	0.876	0.656	0.383
303	0.728	0.742	0.904	0.888	0.876	0.656	0.124
304	0.783	0.745	0.882	0.912	0.876	0.656	0.144
305	0.831	0.871	0.879	0.899	0.876	0.656	0.219
306	0.759	0.851	0.886	0.929	0.876	0.656	0.145
307	0.838	0.869	0.897	0.926	0.876	0.656	0.093
308	0.822	0.770	0.886	0.821	0.876	0.656	0.121
309	0.851	0.868	0.924	0.943	0.876	0.656	0.221
310	0.858	0.730	0.904	0.896	0.876	0.656	0.102
311	0.837	0.760	0.902	0.896	0.876	0.656	0.189
312	0.846	0.831	0.903	0.923	0.876	0.656	0.015
313	0.842	0.789	0.919	0.903	0.876	0.656	0.098
314	0.801	0.835	0.903	0.903	0.876	0.656	0.132
315	0.852	0.861	0.895	0.916	0.876	0.656	0.169
316	0.703	0.818	0.902	0.913	0.876	0.656	0.365
317	0.854	0.832	0.737	0.612	0.876	0.656	0.018
318	0.837	0.817	0.950	0.906	0.876	0.656	0.200
319	0.838	0.844	0.655	0.863	0.876	0.656	0.077
320	0.821	0.820	0.895	0.856	0.876	0.656	0.260

