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SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

RESEARCH AND ANALYSIS OF POSSIBLE SOLUTIONS FOR NAVY-SIMULATED TRAINING TECHNOLOGY

by

Laser-Based Training Assessment Team
Cohort 311-133A

March 2015

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13. ABSTRACT (maximum 200words)

Training of military forces is essential to prepare our military to be successful in combat. Research and analysis has revealed that the Navy currently has a gap in its ability to train against Fast Attack Craft (FAC)/Fast Inshore Attack Craft (FIAC) attacks. The objective of this capstone project was to research current training capabilities, determine training requirements, determine what training gaps remain based on analysis of a prototype laser-based training system, and provide recommendations to meet the needs for a Navy live-simulated training environment. Currently, there is no single technology that can satisfy all training needs and requirements of the Navy to defend against this threat. Recommendations include further evaluation of the prototype system, using the prototype during certain training exercises, and blending several technologies into one combined training system. Laser-based technology can benefit the Navy when used in the right training scenarios and with the correct blend of technology.

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RESEARCH AND ANALYSIS OF POSSIBLE SOLUTIONS FOR NAVY-SIMULATED TRAINING TECHNOLOGY

Cohort 311-133A/Laser-Based Training Assessment Team

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requirements for the degrees of

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ABSTRACT

Training of military forces is essential to prepare our military to be successful in combat. Research and analysis has revealed that the Navy currently has a gap in its ability to train against Fast Attack Craft (FAC)/Fast Inshore Attack Craft (FIAC) attacks. The objective of this capstone project was to research current training capabilities, determine training requirements, determine what training gaps remain based on analysis of a prototype laser-based training system, and provide recommendations to meet the needs for a Navy live-simulated training environment. Currently, there is no single technology that can satisfy all training needs and requirements of the Navy to defend against this threat. Recommendations include further evaluation of the prototype system, using the prototype during certain training exercises, and blending several technologies into one combined training system. Laser-based technology can benefit the Navy when used in the right training scenarios and with the correct blend of technology.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
AAR	After action review
BLOS	Beyond line-of-sight
C2	Command and Control
CO	Commanding Officer
COMNAVFORINST	Commander Naval Fleet Forces Instruction
CONOPs	Concept of Operations
CSW	Crew Served Weapons
DOD	Department of Defense
DON	Department of the Navy
ECP	Entry Control Point
EPA	Environmental Protection Agency
ESOH	Environmental, Safety and Occupational Health
FAC	Fast Attack Craft
FIAC	Fast Inshore Attack Craft
FLETC	Federal Law Enforcement Training Center
FoF	Force on Force
FoT	Force on Target
FP	Force Protection
FPCONs	Force Protection Condition
GAO	Government Accountability Office
GP	Geometric Pairing
GPS	Global Positioning System
HSMST	High Speed Maneuvering Surface Targets
IAW	In Accordance With
ISP	Import Security Plan

I-TESS II	Instrumented-Tactical Engagement Simulation System
ITS	Independent Target System
JQR	Joint Qualification Requirements
LOS	Line of sight
LVC	Live Virtual Constructive
M2	Mark II
MAJiK	Mirror Alignment Jig Kit
MDS	Man-worn Detection System
MILES	Multiple Integrated Laser Engagement System
mm	Millimeter
MMPA	Marine Mammal Protection Act
NAVAIR	Naval Air Systems Command
NPS	Naval Postgraduate School
NAVSEA	Naval Sea Systems Command
NEPA	National Environmental Policy Act
NPL	National Priorities List
NVG	Night vision goggles
OPNAVINST	Office of the Chief of Naval Operations Instruction
OPFOR	Opposing Force
OPSEC	Operational Security
OV	Operational View
PQS	Personnel Qualification Standards
RADM	Rear Admiral
RF	Radio Frequency
RHIBS	Rigid Hull Inflatable Boats
ROE	Rules of Engagement
RPG	Rocket-Propelled Grenade
SAG	Surface Action Group
SAT	Small Arms Transmitter

SME	Subject Matter Expert
SMRFI	Serial Radio Frequency Module
TAO	Tactical Action Officer
TNT	Trinitrotoluene
UHF	Ultra High Frequency
USFF	United States Fleet Forces
USS	United States Ship
USV	Unmanned Surface Vessel
VHF-TDMA	Very High Frequency Time Division Multiple Access
VKC	Vehicle Kill Controller
VKM	Vehicle Kill Mast

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EXECUTIVE SUMMARY

Training of military forces is essential to prepare our military to be successful in combat. Research and analysis has revealed that the Navy currently has a gap in its ability to train against Fast Attack Craft (FAC)/Fast Inshore Attack Craft (FIAC) attacks. The need for the surface Navy to prepare and train itself for the FAC/FIAC threat was most apparent in the *USS Cole* tragedy where terrorists exploded a small craft alongside the Navy Destroyer during refueling. The Navy's response and subsequent modification to force protection training requirements was sufficient; however, a gap still remains in force-on-force (FoF) surface training. Several Navy commands are investigating using laser-based training systems to fill this gap. As a result of this capstone report, this team recommends the incorporation of laser-based simulation into live fire training exercises to increase the fleet's readiness and preparedness in response to FAC/FIAC threats.

The objective of this capstone project was to perform a gap analysis on the current Instrumented-Tactical Engagement Simulation System- (I-TESS II) based prototype system by researching current training capabilities, determining training requirements, which training gaps remain based on analysis of the I-TESS II prototype system, and provide recommendations to meet the needs for a simulated Naval live-fire training environment. A tailored system engineering approach was developed in order to progress from the refined problem statement to the final project deliverable. The process divided the project into three distinct segments: requirements development, prototype capabilities analysis, and function-based gap analysis. The resulting product of this analysis is a determination of functions that a laser-based training system needs to fulfill, the comparison of those functions to an I-TESS II prototype system, and recommendations for the inclusion of laser-based training for use by the Navy.

Currently, there is no single technology that can satisfy all training needs and requirements of the Navy. Gaps exist between the customer defined requirements and the currently implemented capabilities of the prototype I-TESS II system. The current system is satisfactory for use in certain training scenarios with the identified shortfalls if the Concept of Operations (CONOPs) for those scenarios is sufficiently limited in scope.

The gaps identified in the I-TESS II prototype system can be mitigated by additional technologies such as geopairing, simulated rounds, and the development of CONOPs for the training system.

ACKNOWLEDGMENTS

The Laser-Based Training Assessment Team of Cohort 113-133A would like to thank the following people for their support, participation, and advisement of our capstone project. First, we would like to thank our capstone advisors, Mr. Ronald Carlson and Mr. Joseph Sweeney. They played crucial roles in guiding us through our development process and ultimately to the completion and presentation of this research. We would also like to thank our capstone sponsor, Mr. David Purdy from NAVAIR, Surface Targets. He is the author of the problem statement and has been fundamental in our research efforts, providing both timely feedback and logical course corrections throughout our process. Additionally, the following stakeholders have provided necessary input to requirements and valuable feedback when requested: Mr. David Smith (USFF N7), Mr. Chip Carpenter (USFF N72), Captain Curt Seth (CSG-4 N7), Ms. Kim McConnaughey (NSWC Corona), Ms. Bernadette Blixt (NSWC Pt Hueneme), and Mr. Bill Espinosa (Navy T&E). Their feedback with respect to fleet forces and overall naval training was invaluable. We would like to thank USMC Program Manager for Training Systems (PMTRASYS) for providing information on the I-TESS II training system and insight to future development efforts. We would also like to thank Cubic Defense Applications Inc. for their support throughout our systems engineering process and willingness to provide information on the I-TESS II system. We would like to thank the Naval Postgraduate School, Department of Systems Engineering, for its resources and assistance throughout the development of this report. Lastly, we would like to extend tremendous thanks to our families. Your understanding, flexibility, and patience is appreciated beyond words, not only during the time spent developing this capstone report, but for the duration of our pursuit of this master’s degree. Our most sincere gratitude to all of you. We hope our work efforts will bolster the Navy’s pursuit of a suitable training system to defeat the FAC/FIAC threat facing our warfighters.

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I. BACKGROUND

On October 12, 2000, suicide terrorists detonated a small craft loaded with explosives alongside the Navy Destroyer *USS Cole* (DDG-67) as it was refueling, killing 17 American sailors and causing injury to many more (Federal Bureau of Investigation 2014). Figure 1 shows the damage that was caused by the attack.

Figure 1. Damage to the *USS Cole* after Bombing (from Dreyer 2003)

The attack on the *USS Cole*, just off the coast of Yemen, demonstrated that U.S. warships were vulnerable to asymmetric attacks from small craft. Figure 2 shows the details on how the attack was carried out.

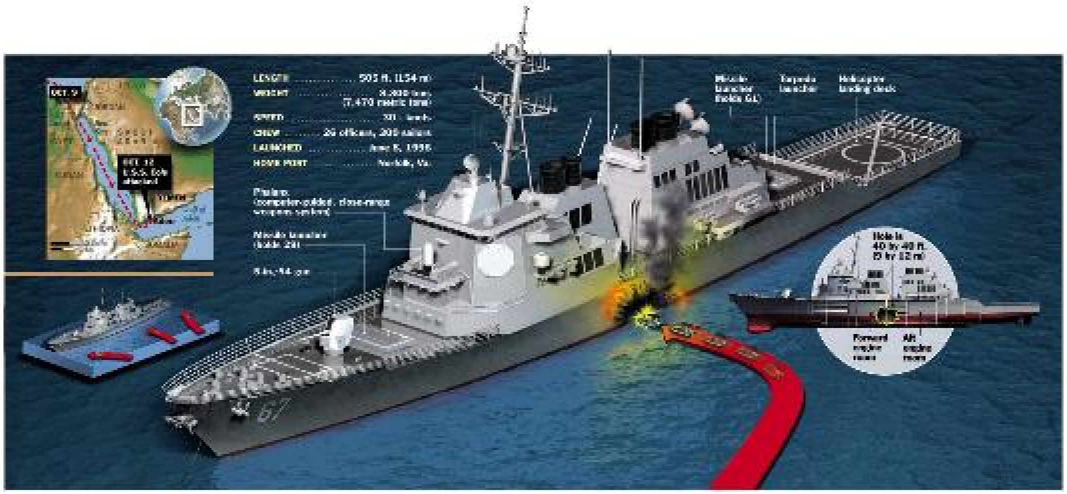

Figure 2. The Attack on the *USS Cole* (from Durham Specialist Risk Management 2013)

In the wake of this attack, the threat of FAC/ FIAC became much more apparent. The following is a statement from LT Kevin Ralston at that time, Operations Officer from Destroyer Squadron 21:

> The [FAC/FIAC] threat is extremely real. We saw what happened to the *USS Cole* when it was attacked by a small boat. We want to be ready at all times to handle whatever is out there. (Logico 2007)

The Department of the Navy (DON) determined that training against this apparent threat was a priority; however, training with live ammunition was a significant safety concern.

> In the interest of safety, simulated weapons (RED/BLUE guns) vice shipboard weapons shall be utilized during all training and assessment periods. All Crew Served Weapons (CSW) shall be verified “clear and safe” with no ammunition on deck, prior to conducting training or assessment. (Department of the Navy 2007, 3–15)

Training CSW watchstanders to defend their ship against a FAC/FIAC attack using RED/BLUE guns lacks realism not only for the watchstanders, but also for the ship’s command and control (C2) structure. The Navy also uses at sea training targets for live ammunition training when underway. This type of training is intended to maintain CSW watchstander marksmanship skills. The team’s research and analysis revealed that the Navy currently has a gap in Force-on-Force (FoF) training, or the ability for both sides of the engagement to inflict damage on the other. The gap in FoF training was determined to be a critical mission capability gap through the system assessment and functional gap analysis performed.

Both the Army and Marine Corps have developed and fielded a variety of training systems to facilitate FoF training. One of their solutions was to integrate laser-based training systems into ground force training thereby maintaining sailor safety in simulated attack events and enabling training that otherwise was unfeasible. These benefits were achieved by using fewer live rounds and incorporating the capability to evaluate individual and unit performance. As can be seen below, the incorporation of laser-based simulation technology is in line with the Naval Education Training Command Strategic Plan.

The Naval Education Training Command Strategic Plan for the next 10 years highlighted training effectiveness as its number one strategic focus area (RADM Quinn 2013). Training effectiveness is defined as "prompt development, deployment, and delivery of effective, high quality training, leveraging state of the art technology and philosophies to satisfy validated and resourced Fleet requirements" (RADM Quinn 2013, 5).

Several studies have been conducted by the Government Accountability Office (GAO) to determine the effectiveness of both live and simulated training within different U.S. military organizations. According to one of GAO's reports, "Navy Training: Observations on the Navy's Use of Live and Simulated Training" (Government Accountability Office 2012), the Navy uses a set of guiding principles in order to provide flexibility in determining the best, most appropriate, solution for a specific training requirement or gap. The following is a list of the 12 published guiding principles.

1) Effective training requires an efficient balance of live and synthetic approaches.

2) Simulator decisions are complex and require thoughtful and thorough analysis.

3) Train in port and validate at sea, or train on the ground and validate in the air, or train at home base and validate in the field.

4) Training simulators should be used to replace live training to the maximum extent possible where training effectiveness and operational readiness are not compromised.

5) Some live training events cannot or should not be replaced by a simulator.

6) If a skill or talent can be developed or refined, or if a proficiency can be effectively and efficiently maintained in a simulator, then these skills/talents/proficiencies should be developed/refined/maintained in a simulator.

7) If a qualification or certification can realistically and economically be accomplished in a simulator, do it in a simulator.

8) Simulator training objectives must be directly linked with specific Navy Mission Essential Tasks or individual personnel qualification standard requirements.

9) Simulators that are intended to interface with other simulators during Fleet Synthetic Training events must be compatible with the Navy Continuous Training Environment network.

10) Simulators that could conceivably be used for multi-platform or cross-platform mission area training should be designed with integration as a primary goal.

11) Simulators should provide the appropriate level of fidelity required to effectively and economically train to the specified task(s).

12) Simulator procurement needs to stay aligned with Fleet-wide technical innovation to deliver timely, cost effective solutions.

Encouraged by both the Naval Education Training Command Strategic Plan and the 12 guiding principles summarized by GAO contained within the "Overarching Fleet Training Simulator Strategy," simulated training has continued to expand. In response to this effort, Naval Air Systems Command (NAVAIR) and Naval Sea Systems Command (NAVSEA) are investigating implementation of a variant of the Multiple Integrated Laser Engagement System (MILES) code complaint laser-based system for use in live training with simulated ammunition.

This report encompasses several areas of research to conduct a systems assessment of a prototype MILES compliant training system as a replacement or augmentation for live ordnance training events. In 2012, the Navy acquired two prototype, MILES compliant, laser-based systems from Cubic Defense Applications, Incorporated for the purpose of evaluating their usefulness in training surface units to defend themselves against FAC/FIAC attacks, or force-on-target (FoT) training. One of these systems was used during an operational FoT concept demonstration in June 2012 with the results documented in NAVSEA Corona trip report 06/22/12 (not releasable to all) (Naval Surface Warfare Center - Corona Division 2012). Details of the results from the Corona trip report have been incorporated into the capability and gap analysis efforts in order to define where gaps exist.

Inputs from stakeholders and the application of a tailored systems engineering approach produced mission and system level requirements and identified the functions needed in a FAC/FIAC training system. To determine what capability gaps existed, the identified functions were compared with the results of an analysis that was performed to determine the current training capabilities of the Navy's prototype FAC/FIAC training systems. Based on this comparison, an analysis of technology was conducted to provide recommendations for follow-on research for a final material solution(s) and recommended path forward for FAC/FIAC laser-based training systems. Due to the classification of weapon systems capabilities, this effort focused on CSW limited to the .50-caliber (M2) and 7.62mm (M240) machine guns installed onboard surface ships because their data and information were widely distributable yet relevant to the purposes of this paper.

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II. PROJECT INTRODUCTION

A. PROBLEM STATEMENT

The objective of this research effort is to examine the use of virtual bullets for replacement in live ammunition training. Specifically, this project will research the possible uses of MILES and other technologies to meet surface Navy's FoF training needs in FAC/FIAC engagement scenarios. The capstone sponsor, Mr. David Purdy, Head, Surface Targets Engineering Branch, NAVAIR, provided an overarching need that has been paraphrased in the following statement:

> The Navy needs the Multiple Integrated Laser Engagement System (MILES) or geometric pairing (using GPS) solutions to use 'virtual' bullets for use in training and weapons test and evaluation.

Research of the sponsor's initial need statement led to the development and refinement of the following problem statement:

> The Navy does not currently have a realistic way to simulate "live ammunition" in FoF training; therefore, the Navy will continue to lack effective ways to train against FAC/FIAC attacks.

The research that was conducted in order to answer the problem as stated above was centered on the following related questions:

1. What are the current training requirements that might be fulfilled using laser-based training systems?
2. What are the capabilities and limitations of laser-based training?
3. What are the impacts, negative training, of using laser-based training on "training realism?"
4. What are the environmental impacts of "live" ordnance training?
5. What are the environmental impacts of laser-based training?
6. What are the safety concerns of using laser-based training systems?

The results from the research were used to aid in the functional gap analysis in determination of the capabilities, limitations, environmental impacts, and negative training impacts of laser-simulated weapons and ammunition.

B. STAKEHOLDERS

A summary of the key stakeholders involved with this capstone is provided in Table 1.

Table 1. Key Stakeholders for Laser-Based Training Assessment Team's Capstone

Stakeholder Name	Organization	Role
Mr. David Purdy	NAVAIR, Head, Surface Targets Engineering Branch	Capstone Sponsor
Mr. David Smith	U.S. Fleet Forces (USFF) N7	Mission requirements Top-level reviewer and fleet training representative
Mr. Chip Carpenter	USFF N72	Mission requirements Top-level reviewer and fleet training representative
Captain Curt Seth	CSG-4 N7	Mission requirements Top-level reviewer and Carrier fleet training representative
Ms. Kim McConnaughey	Naval Surface Warfare Center (NSWC) Corona East Coast Range Manager	Mission requirements Top-level reviewer, surface targets provider
Ms. Bernadette Blixt	NSWC Port Hueneme Division	Mission requirements Top-level reviewer, surface targets provider
Mr. Bill Espinosa	Navy Test & Evaluation	Test Subject Matter Expert (SME)

Representatives from USFF command represent the Top-level view point. Representatives from NSWC represent suppliers of opposing force (OPFOR) equipment and managers of the two prototype systems. Captain Seth is responsible for Carrier Strike Group training. Mr. Bill Espinosa represents the test community. All stakeholder inputs were vital in the development of mission requirements. Principle stakeholder inputs were concerned with training scenario fidelity, supporting FoF and FoT training, and exercising C2 roles and responsibilities. Stakeholder inputs are further expanded on below.

1. Scenario Fidelity

Scenario fidelity is decomposed into providing the capability to have Blue forces (friendly), Red forces (enemy), and the system's ability to be mounted and used on existing CSWs that comprise Red and Blue force systems. Derived requirements include an indication for personnel and system kills and limiting the use of weapons when kills are indicated.

2. Force-on-Force Training

Conducting FoF training captures many of the requirements for live-action, reality based scenarios that allow for both offensive and defensive engagements. This has been decomposed into several system requirements for simulating a Red force versus Blue force engagement based on use-case scenarios. FoF training includes simulating direct fire from and towards the opposing force for CSW range, accuracy, and ballistics. Simulating weapons includes the system requirements for several weapon types.

3. Force-on-Target Training

Force-on-Target training, similar to FoF training, focuses on the necessary requirements such as simulating CSW fire on at sea training targets, identified below, with a high-fidelity detection system for real time performance assessment. The scenarios developed for FoF analysis were used to ensure that all FoT requirements were identified as well.

4. Centralized Command and Control

Enabling a Centralized C2 includes the mission requirements of communication within Line of sight (LOS) as well as communication Beyond LOS (BLOS). Command and control not only includes the requirement for a network and communication but also the approved frequency bands in which communication must occur. System requirements include information updates at a rate of one update per second and the system shall maintain connectivity/data availability to within a 3% error rate.

Command and control of training requires the functionality to have a "God's eye" view of the training exercise. The system must be able to monitor all the entities, display all engagements, reflect status changes, and provide the ability to "reset" players. Command and control should also include the ability to conduct an after-action review (AAR) within 60 minutes of exercise completion.

Centralized C2 is required by naval ships and is assumed to be provided by the ship, and therefore will not be part of the system under assessment. This assessment will focus on Scenario Fidelity, FoF and FoT training system requirements as they relate to the FAC/FIAC force protection mission.

C. PROJECT TEAM

The Laser-Based Training Assessment Team has been tasked to execute a group capstone project for the Naval Postgraduate School (NPS) Master of Science in Systems Engineering/Engineering Systems curriculum. Figure 3 shows the members of the Laser-Based Training Assessment Team and the organizational structure for the overall capstone project as well as their individual areas of expertise. The capstone advisors' responsibility for the duration of this project will be to provide guidance and insight for the Laser-Based Training Assessment Team to transform initial tasking into a well-researched system analysis.

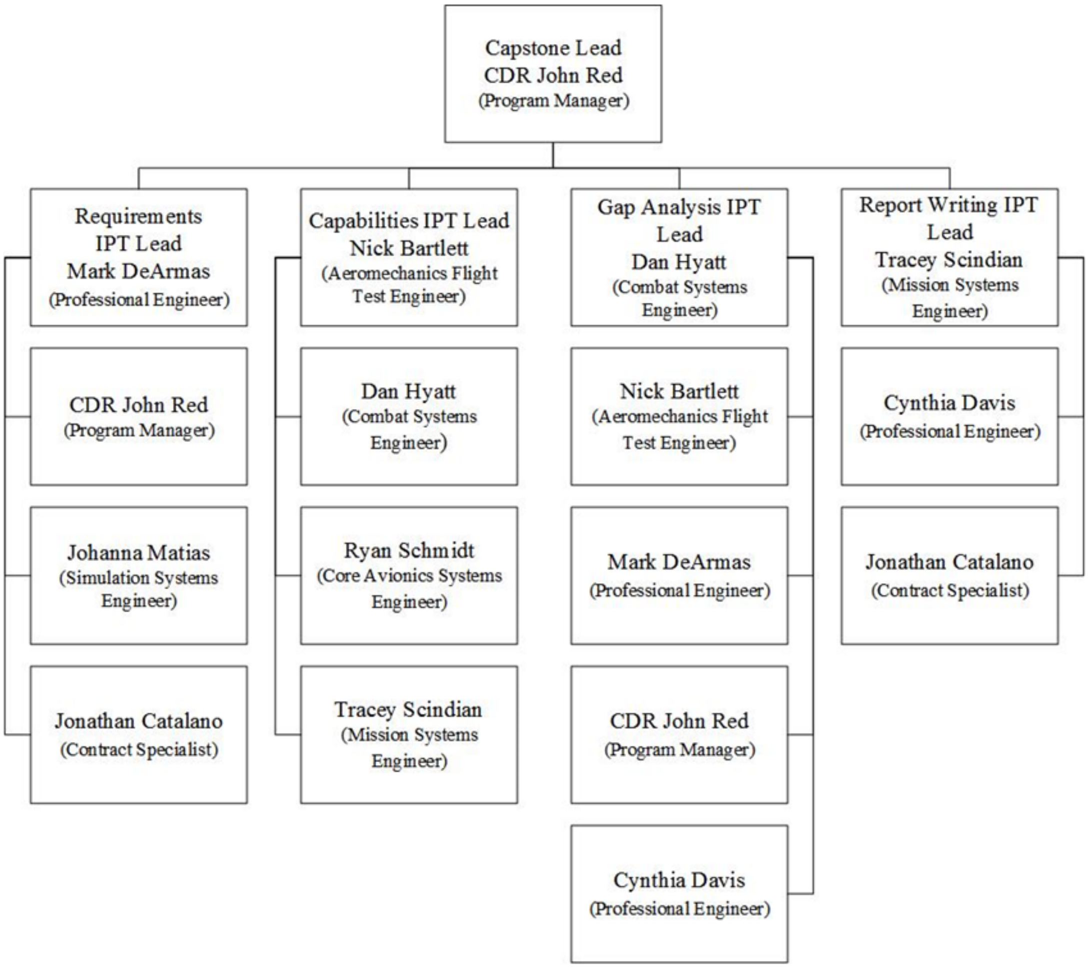

Figure 3. Laser-Based Training Assessment Team Project Organization

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III. SYSTEMS ENGINEERING PROCESS

A. PROCESS OVERVIEW

The team developed a tailored systems engineering process, based on the original research questions, in order to progress from the refined problem statement to the final project deliverable. Figure 4 shows the process developed for this capstone. The process breaks down the project into three distinct segments: mission and system requirements development (blue), prototype capabilities analysis (red), and function based gap analysis (purple). The resulting product was the identification of functional gaps between the functions needed in a FAC/FIAC training system derived from mission requirements segment and the functions provided by the I-TESS II prototype system as identified through the capabilities assessment segment. A set of recommendations for potential solutions and improvements to the Navy's prototype system to simulate live fire in FoF training against FAC/FIAC threats will conclude this process.