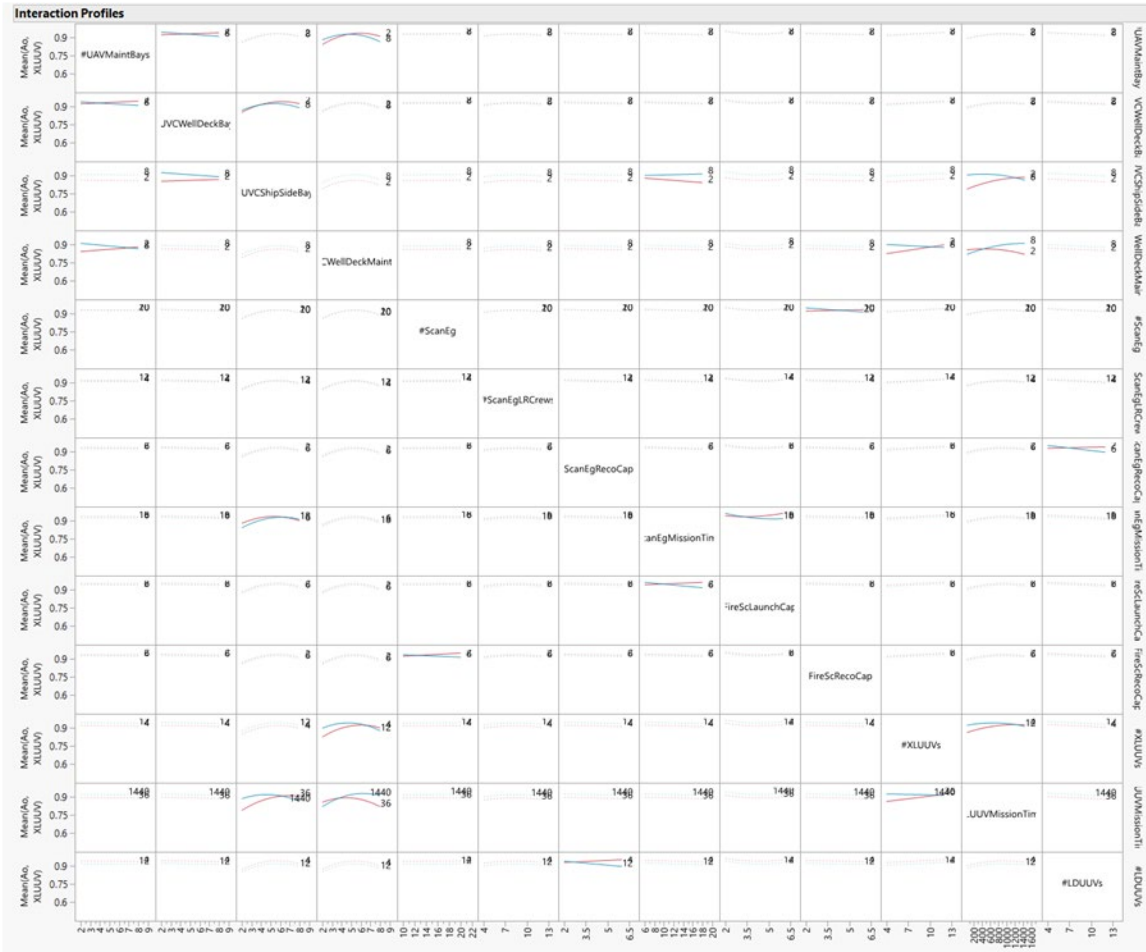
APPENDIX I. INTERACTION PLOTS



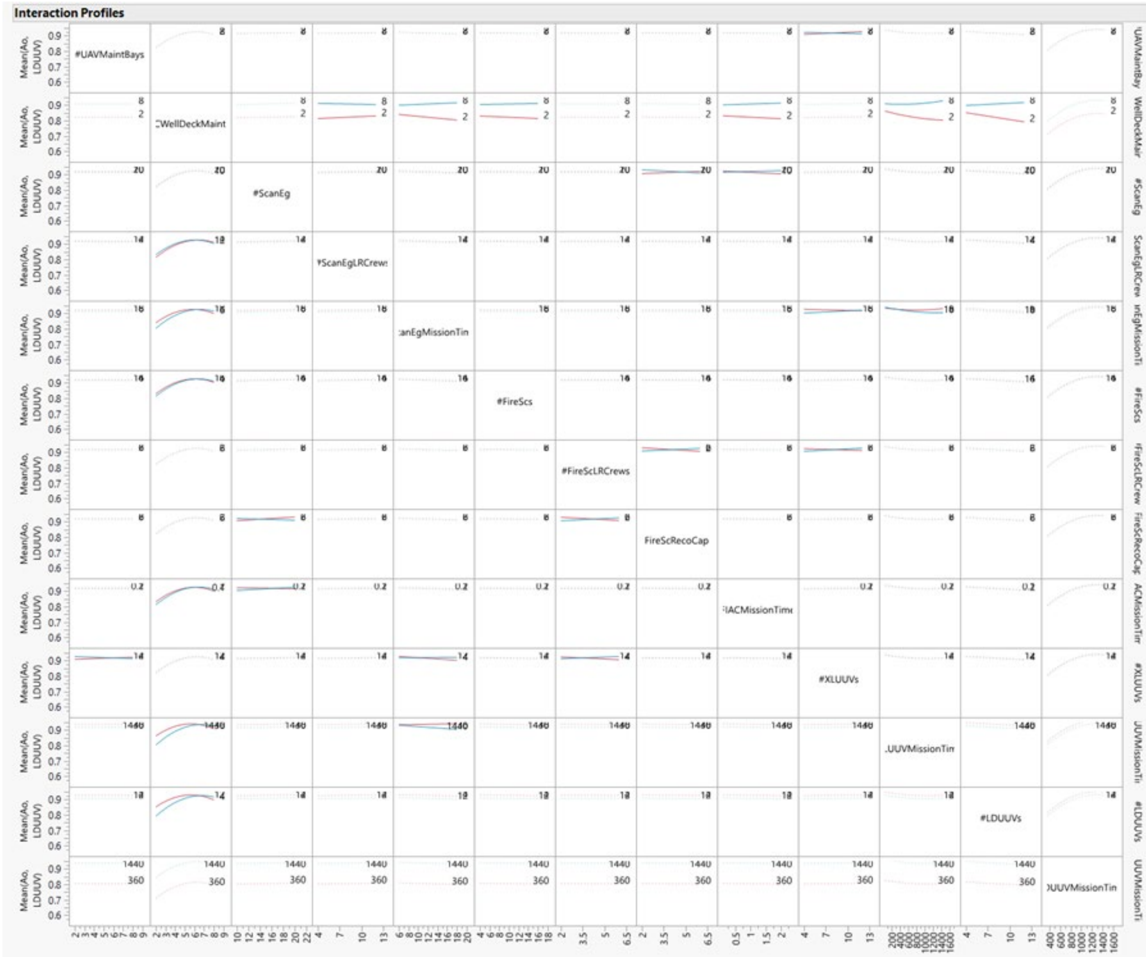
RQ-21 Scan Eagle Ao Interactions