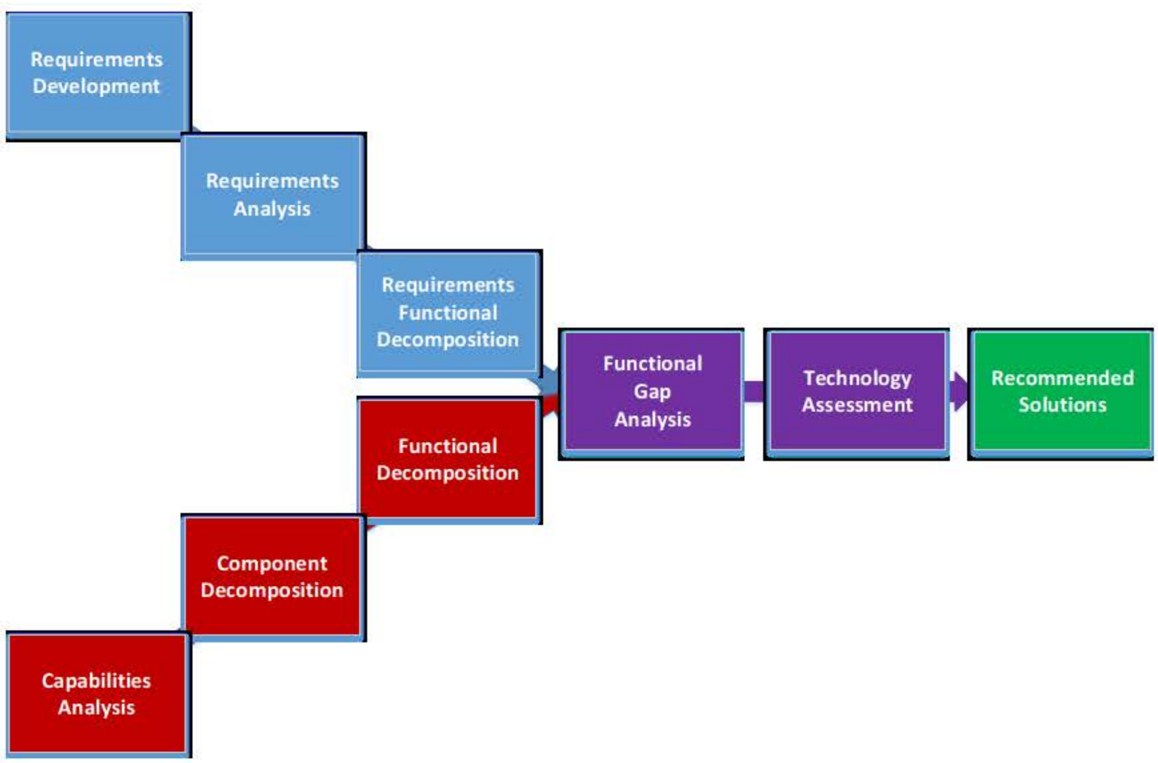

Figure 4. Capstone Systems Engineering Process

The requirements development segment is comprised of FAC/FIAC training requirements: mission requirements development, system requirements analysis, and requirements functional decomposition. The problem statement, discussions with stakeholders, and research identified the needs of a FAC/FIAC training mission. These needs were then translated into mission requirements, which were then decomposed into system requirements, resulting in the identification of system functions needed to meet those training requirements. The system functions were then used as an input into the gap analysis process.

The capabilities analysis segment was comprised of prototype system capabilities assessment, which resulted in the identification of components and functional decomposition of the components of the I-TESS II prototype system that the Navy procured as a proof of concept. The prototype system's functions were used as an input into the gap analysis process.

The functional gap analysis segment compared inputs from the training requirements analysis segment (training system functions) and the prototype capabilities analysis segment efforts (prototype functions). This segment results in identification of functional gaps between the I-TESS II prototype and functions required to fulfill the FAC/FIAC training need. The gaps were further analyzed against functions that are native to the ship or to the Red force unit (i.e., communications systems, crew served weapons), as well as other existing technologies to determine if any technologies were available to fulfill them. This process resulted in technology recommendations that should be considered by the Navy to minimize those residual functional gaps.

B. REQUIREMENTS DEVELOPMENT

Requirements were developed based on inputs received from the capstone sponsor and other stakeholders. These requirements were refined based on the Navy CSW training requirements, research of potential threats to Naval Forces, and analysis of use-case scenarios.

1. Research

Research was performed on all of the CSW training for force protection against FAC/FIAC attacks in which the Navy could benefit from the use of laser-based simulation to supplement live ammunition, or live fire, training. This section discusses the three areas in which simulated training will provide or has already begun to provide training benefits for the Navy. The Navy uses a three-phased approach to train CSW watchstanders: individual training, single unit training, and fleet training.

a. Individual Weapons Training

Prior to a deployment, each naval unit is required to achieve readiness in each of its assigned mission areas. Readiness is the "state of preparedness of forces or weapon systems to meet a mission or to engage in military operations based on adequate and trained personnel, material condition, supplies/reserves of support systems and ammunition, number of units available, etc." (Brown, Hagan and Leggett 2009, 196). Every combat unit has Force Protection as a mission. In order to achieve readiness in this mission area, the unit must have weapons qualified watchstanders. These watchstanders are trained in the usage of pistols, rifles, shotguns, and light to heavy machineguns in accordance with Office of the Chief of Naval Operations Instruction (OPNAVINST) 3591.1F, "Small Arms Training and Qualification" (Chief Naval Office 2009). Once qualified, the watchstanders progress to unit level training. Individual weapons marksmanship training and qualification requirements are well documented and not within scope of this report.

b. Unit Level Crew Served Weapons (CSW) Training

Unit level training is outlined in Tab C of Commander Naval Surface Force Instruction (COMNAVSURFORINST) 3502.1D and is summarized in Appendix A, Table 17. The following note, restated from above, captures the essence of CSW training:

> Note: In the interest of safety, simulated weapons (RED/BLUE GUNS) vice shipboard weapons shall be utilized during all training and assessment periods. All CSW shall be verified 'clear and safe' with no

ammunition on deck, prior to conducting training or assessment. (Department of the Navy 2007)

Unit level training is being conducted using RED/BLUE simulated weapons and live ammunition against at sea training targets. These approaches to training limit personnel exposure to additional risk. Training with RED/BLUE simulated weapons provides procedural reinforcement for the CSW watchstanders and chain of command responsibility for defending the ship/unit, but lacks in its ability to replicate combat conditions. Engaging at sea training targets with actual weapons using live ammunition provides procedural reinforcement and marksmanship qualification currency for the CSW watchstanders; however, it also lacks in the ability to replicate combat conditions because operators are not exposed to the risk of enemy fire. Unit level training is relevant to the capstone stakeholders and will be addressed as part of this capstone project.

c. Fleet Level Training

Due to the classification of tactics, techniques, and procedures (TTPs), fleet level training will be addressed only as multiple surface units working together for mutual defense. Both unit level training and fleet level training are conducted underway with at sea training devices either with RED/BLUE simulated weapons or live ammunition. As noted above, these approaches lack the ability to replicate combat conditions. Currently, much of FAC/FIAC live fire training events are done against various targets, the Killer Tomatoes (see Appendix A), High Speed Maneuvering Surface Targets (HSMST), and other unmanned targets. As a result of live fire training, these targets are either destroyed or require maintenance before they can be available for reuse. Fleet level training is relevant to the capstone stakeholders and will be addressed as part of this capstone project.

d. Current at Sea Trainers

Underway training for FAC/FIAC unit defense can be categorized in two basic categories: 1) simulated training as summarized in the note above—just pointing an inert weapon at a target or 2) use live ammunition to shoot holes into a target. Neither form of training is the optimum solution. Pointing an inert or play gun or shooting at a target that does not have the ability to shoot back both have limited value and neither represent combat conditions.

The Navy has attempted to bridge the training gap by investing in multiple systems such as the remote controlled Jet Ski, remote controlled Unmanned Surface Vessel (USV), and modified Rigid Hull Inflatable Boats (RHIBS). The HSMST, Figure 5, is an unmanned modified speedboat that may operate alone or in groups.

Figure 5. Unmanned HSMST

Unmanned targets are designed to support FoT, not FoF. As with most training, some of benefits are in the abilities to replicate real-world conditions, record participant actions, and compare those actions against training objectives. Without a training system that is capable of recording and reporting the results of weapon fire related data, the Navy appears to have no capability for evaluating CSW operators' or unit C2 effectiveness against FAC/FIAC attacks aside from successful neutralization/destruction of the target.

2. Mission Requirements Development

In an effort to understand the mission and accurately represent mission training requirements, the team designed training scenarios based on the proof of concept demonstration documented in NAVSEA Corona 2012 trip report (Jauregui 2012). These scenarios helped to identify the roles and communications required to execute the mission. Three scenarios were developed based on the potential tactical situations that might represent the FAC/FIAC threat: a single ship versus a single attacker, a three-ship Surface Action Group (SAG) versus multiple attackers, and a two-ship SAG versus multiple attackers at night. Scenarios one and two provided useful information; however, scenario three did not add to the requirements development process and was consequently excluded from the analysis, Appendix A.

a. Scenario One—Single Ship vs. Single FAC

Scenario one, shown in Figure 6, identified primary mission tasks to enhance the requirements analysis. Mission tasks identified during this analysis depended on the role of the participant. The participants involved in this example scenario were the Commanding Officer (CO), Tactical Action Officers (TAO), and the force protection forces (watchstanders/gunners). The CO is responsible for the safety of the unit and associated forces. The TAO is responsible to the CO for the execution tactics; both fulfill the roles of C2 for the watchstanders. The force protection watchstanders manned the CSWs and engaged the enemy forces. Scenario one identified the major interactions that needed to be carried out by the watchstanders for a unit to successfully defend itself when faced with a FAC/FIAC threat. The watchstanders tasks are summarized below:

1. Respond to the CO's/TAO's orders and report to their assigned station.
2. Load the assigned weapon (one member of the crew brings ammo, while the other inspects and prepares the weapon).
3. Identify visually the attacking speedboat.
4. Slew weapon toward target.
5. Aim the loaded weapon.
6. Receive order to fire weapon.
7. Fire the weapon.
8. Visually determine impact location of projectile.
9. Report status of engagement.
10. Adjust aim.
11. Repeat steps 5-10 until the attacking speedboat is destroyed, turns away, or the protecting force is no longer able to fire (injured or out of bullets).
12. Reload weapon as required.
13. Report status of engagement to ship's TAO.

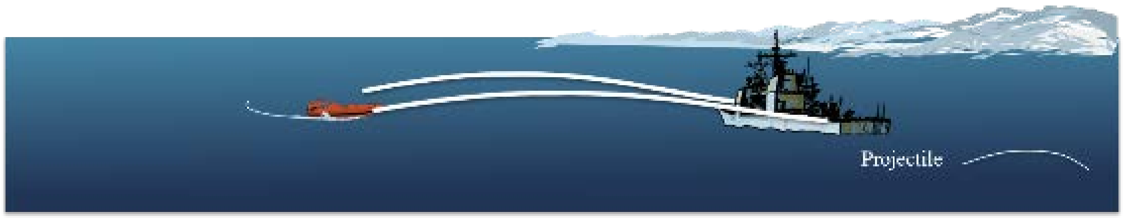

Figure 6. Scenario One OV-1

The CO of the ship serves as decision authority, the TAO's role is to coordinate the execution of orders and defense of the ship, and the watchstanders/gunners roles are to observe, communicate and follow the orders given to protect the unit.

From the above list of mission requirements, it was determined that normally the ship would be equipped to support communications between the watchstanders and command authority. The ship would also have the capability to verbally warn the approaching boat either via loud speaker or radio. It is assumed that watchstanders would either be trained in estimating range to potential threats or be equipped with a laser range finder. The remaining mission requirements were determined to be the focus of further analysis.

b. Mission Requirements

Development of detailed requirements was performed using use-case scenarios, functional flow block diagrams (FFBD), and Integration Definition Models (IDEF0) diagrams, which enabled a definition of the top-level mission requirements, measures of effectiveness (MOE), and system requirements. The top-level mission requirements were deconstructed into MOEs, which were further deconstructed into the applicable system requirements.

Top-level mission requirements are shown in Table 2. The mission requirements enable multiple Blue force assets, CSW watchstanders and C2 to train together. Top-level mission requirements also include the need to have multiple Red force participants that can simulate direct fire on Blue forces. These two mission requirements are key in facilitating FoF training. The remaining mission requirements result from the need for accurate training, actionable and metric-based reports, and information to the trainees and trainers. Threshold and objective valves were developed through discussions with stakeholders and analysis by the team.

Table 2. Top-Level Mission Requirements

Reference	Description	Threshold	Objective
A	Shall support multiple Blue force assets participation simultaneously	3	6
B	Shall simulate multiple Blue force ship's crew served weapon types	2	3
C	Shall support multiple Red force assets participation simultaneously	20	30
D	Shall simulate multiple Red force ship's crew served weapons	1	2
E	Shall support training scenario Command & Control via secure network and secure voice	Y	Y
F	Shall continuously record transmitted data without errors	95%	100%
G	Shall continuously record transmitted data on digital media for the duration of the training event	24 hrs	72 hrs
H	Shall provide timely scenario after action report and replay, compatible with existing Navy reporting and replay systems	3 HRS	30 MIN

The developed MOEs are listed below in Table 3. These are intended to provide a greater level of detail in regards to the needs of a training system. They include the number of simultaneous weapons to be simulated, required accuracy levels of weapon fire being simulated, types of weapons simulated, and further definition of data management and reporting information required. Mission requirements were then analyzed, and decomposed into system requirements.

Table 3. Measures of Effectiveness

Reference	Description	Threshold	Objective
A.1	Shall collect data from each unique Blue force unit	Y	Y
A.2	Shall accurately calculate damage assessment for each Blue force unit based on Red force weapons lethality characteristics	90%	95%
B.1	Shall enable multiple CSW positions per ship simultaneously	5	10
B.2	Shall collect data from each unique CSW position	Y	Y
B.3	Shall simulate Blue force ship's .50-caliber (CAL) weapons characteristics	90%	95%
B.4	Shall simulate Blue force ship's M240B weapons characteristics	90%	95%
C.1	Shall collect data from each unique Red force unit	Y	Y
C.2	Shall accurately calculate damage assessment for each Red force unit based on Blue force weapons lethality characteristics	90%	95%
D.1	Shall enable weapon(s) positions per Red force unit simultaneously	1	2
D.2	Shall collect data from each unique weapon position, yes or no	Y	Y
D.3	Shall simulate Red force ship's .50-CAL weapons characteristics	90%	95%
D.4	Shall simulate Red force ship's RPG weapons characteristics	90%	95%
E.1	Shall establish a secure local area network capable of carrying participating units information to centralized control and collection systems data without errors	95%	100%
E.2	Shall establish a secure local area network capable of carrying command and control data to participating units without errors	95%	100%
E.3	Shall establish a secure voice network capable of carrying participating units information to centralized control and collection systems without errors	95%	100%
E.4	Shall establish a secure local area network capable of carrying command and control data to participating units without errors	95%	100%

Reference	Description	Threshold	Objective
F.1	Shall continuously record Blue force transmitted data without errors	95%	100%
F.2	Shall continuously record Red force transmitted data without errors	95%	100%
F.3	Shall continuously record command and control transmitted data without errors	95%	100%
G.1	Shall continuously record Blue force transmitted data on digital media for the duration of the training event	24 hrs	72 hrs
G.2	Shall continuously record Red force transmitted data on digital media for the duration of the training event	24 hrs	72 hrs
G.3	Shall continuously record C2 transmitted data on digital media for the duration of the training event	24 hrs	72 hrs
H.1	Shall automatically produce timely after action report compatible with existing Navy reporting systems	3 hrs	30 min
H.2	Shall automatically produce timely mission replay compatible with existing Navy replay systems	3 hrs	30 min

3. System Requirements Analysis

Navy combatants do not always deploy alone, as described in scenario one, and they often deploy as part of an Aircraft Carrier Strike Group (CSG), Expeditionary Strike Group (ESG) or a SAG. As the name indicates, a CSG includes an aircraft carrier and several other ships. Due to both the inclusion of fixed wing aircraft and helicopters as part of the force protection mission and the increased complexity of analysis, this was considered outside the scope of this project. At a similar level of complexity is the ESG which is also comprised of several different types of ships and aircraft. The SAG, on the other hand, is a scalable force comprised of at least two surface combatants that may or may not be supported by aircraft.

a. Scenario Two—Multiple Attackers vs. Three-Ship SAG

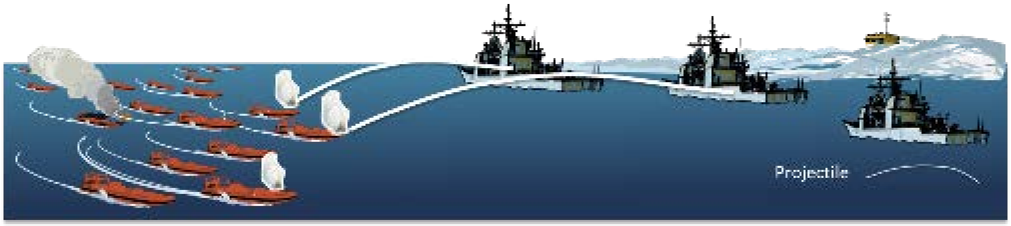

Figure 7. Scenario Two OV-1

Scenario two, pictured in Figure 7, multiple FAC attacking a three-ship SAG, analysis determined that its execution followed the same communications flow and actions as described in scenario one with the exception of an increase in complexity from the inclusion of multiple Blue force platforms. For this scenario, a hierarchical command structure was established. This command structure allows for coordination of protection sectors and responses to emerging threats. Analysis determined that coordination at the TAO and unit CO level required additional data sharing and increased communications. Scenario two is scalable to encompass a significantly larger force based on the military hierarchical structure without changing the process. Sequence diagrams were developed to enhance the analysis and are included as Appendix B.

b. System Requirements

The requirements analysis was precluded by research on all CSW training for force protection against FAC/FIAC attacks in which the Navy could benefit from the use of laser-based simulation to supplement live ammunition training. An iterative approach was used to decompose the mission requirements and MOEs into system-level requirements. Table 4 shows the top two levels of system requirements related to the ideal training system that would meet most FAC/FIAC training needs (see Appendix C, Table 18, for a more detailed list of system requirements). Threshold and objective values were developed through discussions with stakeholders and analysis by the team.

Table 4. System Requirements

Reference	Description	Threshold	Objective
A.1.1	Shall support unique position identification for each Blue force unit	Y	Y
A.1.2	Shall collect periodic geographic position data from each unique Blue force unit	1 hz	2 hz
A.1.3	Shall collect periodic heading data from each unique Blue force unit	1 hz	2 hz
A.1.4	Shall collect periodic velocity data from each unique Blue force unit	1 hz	2 hz
A.1.5	Shall collect periodic status data from each unique Blue force unit	1 hz	2 hz
A.2.1	Shall simulate damage sustained to Blue force units by disabling the impacted area or system	Y	Y
A.2.2	Shall support Blue force unit reset	Y	Y
B.1.1	Shall simulate damage sustained to Blue force CSW stations by disabling the operator	Y	Y
B.1.2	Shall support Blue force CSW reset	Y	Y
B.1.3	Shall support unique position identification for each Blue force CSW position	Y	Y
B.2.1	Shall collect periodic position data from each CSW position	1 hz	2 hz
B.2.2	Shall collect periodic aiming data from each unique CSW position	1 hz	2 hz
B.2.3	Shall collect periodic firing data from each unique CSW position	1 hz	2 hz
B.2.4	Shall collect periodic ammunition data from each unique CSW position	1 hz	2 hz
B.2.5	Shall collect periodic status data from each unique CSW position	1 hz	2 hz
B.3.1	Shall simulate Blue force ship's .50-CAL weapons accuracy	90%	95%
B.3.2	Shall simulate Blue force ship's .50-CAL weapons range	90%	95%
B.3.3	Shall simulate Blue force ship's .50-CAL weapons ballistics	90%	95%
B.3.4	Shall simulate Blue force ship's .50-CAL weapons projectile	90%	95%
B.3.5	Shall simulate Blue force ship's .50-CAL weapons lethality	90%	95%
B.3.6	Shall not increase Blue force ship's .50-CAL	10%	5%

Reference	Description	Threshold	Objective
	weapons weight		
B.4.1	Shall simulate Blue force ship's M240B weapons accuracy	90%	95%
B.4.2	Shall simulate Blue force ship's M240B weapons range	90%	95%
B.4.3	Shall simulate Blue force ship's M240B weapons ballistics	90%	95%
B.4.4	Shall simulate Blue force ship's M240B weapons projectile	90%	95%
B.4.5	Shall simulate Blue force ship's M240B weapons lethality	90%	95%
B.4.6	Shall not increase Blue force ship's M240B weapons weight	10%	5%
C.1.1	Shall support unique position identification for each Red force unit	Y	Y
C.1.2	Shall collect periodic position data from each unique Red force unit	1 hz	2 hz
C.1.3	Shall collect periodic heading data from each unique Red force unit	1 hz	2 hz
C.1.4	Shall collect periodic velocity data from each unique Red force unit	1 hz	2 hz
C.1.5	Shall collect periodic status data from each unique Red force unit	1 hz	2 hz
C.2.1	Shall simulate damage sustained to Red force weapon stations by disabling the operator	Y	Y
C.2.2	Shall support Red force weapon reset	Y	Y
D.1.1	Shall support unique position identification for each Red force weapon position	Y	Y
D.1.2	Shall collect periodic geographic position data from each weapon position	1 hz	2 hz
D.1.3	Shall simulate damage sustained to Red force units by disabling the impacted area or system	Y	Y
D.1.4	Shall support Red force unit reset	Y	Y
D.2.1	Shall collect periodic aiming data from each unique weapon position	1 hz	2 hz
D.2.2	Shall collect periodic firing data from each unique weapon position	1 hz	2 hz
D.2.3	Shall collect periodic ammunition data from each unique weapon position	1 hz	2 hz
D.2.4	Shall collect periodic status data from each unique weapon position	1 hz	2 hz

Reference	Description	Threshold	Objective
D.3.1	Shall simulate Red force ship's .50-CAL weapons accuracy	90%	95%
D.3.2	Shall simulate Red force ship's .50-CAL weapons range	90%	95%
D.3.3	Shall simulate Red force ship's .50-CAL weapons ballistics	90%	95%
D.3.4	Shall simulate Red force ship's .50-CAL weapons projectile	90%	95%
D.3.5	Shall simulate Red force ship's .50-CAL weapons lethality	90%	95%
D.4.1	Shall simulate Red force ship's RPG weapons accuracy	90%	95%
D.4.2	Shall simulate Red force ship's RPG weapons range	90%	95%
D.4.3	Shall simulate Red force ship's RPG weapons ballistics	90%	95%
D.4.4	Shall simulate Red force ship's RPG weapons projectile	90%	95%
D.4.5	Shall simulate Red force ship's RPG weapons lethality	90%	95%
E.1.1	Shall receive data transmissions from participating Blue force units without errors	95%	100%
E.1.2	Shall receive data transmissions from participating Red force units without errors	95%	100%
E.2.1	Shall enable Blue force units receipt of command and control data without errors	95%	100%
E.2.2	Shall enable Red force units receipt of command and control data without errors	95%	100%
E.3.1	Shall receive secure voice transmissions from participating Blue force units without errors	95%	100%
E.3.2	Shall receive secure voice transmissions from participating Red force units without errors	95%	100%
E.4.1	Shall enable Blue force units receipt of command and control voice transmissions without errors	95%	100%
E.4.2	Shall enable Red force units receipt of command and control voice transmissions without errors	95%	100%
F.1.1	Shall continuously record Blue force unit data without errors	95%	100%
F.1.2	Shall continuously record Blue CSW station data without error	95%	100%

Reference	Description	Threshold	Objective
F.2.1	Shall continuously record Red force unit data without errors	95%	100%
F.2.2	Shall continuously record Red force station data without errors	95%	100%
F.3.1	Shall continuously record C2 unit transmitted data without errors	95%	100%
F.3.2	Shall continuously record C2 received data without errors	95%	100%
G.1.1	Shall continuously record Blue force unit data for the duration of the training event	24 hrs	72 hrs
G.1.2	Shall continuously record Blue CSW station data for the duration of the training event	24 hrs	72 hrs
G.2.1	Shall continuously record Red force unit data for the duration of the training event	24 hrs	72 hrs
G.2.2	Shall continuously record Red force station data for the duration of the training event	24 hrs	72 hrs
G.3.1	Shall continuously record C2 unit transmitted data for the duration of the training event	24 hrs	72 hrs
G.3.2	Shall continuously record C2 received data for the duration of the training event	24 hrs	72 hrs
H.1.1	Shall produce timely Blue force after action report compatible with existing Navy reporting systems	3 hrs	30 min
H.1.2	Shall produce timely Red force after action report compatible with existing Navy reporting systems	3 hrs	30 min
H.2.1	Shall produce timely Blue force mission replay compatible with existing Navy reporting systems	3 hrs	30 min
H.2.2	Shall produce timely Red force mission replay compatible with existing Navy reporting systems	3 hrs	30 min

4. Requirements Functional Decomposition

The third step in the Laser-Based Training Assessment Team capstone systems engineering process, as part of the effort in determining the stakeholders' training system requirements, is the functional analysis phase. As described in *Systems Engineering and Analysis, fifth edition*, by Benjamin S. Blanchard and Wolter J. Fabrycky, the development of a functional description is essential to serve as a basis for identifying resources required for the system to fulfill its intended purpose (Blanchard and Fabrycky 2011). Training system requirements described the system with respect to its environment. In contrast, the functional analysis translates requirements into the types of functions the system will support, and describes the data needed for inputs and outputs of the system: “A function refers to a specific or discrete action (or a series of actions) that is necessary to achieve a given objective” (Blanchard and Fabrycky 2011, 86).

The team used Vitech’s University Edition of CORE to complete the functional analysis. The principle model used was the functional flow block diagram (FFBD). In the aforementioned text, Blanchard and Fabrycky provided the following examples of inputs, outputs, controls, and mechanisms which were used to conduct this analysis:

- Inputs—System requirements, organizational structure, raw materials, data/documentation
- Controls—Technical, Political, Sociological, Economic, Environmental
- Outputs—System /product ready for the customer use, Supporting resources, Waste (residue)
- Mechanisms—Human resources, Materials, Computer resources, Facilities/utilities, Maintenance and support (Blanchard and Fabrycky 2011)

a. Functional Flow Block Diagrams (FFBD)

The team used FFBDs to transform mission and system requirements into functions needed to fulfill the FAC/FIAC mission needs. These requirements guided the development of the Top-level FFBD. Figure 8 depicts the FFBD diagram of the functions that were identified as part of the system requirements analysis. This level is comprised of the functions of simulating Red forces, simulating Blue forces, managing information, and evaluating the training evolution. In Figure 8, the white boxes are the functions, while the green ovals depict the control for the associated box. As depicted, “simulate Blue forces” and “simulate Red forces” occurs in parallel followed by “manage information” ending with “evaluate performance.”