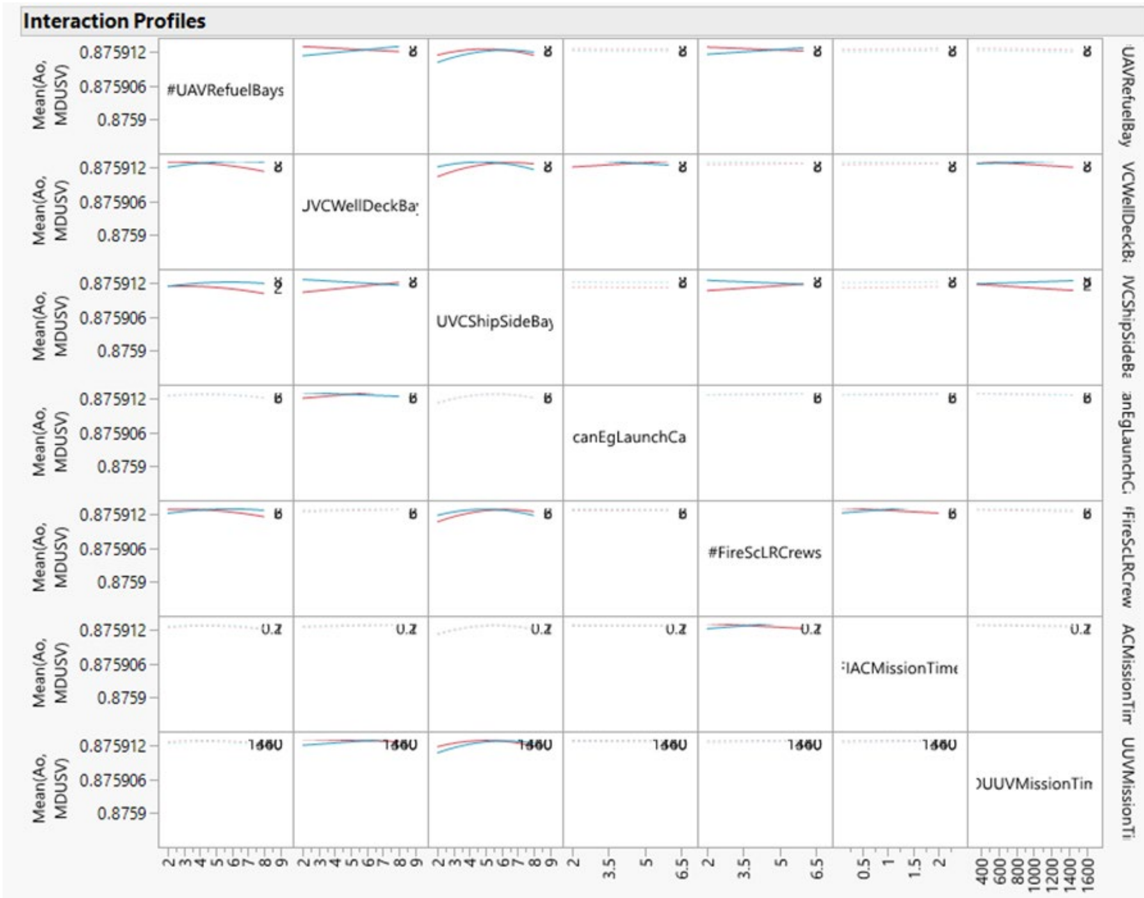
MQ-8 Fire Scout Ao Interactions



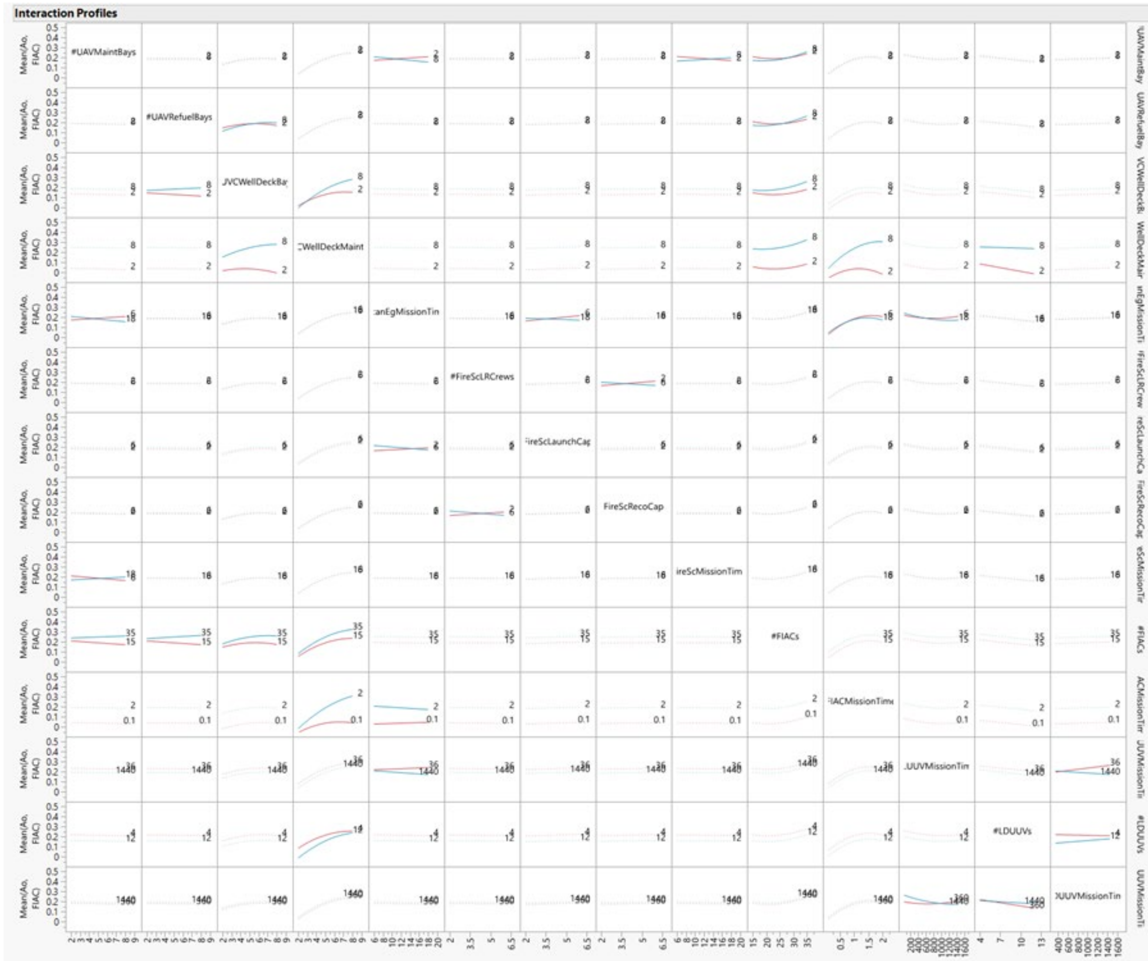
XLUUV Ao Interactions



LDUUV Ao Interactions



MUSV Ao Interactions



FIAC Ao Interactions

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