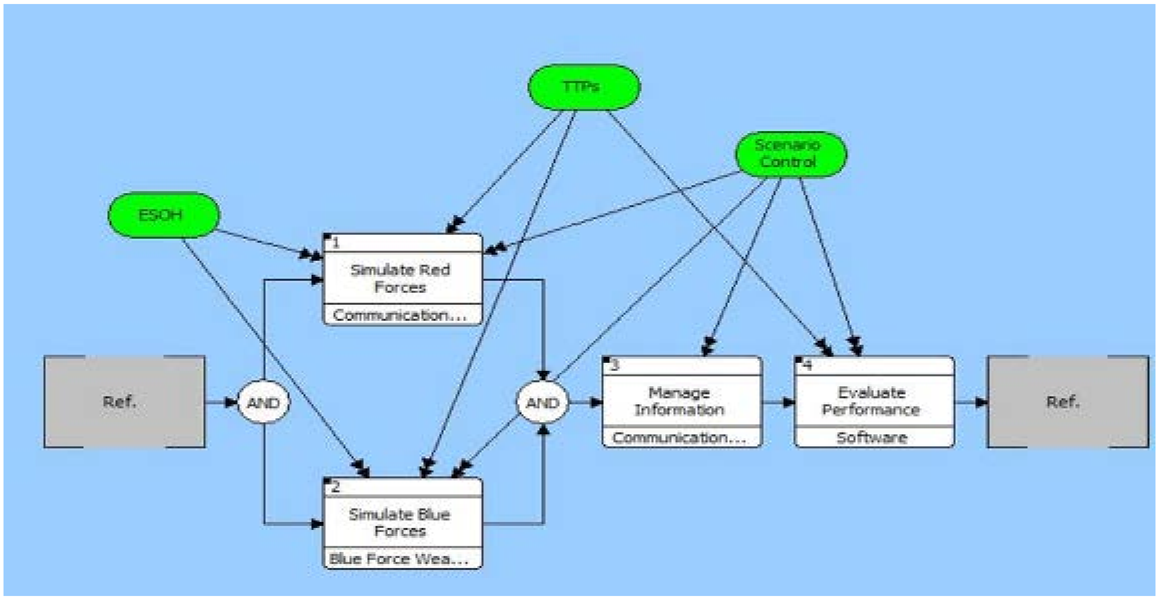

Figure 8. Level 1 FFBD—FAC/FIAC Training Top-Level Functions

Simulate Red forces, Figure 9, which follows the same format as above, is defined as using small water craft, up to 15 units, which are armed with either a .50-caliber (CAL) machine gun or a Rocket Propelled Grenade (RPG) launcher in place of an actual hostile unit. The Red forces weapons need to simulate the effects of live fire on Blue forces. Red force units will also need to simulate damage by Blue force simulated weapons fire. All associated Red force information will need to be transmitted to a command and control unit. These functions can be mapped to Requirements Table 4. , References C.2.1-C.2.2, C.1.1-C1.5, and D1.1-D.1.3.

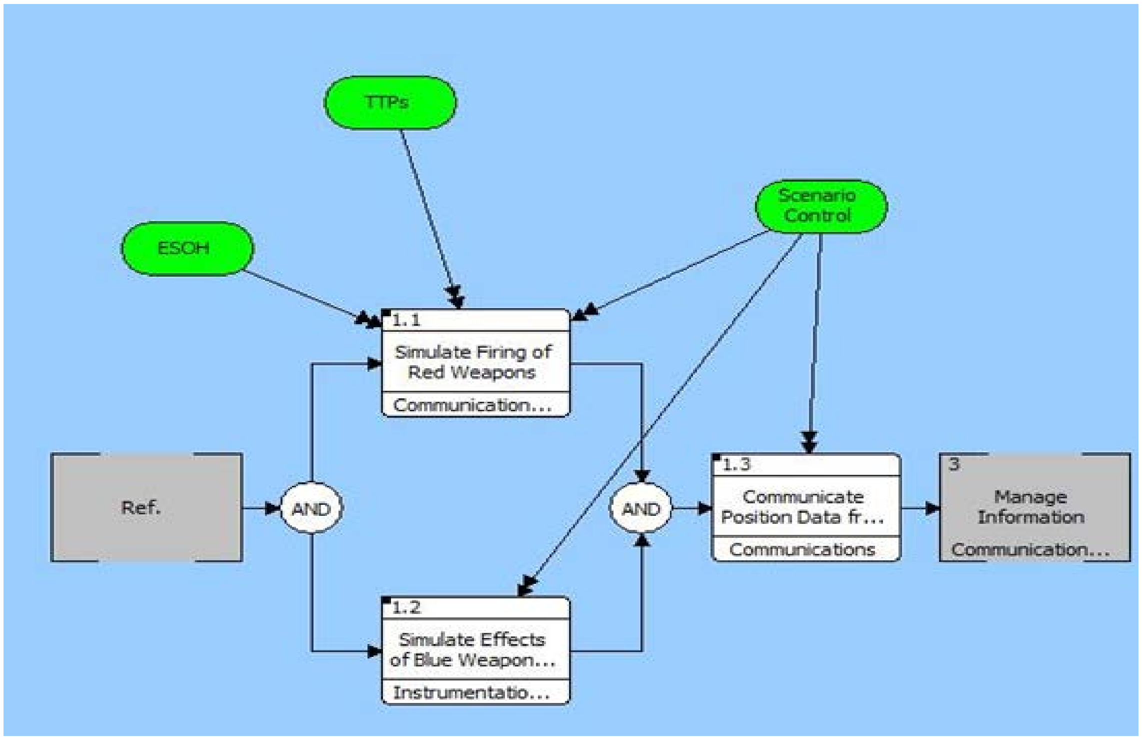

Figure 9. Level 2 FFBD—Simulate Red Forces

Simulate Blue forces, Figure 10, is defined as using Naval Combatants, up to three units, which are armed with multiple weapon types. This analysis was limited to .50-CAL machine guns, M240B machine guns, and MK-19 grenade launcher. Blue force weapons must simulate the effects of live fire on Red forces. Blue force units will also need to simulate damage by Red force simulated weapons fire. Additionally, all associated Blue force information will need to be transmitted to a command and control unit. These functions can be mapped to Requirements Table 4, References A.1.1, A.2.1, and B.1.1-B.4.6.

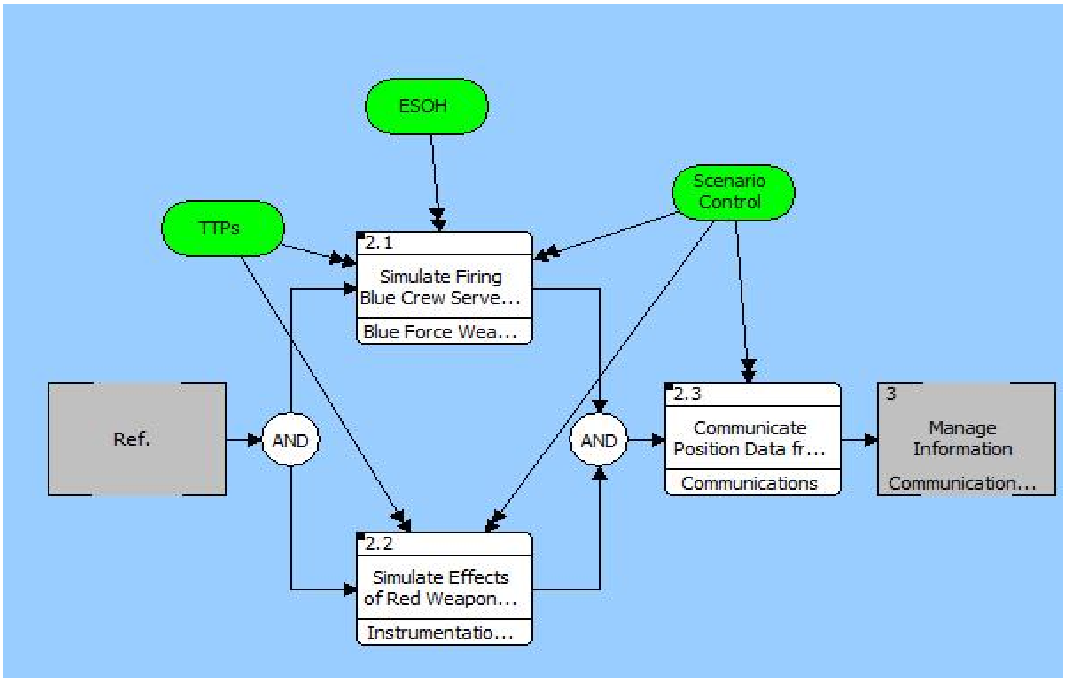

Figure 10. Level 2 FFBD—Simulate Blue Forces

Managing information requires that all associated information from participating units be received, processed, transmitted, and recorded. Information that will need to be received from each unit includes positional information, health status, and weapons data. Processing information includes determining the effects of the weapons. Transmitted information includes all received data and all processed data to the C2 node. These functions can be mapped to Requirements Table 4, References A.1.1-A.1.5, B.1.1-B1.3, and B3.1-B.4.6.

The system will require the ability to record associated data. The data being recorded will be available for after action analysis and training effectiveness determination. The analyzed data is the basis for after action reports and determination of unit preparedness.

Figures 8-10 provided the top levels of the FFBD for a FAC/FIAC training system. Each function was broken down into sub-functions (for more a complete set of FFBD's see Appendix D). These detailed FFBDs were further analyzed using IDEF0 Models.

b. Integration Definition Models (IDEF0)

Integration Definition Models for the FAC/FIAC training system were used to fully understand the inputs, controls, outputs, and mechanisms' interactions. The Top-level IDEF0, Figure 11, depicts the necessary inputs, mechanisms, and controls associated with the training system.

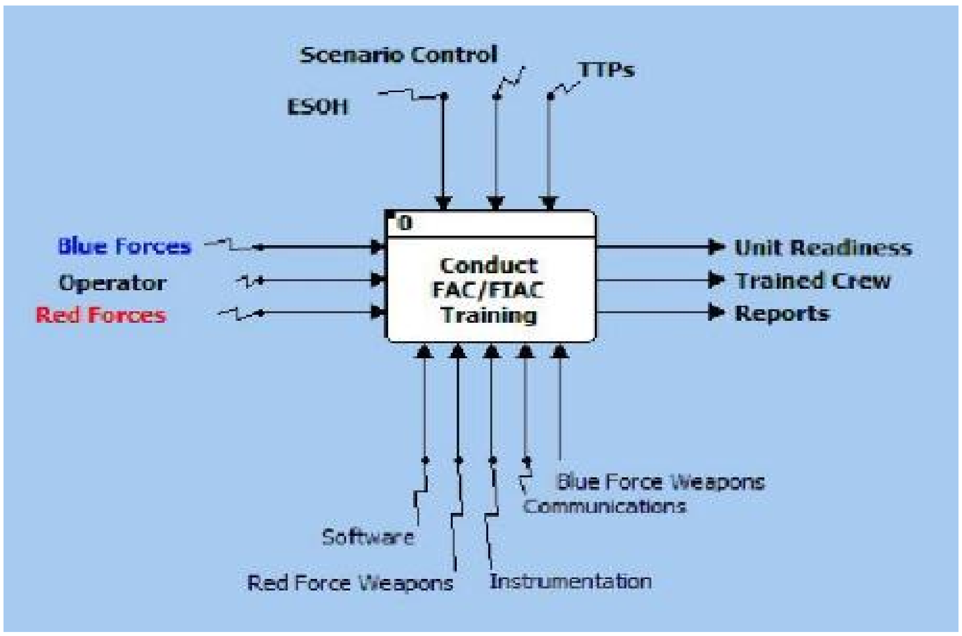

Figure 11. Conduct FAC/FIAC Training A0 IDEF0

Each function was individually analyzed in order to determine inputs, controls, outputs and mechanisms. Each functions' inputs were identified along with the associated outputs, mechanisms and controls. The Top-level inputs to a FAC/FIAC training system include: Red forces, Blue forces, and associated operators. Top-level controls for this system were determined to be scenario control instructions, environmental and safety regulations, and TTPs. Mechanisms required by the system were determined to be software, weapons, instrumentation, and communications. Outputs of the system were determined to be unit readiness, associated reports and trained crews. The complete breakdown of each function is available in Appendix E. IDEF0 Tables and Diagrams.

c. *FAC/FIAC Training System Functions*

The Top-level functions of conduct FAC/FIAC training, as depicted in the FFBD, are decomposed into four major functional areas: 1) Simulate Red forces, 2) Simulate Blue Forces, 3) Manage Information, and 4) Evaluate Performance. The results of the functional analysis for hierarchical levels 0 through 3 are provided in Table 5. The functions identified were provided as an input into the functional gap analysis segment. The remaining functions are provided in Appendix D, Table 19.

Table 5. Derived FAC/FIAC Training Functions

Number	Function
0	Conduct FAC/FIAC Training
1	Simulate Red Forces
1.1	Simulate Firing of Red Weapons
1.1.1	Simulate Red .50-CAL Weapons
1.1.2	Simulate Red RPG Weapons
1.1.3	Communicate Red Force Weapon Data
1.2	Simulate Effects of Blue Weapons on Red Forces
1.2.1	Receive Blue Forces Weapons effects
1.2.2	Simulate Effects of Blue .50-CAL Weapons on Red Forces
1.2.3	Simulate Effects of Blue M240B Weapons on Red Forces
1.2.4	Simulate Effects of Blue Mrk 19 Weapons on Red Forces
1.3	Communicate Position Data from Red Platforms
1.3.1	Transmit Position Information from Red Platforms
1.3.2	Transmit Heading Information from Red Platforms
1.3.3	Transmit Velocity Information from Red Platforms
2	Simulate Blue Forces
2.1	Simulate Firing Blue Crew Served Weapons
2.1.1	Simulate Blue .50 Weapons
2.1.2	Simulate Blue M240B Weapons
2.1.3	Simulate Blue Mrk 19 Weapons
2.1.4	Communicate Blue Force Weapon Data
2.2	Simulate Effects of Red Weapons on Blue Forces
2.2.1	Receive Red Force Weapons Effects
2.2.2	Simulate Effects of Red RPG Weapons on Blue Forces
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue Forces
2.3	Communicate Position Data from Blue Platforms
2.3.1	Transmit Position Information from Blue Platforms
2.3.2	Transmit Heading Information from Blue Platforms

Number	Function
2.3.3	Transmit Velocity Information from Blue Platforms
3	Manage Information
3.1	Receive Information
3.1.1	Receive Information From Red Weapons
3.1.2	Receive Information From Blue Weapons
3.1.3	Receive Information From Red Platforms
3.1.4	Receive Information from Blue Platforms
3.2	Process Information
3.2.1	Determine Effects of Red Weapons
3.2.2	Determine Effects of Blue Weapons
3.3	Transmit Information
3.3.1	Transmit Red Platform Status Information
3.3.2	Transmit Red Weapon Status Information
3.3.3	Transmit Blue Platform Status Information
3.3.4	Transmit Blue Weapon Status Information
3.4	Record Data
3.4.1	Record Red Weapon Data
3.4.2	Record Red Platform Data
3.4.3	Record Blue Weapon Data
3.4.4	Record Blue Platform Data
4	Evaluate Performance
4.1	Evaluate Data
4.1.1	Score Data Based on Metrics
4.1.2	Determine Readiness
4.2	Generate Reports
4.2.1	Readiness Report
4.2.2	After Action Report

C. PROTOTYPE CAPABILITIES ANALYSIS

1. I-TESS II Prototype System Capabilities

The I-TESS II prototype system in the Navy's possession was designed for U.S. Marine Corps (USMC) ground combat and modified for naval ship-to-surface training using instrumented HSMST and CSW. This prototype I-TESS II system was used during the operational demonstration proof of concept to demonstrate the capability of the system to support FoT training. Top-level capabilities that were demonstrated are depicted in Table 6.

Table 6. Prototype Capabilities (after Naval Surface Warfare Center—Corona Division 2012)

Capabilities
Simulated Blue force CSWs "fires"
Simulated effects of Blue force fires on four Red force FAC/FIAC
Command and Control of the demonstration
Data collection
After Action Replay
Data Analysis

The demonstration added instrumentation to existing CSWs (0.50-Caliber and M240B machine guns) which enabled the simulation of Blue forces "fires" with laser transmitting technology. Instrumentation onboard the simulated threats enabled the detection of laser energy and a determination of miss, near miss, or hit. Data collection, provided as part of the system, and data analysis was enabled with software operating on a laptop computer. Software was also utilized for AARs (Jauregui 2012). The team analyzed the prototype system to determine components and associated functions.

2. U.S. Naval Prototype Component Decomposition

This section details the components of this I-TESS II prototype system, shown in Figure 12, and their description as detailed in the FIAC Candidate Solution Report (Naval Surface Warfare Center - Corona Division 2012). The components of the I-TESS II system were distributed between the simulated Red forces (three manned HSMSTs and one QST) and five Blue force CSW positions onboard the DDG. Figure 12 shows a breakdown of a typical instrumented HSMST, its components, and the Man-worn Detection System (MDS).

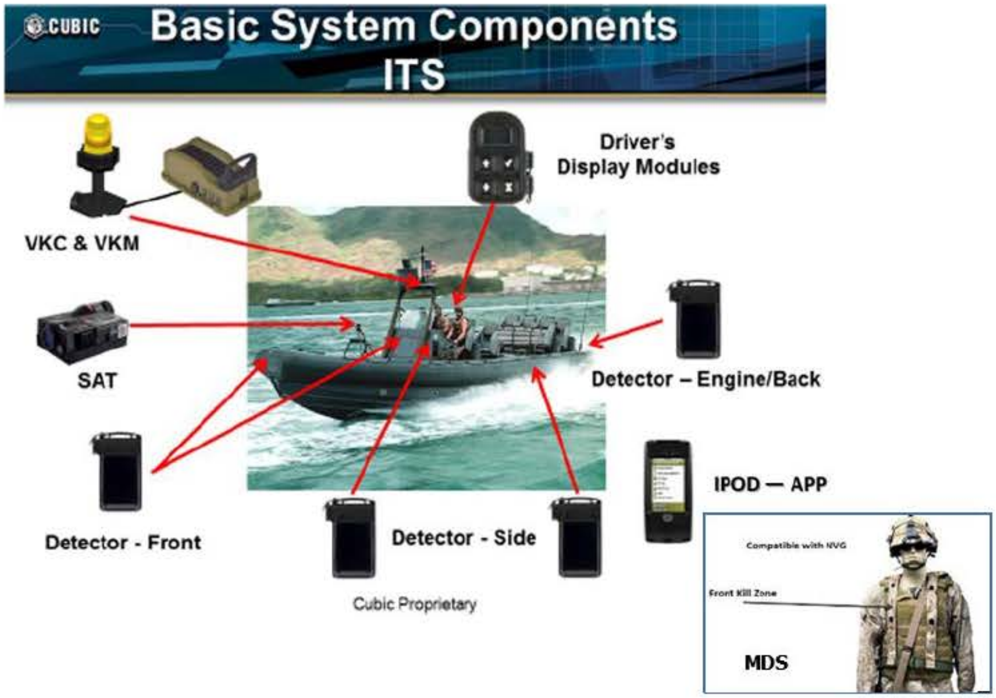

Figure 12. HSMST and MDS (after Cubic Defense Applications 2011)

The basic components of the prototype, locations and associated descriptions are detailed in Table 7. The target instrumentation was installed on the HSMST, while the CSW and C2 instrumentation were installed on the ship

Table 7. Prototype Component Description (from Cubic Defense Applications 2011)

Component	HSMST	Instrumented Ship	Description
Vehicle Kill Controller (VKC)	X		ITS controller, stops vehicle from operating if "hit"
Vehicle Kill Mast (VKM)	X		Training beacon (kill/near miss), indicates if the unit has been killed or missed
Detectors	X		Target sensors, senses laser transmitted information
Display Module	X		Operator interface, allows for the operator to view system information
Man-worn Detection System (MDS)	X	X (harness only)	Integrated harness, UHF transmitter, detectors, & halo, provides sensors for detecting laser

			energy and a transmitter/receiver for machine to machine transfer of data
Controller Gun	X		Kill revival, allows for a unit to be reset and continue participation
Very High Frequency Time Division Multiple-Access (VHF-TDMA)	X		Transmitter, transmits system information
Serial Radio Frequency Module (SMRFI)	X		Wireless bridge between detectors &VKC, allows for data transfer between elements of the system
Small Arms Transmitter (SAT)		X	Class 3R laser—simulates weapon fire by transmitting laser energy
Man-portable C2 unit		X	Command & Control unit, enables command and control functions via portable unit
Mirror Alignment Jig Kit (MAJiK)		X	SAT alignment, enables user alignment of SAT with weapon sights

3. U.S. Naval Prototype Functions

The prototype system's capabilities, Table 6, and component descriptions, Table 7. , were analyzed to determine associated functions as they pertained to a FAC/FIAC laser-based training system. The approach was a "top-down" look at the system, from major functions (i.e., does it simulate Blue forces) down to the component level. The prototype's major functions include simulate red forced, simulate blue forces, manage information, and evaluate performance

The results of the Laser-Based Training Assessment Team's functional analysis for hierarchical levels 0 through 3 are provided in Table 8. The functions identified were provided as an input into the functional gap analysis segment. The remaining functions, with associated inputs, controls, outputs, and mechanisms are provided in Appendix E. IDEF0 Tables and Diagrams, Table 20.

Table 8. Derived I-TESS II Prototype Functions

Number	Function
0	Conduct FAC/FIAC FoT Training
1	Simulate Red Forces
1.2	Simulate Effects of Blue Weapons on Red Forces
1.2.1	Receive Blue Forces Weapons effects
1.2.2	Simulate Effects of Blue .50-CAL Weapons on Red Forces
1.2.3	Simulate Effects of Blue M240B Weapons on Red Forces
1.3	Communicate Position Data from Red Platforms
1.3.1	Transmit Position Information from Red Platforms
1.3.2	Transmit Heading Information from Red Platforms
1.3.3	Transmit Velocity Information from Red Platforms
2	Simulate Blue Forces
2.1	Simulate Firing Blue Crew Served Weapons
2.1.1	Simulate Blue .50 Weapons
2.1.2	Simulate Blue M240B Weapons
2.1.4	Communicate Blue Force Weapon Data
2.3	Communicate Position Data from Blue Platforms
2.3.1	Transmit Position Information from Blue Platforms
2.3.2	Transmit Heading Information from Blue Platforms
2.3.3	Transmit Velocity Information from Blue Platforms
3	Manage Information
3.1	Receive Information
3.1.3	Receive Information From Red Platforms
3.1.4	Receive Information from Blue Platforms
3.2	Process Information
3.2.2	Determine Effects of Blue Weapons
3.3	Transmit Information
3.3.1	Transmit Red Platform Status Information
3.3.3	Transmit Blue Platform Status Information
3.3.4	Transmit Blue Weapon Status Information
3.4	Record Data
3.4.2	Record Red Platform Data
3.4.3	Record Blue Weapon Data
3.4.4	Record Blue Platform Data
4	Evaluate Performance
4.2	Generate Reports
4.2.2	After Action Report

D. FUNCTIONAL GAP ANALYSIS

Functional gap analysis was conducted using the functions identified as part of the FAC/FIAC training requirements development (Table 5.) and the capabilities analysis of the prototype Navy I-TESS II system as inputs (Table 8.). The yellow highlighted functions in Table 9 depict the identified functional gaps for hierarchical levels 0 through 3, the non-highlighted rows, either white or grey, are functions that have been fulfilled by the prototype system (see Appendix D, Table 20).

Table 9. FAC/FIAC Functional Gaps

Number	Function
0	Conduct FAC/FIAC Training
1	Simulate Red Forces
1.1	Simulate Firing of Red Weapons
1.1.1	Simulate Red .50-CAL Weapons
1.1.2	Simulate Red RPG Weapons
1.1.3	Communicate Red Force Weapon Data
1.2	Simulate Effects of Blue Weapons on Red Forces
1.2.1	Receive Blue Forces Weapons effects
1.2.2	Simulate Effects of Blue .50-CAL Weapons on Red Forces
1.2.3	Simulate Effects of Blue M240B Weapons on Red Forces
1.2.4	Simulate Effects of Blue Mrk 19 Weapons on Red Forces
1.3	Communicate Position Data from Red Platforms
1.3.1	Transmit Position Information from Red Platforms
1.3.2	Transmit Heading Information from Red Platforms
1.3.3	Transmit Velocity Information from Red Platforms
2	Simulate Blue Forces
2.1	Simulate Firing Blue Crew Served Weapons
2.1.1	Simulate Blue .50 Weapons
2.1.2	Simulate Blue M240B Weapons
2.1.3	Simulate Blue Mrk 19 Weapons
2.1.4	Communicate Blue Force Weapon Data
2.2	Simulate Effects of Red Weapons on Blue Forces
2.2.1	Receive Red Force Weapons Effects
2.2.2	Simulate Effects of Red RPG Weapons on Blue Forces
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue Forces
2.3	Communicate Position Data from Blue Platforms
2.3.1	Transmit Position Information from Blue Platforms
2.3.2	Transmit Heading Information from Blue Platforms

Number	Function
2.3.3	Transmit Velocity Information from Blue Platforms
3	Manage Information
3.1	Receive Information
3.1.1	Receive Information From Red Weapons
3.1.2	Receive Information From Blue Weapons
3.1.3	Receive Information From Red Platforms
3.1.4	Receive Information from Blue Platforms
3.2	Process Information
3.2.1	Determine Effects of Red Weapons
3.2.2	Determine Effects of Blue Weapons
3.3	Transmit Information
3.3.1	Transmit Red Platform Status Information
3.3.2	Transmit Red Weapon Status Information
3.3.3	Transmit Blue Platform Status Information
3.3.4	Transmit Blue Weapon Status Information
3.4	Record Data
3.4.1	Record Red Weapon Data
3.4.2	Record Red Platform Data
3.4.3	Record Blue Weapon Data
3.4.4	Record Blue Platform Data
4	Evaluate Performance
4.1	Evaluate Data
4.1.1	Score Data Based on Metrics
4.1.2	Determine Readiness
4.2	Generate Reports
4.2.1	Readiness Report
4.2.2	After Action Report

As can be seen in Table 9, the functional gaps primarily were in the area of Red force's ability to participate with simulated weapons, and not being able to capture the associated Red force data. Additional gaps were identified in the area of scoring the data collected based on metrics, and producing readiness reports upon completion of the training evolution. The team's identified functional gaps are summarized in Table 10.

Table 10. Summary of FAC/FIAC Functional Gaps

Number	Element
1.1	Simulate Firing of Red Weapons
1.1.1	Simulate Red .50-Cal Weapons
1.1.2	Simulate Red RPG Weapons
1.1.3	Communicate Red force Weapon Data
1.2.4	Simulate Effects of Blue Mrk 19 Weapons on Red forces
2.1.3	Simulate Blue Mrk 19 Weapons
2.2	Simulate Effects of Red Weapons on Blue forces
2.2.1	Receive Red force Weapons Effects
2.2.2	Simulate Effects of Red RPG Weapons on Blue forces
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue forces
3.1.1	Receive Information From Red Weapons
3.2.1	Determine Effects of Red Weapons
3.2.2	Determine Effects of Blue Weapons
3.3.2	Transmit Red Weapon Status Information
3.4.1	Record Red Weapon Data
4.1.1	Score Data Based on Metrics
4.1.2	Determine Readiness
4.2.1	Readiness Report

Understanding the root cause of the gaps was important to the team's efforts to provide the Navy with recommendations towards the integration of laser-based systems for FoF training. The objectives of the prototype demonstration as it related to FoT training might have caused several, if not all, of the functional gaps identified. Further analysis of the Marine Corps implementation of I-TESS II system was determined to be needed.

E. TECHNOLOGY ASSESSMENT

A technology assessment was conducted by the team to search for technologies that could replace, augment, or integrate with the laser-based training system in an attempt to close the previously identified gaps. Of the gaps identified, the team focused technology research efforts on FoF functions (Red force related functions), and communications limitations (data collection) of the Navy prototype system.

1. USMC I-TESS II System Capabilities

The USMC implemented the I-TESS II training system specifically for FoF scenarios, see Figure 13. In addition to the FoF capabilities the Marine Corps implemented on their I-TESS II system, they also increased its interoperability with several other systems. Assessing the capabilities and functions supported by the Marines' I-TESS II training system provides insight for technologies to fulfill some of the functional gaps previously identified for the Navy system.

The USMC variant of the I-TESS II system is currently capable of simulating the following weapons using the Small Arms Transmitters (SATs):

- M4, M16, M249, AK-47, and M9
  - Class 1 laser certification
  - M9 has built-in SAT
- M2, M240, and M40
  - Class 3R laser certification

The SAT mounting brackets are interchangeable and compatible with both 5.56 and 7.62-caliber weapons. The SATs activate in response to the firing of a blank round, marked round (5.56 or 9mm), or dry fire. The firing mode uses two discreet signals to simulate the flash and "bang" from the weapon to maximize realism. Currently the SAT performance is able to match weapon performance at maximum effective range within +/- 10%.

The full I-TESS II system fielded with the Marine Corps has additional capabilities that were not simulated in the U.S. Naval variant. These capabilities include:

- Hand grenade (M-67) Simulator—Simulate detonation time and blast radius (~10 m)
- Rocket-propelled grenade (RPG) surrogate - RPG-7
  - User-aligned sights
  - Firing realism enhanced by flash and smoke produced by Anti-tank Weapons Effects Simulator (ATWESS)
  - Shoulder position sensor
- Anti-tank (AT-4) surrogate
  - Simulated tube contains control electronics and factory-aligned sights
  - Firing realism enhanced by flash and smoke produced by Anti-tank Weapons Effects Simulator (ATWESS)

Table **Error! Reference source not found.** depicts the functional gaps previously identified in Section D. The functions that would be fulfilled by implementation of the additional features demonstrated on the USMC I-TESS II system, identified above, are highlighted green. Functions that would only be partially fulfilled are highlighted yellow, and non-highlighted functions remain unfulfilled.

Table 11. Marine Corps I-TESS II System Funtional Gap Fills

Number	**Element**
1.1	Simulate Firing of Red Weapons
1.1.1	Simulate Red .50-Cal Weapons
1.1.2	Simulate Red RPG Weapons
1.1.3	Communicate Red force Weapon Data
1.2.4	Simulate Effects of Blue Mrk 19 Weapons on Red forces
2.1.3	Simulate Blue Mrk 19 Weapons
2.2	Simulate Effects of Red Weapons on Blue forces
2.2.1	Receive Red force Weapons Effects
2.2.2	Simulate Effects of Red RPG Weapons on Blue forces
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue forces
3.1.1	Receive Information From Red Weapons
3.2.1	Determine Effects of Red Weapons
3.2.2	Determine Effects of Blue Weapons
3.3.2	Transmit Red Weapon Status Information
3.4.1	Record Red Weapon Data
4.1.1	Score Data Based on Metrics
4.1.2	Determine Readiness
4.2.1	Readiness Report

Even though the Marine Corps was able to demonstrate successfully Simulate Firing Red Weapons and Communicate Red force Weapon Data during their usage, the team has evaluated them as only partially fulfilled for a NAVY system due to different environmental conditions and some issues the NAVY encountered during their operational demonstration. The NAVY prototype system experienced some communication issues during the demonstration. Specifically, one of the simulated Red force FACs (HSMST) dropped in and out of the scenario and one of the CSW positions was not able to receive or report its GPS position. Corona's post-exercise data analysis revealed three issues with the GPS tracking ability of the prototype solution. While the demonstration participants were underway, the GPS signal became degraded. The degraded GPS signal caused one of the CSW positions to stop reporting its data in real time, and caused the locations of HSMSTs to be significantly different than the ground truth location provided by radar. The second issue involved the GPS locations for the Independent Targeting System (ITS) kit and associated MDSs. These locations were inconsistent due to ITS kit and MDS independent reporting cycles and were compounded by poor GPS quality. The final issue involved the reporting rate of the ITS kits and MDSs. The I-TESS II reporting rate was set at four seconds. At speeds of 45 knots, an HSMST can cover 92.6m in that interval. The result is “jumping” of locations at distances near 100m and this was witnessed during replay (AAR). (Jauregui 2012).

The Navy I-TESS II system also suffered from some LOS communication issues. Command and control functionality for the I-TESS II is accomplished via standard network communication protocols between the individual components and the control center as shown in Figure 13. As represented in Figure 14. , the C2 system is a “Live-Virtual-Constructive (LVC) and Joint Training enabled with Distributed Interactive Simulation (DIS), High Level Architecture (HLA) and Test and Training Enabling Architecture (TENA) interface support” (Cubic Defense Applications Inc. 2011, 1). For I-TESS II this network is supported via 2.4 GHz RF wireless line-of-sight communications, which can be difficult to maintain in the maritime environment.

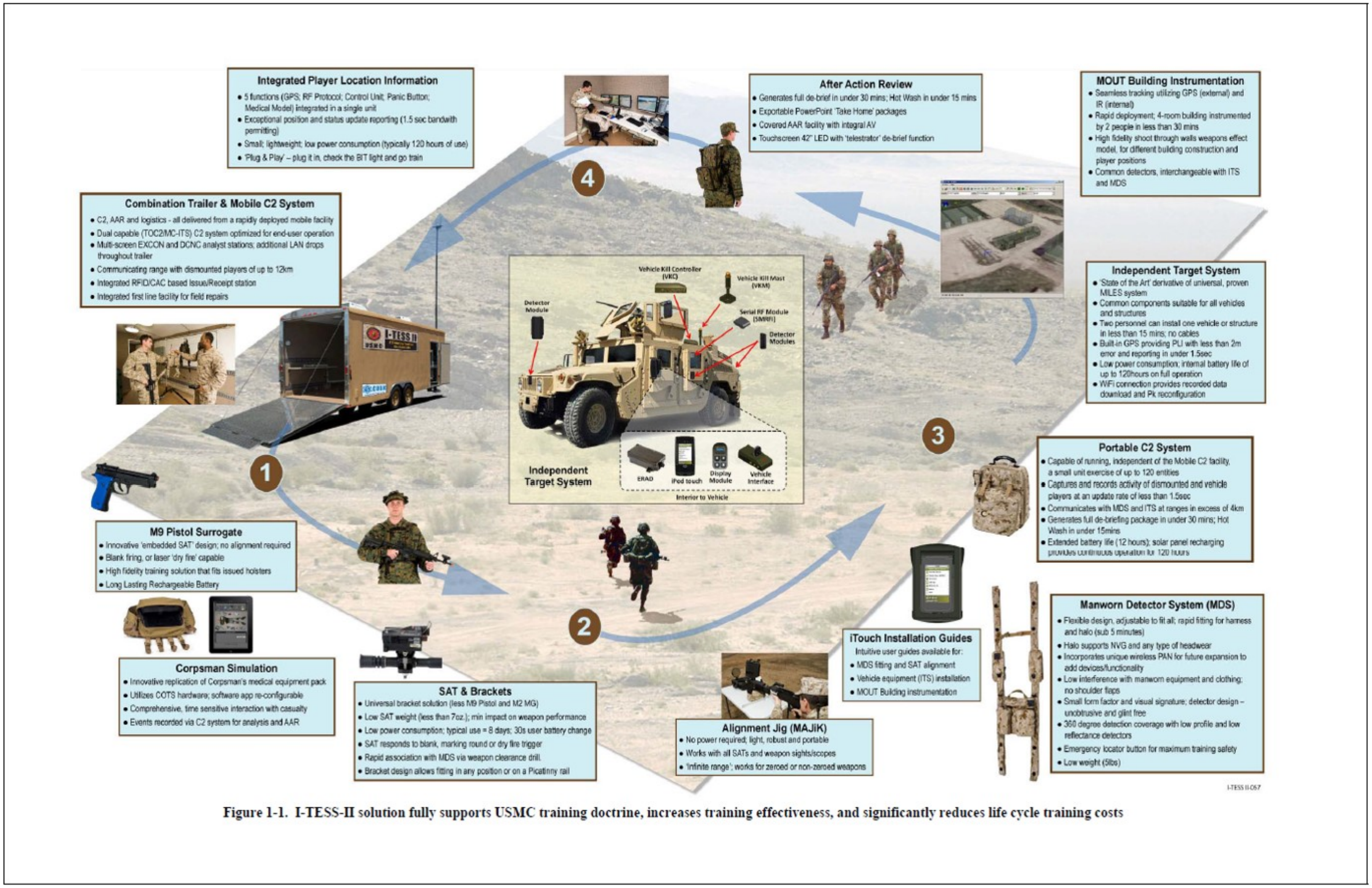

Figure 13. USMC I-TESS II System (from Cubic Defense Applications 2011)

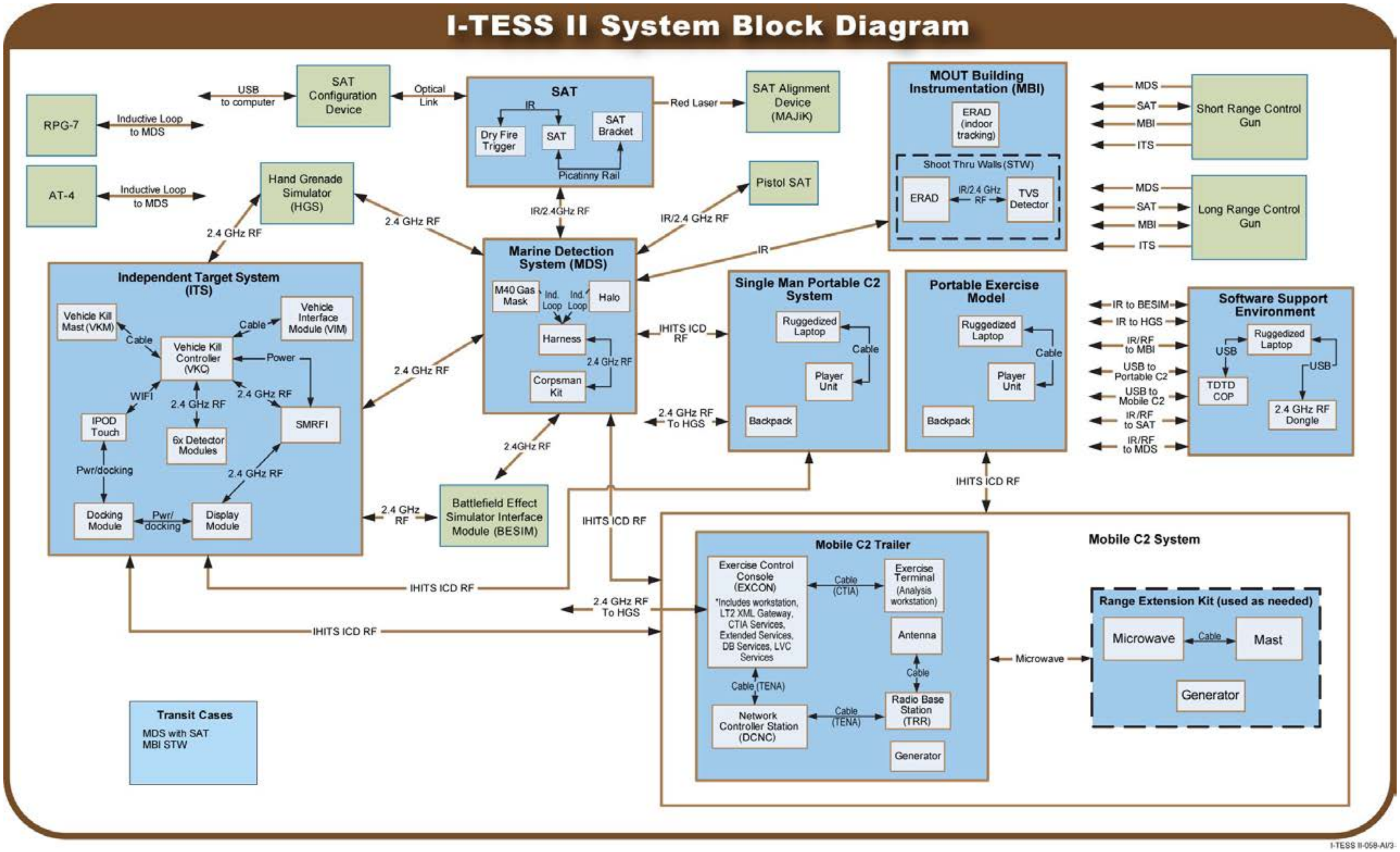

Figure 14. I-TESS II System Block Diagram (from Cubic Defense Applications 2011)

Two major areas remaining unfulfilled are Simulate the effects of Red force weapons on Blue forces and Score Data. Even though the USMC's implementation has shown that the I-TESS II system is capable of being incorporated on many different types of vehicles for FoF training, the team's assessment is that this capability and associated functions (simulated/determining the effects of Red force weapons) has not been demonstrated on a platform the size of a naval destroyer. SAT sensitivity, as described in the Corona trip report exert below, is one issue that will need to be overcome for I-TESS II to be useful in FoF training for the Navy.

> SAT sensitivity versus target density—in multi-ship and multi-FAC scenarios at ranges of 500-1,000 yards. [As shown in **Error! Reference source not found.**] target sensitivity of the SAT currently overlaps at 500m. Beyond 400m, the SAT model diameter coverage overlap grows linearly, with the possibility of hitting or killing one of two detectors at distances greater than 800m. (Jauregui 2012)

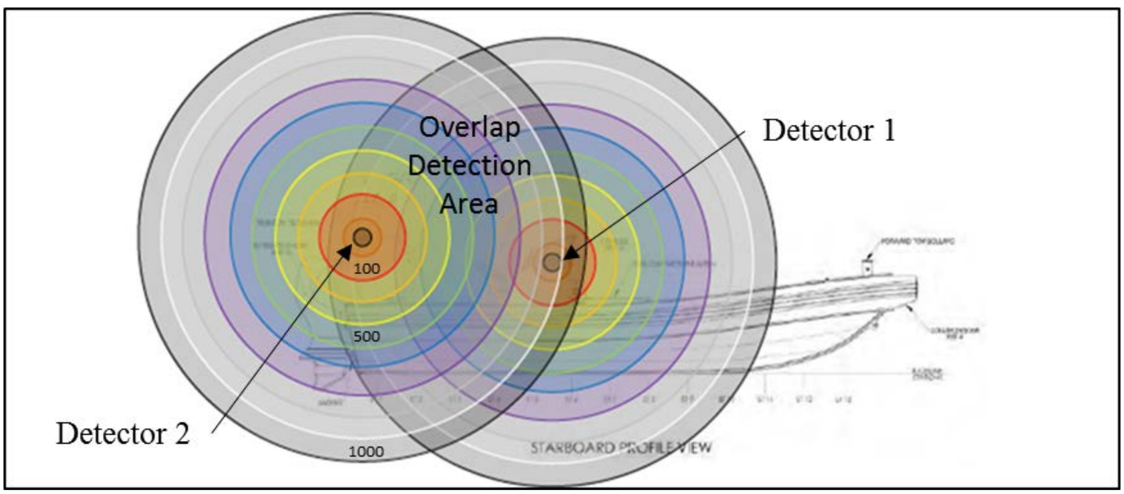

Figure 15. I-TESS II SAT Sensitivity Model (after Naval Surface Warfare Center—Corona Division 2012)

Table **Error! Reference source not found.** shows the specific model diameters for different engagement ranges (Jauregui 2012). The effect of overlapping targets is magnified during multi-ship/multi-Red force scenarios that have additional targets installed in multiple locations and orientations.

Table 12. I-TESS II Detection Model at 16 mrads (after Naval Surface Warfare Center—Corona Division 2012)

Engagement Range (m)	Model Diameter (SAT sensitivity) (m)
50	0.08
100	0.16
200	0.32
300	0.48
400	0.65
500	0.80
600	0.96
700	1.12
800	1.28
900	1.44
1000	1.60

Finally, neither the Navy nor the Marine Corps version of the I-TESS II system incorporates the ability to automatically evaluate performance compared to a matrix or determine unit readiness, so those Navy functions remain unfulfilled. Table 13. summarizes the remaining FAC/FIAC functional gaps after including functions demonstrated by the USMC's system integration. The first two highlighted yellow are only partially fulfilled as discussed above.

Table 13. Summary of Remaining FAC/FIAC Functional Gaps

Number	Element
1.1	Simulate Firing of Red Weapons
1.1.3	Communicate Red force Weapon Data
2.2	Simulate Effects of Red Weapons on Blue forces
2.2.1	Receive Red force Weapons Effects
2.2.2	Simulate Effects of Red RPG Weapons on Blue forces
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue forces
3.2.1	Determine Effects of Red Weapons
3.2.2	Determine Effects of Blue Weapons
4.1.1	Score Data Based on Metrics
4.1.2	Determine Readiness
4.2.1	Readiness Report

The current implementation of the prototype system requires the use of wired and wireless LOS technologies when transferring data which in a maritime environment can significantly limit range. Radio frequency identification (RFID) was assessed by the team as a potential technology to improve wireless data transfer and overcome the prototypes range and LOS limitations. RFID will be discussed in the next section.

Simulating the effects of Red force weapons fire on Blue forces (and subfunctions), and the effects of Blue weapons on Red forces is another outstanding gap. Two technologies were identified that might fulfill this gap, motion capture, and geometric pairing (geopairing). Geopairing, which may also be valuable to overcome LOS gaps, will be discussed in section 3 and motion capture, ultimately found not be a viable solution, can be found in Appendix F. Motion Capture. It was further determined that "Score Data Based on Metrics," "Determine Readiness," and "Readiness Reports" will require the development of additional software in order to fulfill and will not be discussed further.

2. Radio Frequency Identification

Radio frequency identification uses radio waves to transfer data. RFID technology uses small transponders, or tags, attached to a physical object with identifying information. An RFID system also uses a two-way radio transmitter-receiver, called an RFID reader, to wirelessly interrogate the tags. Figure 16 illustrates the major components of any RFID systems (International Air Transport Association 2013).

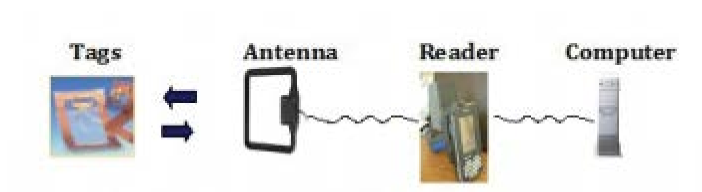

Figure 16. Major Components of any RFID System

Radio frequency ID technology has been around since the 1950s but has grown tremendously in recent years. It is commonly found on highways for automatic toll collections and has transformed global supply chain management and inventory controls.

It is a mature technology that can provide ability to read, write, and change data and information on tags quickly and accurately. RFID technology can also read hundreds of tags per seconds without LOS. The Department of Defense (DOD) has adopted RFID technology to address key challenges in asset visibility to help enable accurate, hands-free data capture for logistics support. Specific RFID tags are required for shipments to a growing list of distribution depots around the globe as mandated by DOD Federal Acquisition Regulations (DFARS) Clause 252.211-7006.

The RFID tags can be passive, semi-passive, or active. A passive tag does not require a battery and instead uses the radio energy transmitted by the reader to return a signal. Because of the need to transform the reader's radio energy to transform a signal, passive RFID does not have a long range. A semi-passive RFID tag has a battery and is activated in the presence of an ID reader. In contrast, an active tag has an on-board battery or power source to respond to or initiate a signal (Weiss 2007). Table 14 summarizes the RFID configurations.

Table 14. RFID Passive, Semi-Passive, and Active Comparison

Tag Type	**Passive**	**Semi-Passive**	**Active**
Power Source	Harvest RF Energy	Battery	Battery
Communication	Response Only	Response Only	Response or Initiate
Max Range	<10m	>100m	>100m
Relative Cost	Least	More	Most

Different RFID Systems also operate in different frequencies ranging from Low Frequency (LF), High Frequency (HF), Ultra-high Frequency (UHF), and Microwave bands. Each range of frequencies offered different operating ranges, power requirements, and performance. Figure 17 illustrates the most commonly used passive RFID frequencies and read distances. An active RFID can increase read range to as much as 300 feet (Defense Acquisition University 2007).

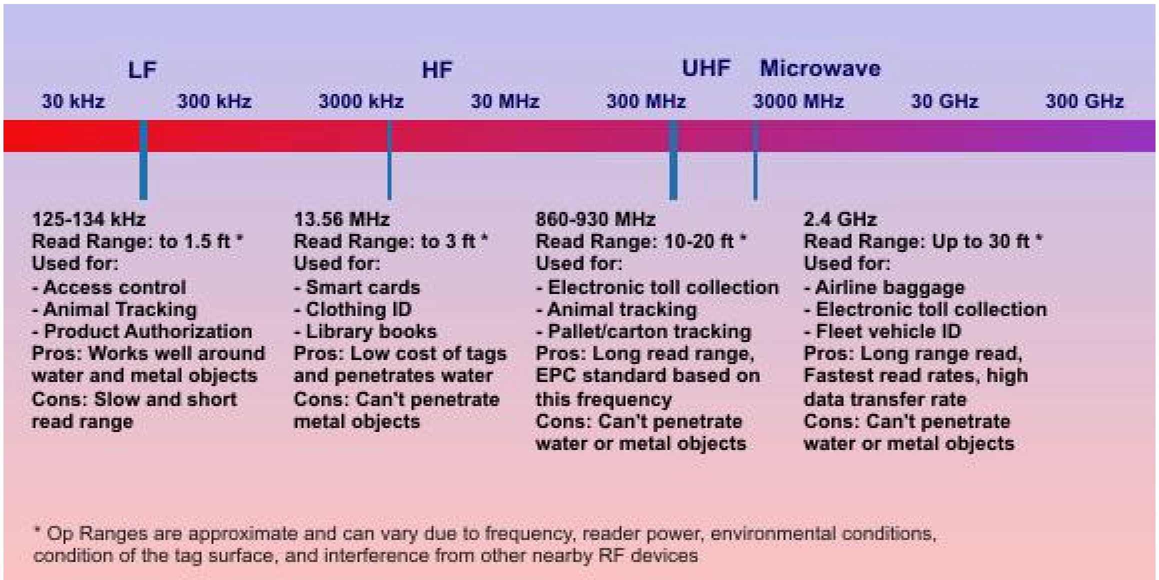

Figure 17. RFID Operating Frequency/Read Distance/Usage Chart (from Defense Acquisition University 2007)

Of the prototype gaps that might be fulfilled using RFID technology, additional frequencies and data transfer rates, loss of data due to range or LOS limitations (Communicate Red force data) is a critical one; however, there are too many drawbacks. One serious drawback is that while it has the ability to read hundreds of tags simultaneously, it reads tags that it was not supposed to read. There is a considerable challenge with data discrimination in knowing which items are to be read and which items are to be ignored. Even though RFID technology does not require direct LOS, and has proven effective at simulating indirect fire in MILES ground combat training for grenades and IEDs, it does not appear to be useful in the FAC/FIAC environment especially given the challenges with data discrimination. Given the range limitations and open water operating environment with engagements at upwards of 1500m, current RFID technology does not appear to be a viable augmentation to a laser-based training system for the Navy. The gaps identified in Table **Error! Reference source not found.** remain unchanged.

3. Geometric Pairing

One of the current gaps in the Navy's evaluation system (I-TESS II) is the necessity of LOS for the system to properly communicate. This issue also affects the system's ability to determine shot effects on targets outside LOS. The Marine Corps and Army have also noted this. "Since the early 1980s, the U.S. Army has conducted force-on-force Tactical Engagement Simulation (TES) exercises using laser-based systems such as… [MILES] for Real Time Casualty Assessment (RTCA). However, this laser-based approach requires… [LOS] between emitter and sensor to match a shooter with a target for a given direct-fire event (shot pairing) and is, therefore, inadequate for non-line-of-sight shot pairing" (Trivette, Jr, Deres and Youmans 1999, 1-2).

Geometric Pairing (a.k.a. geopairing, geo-pairing, or GP) is a combination of physical measurements from sensors, geometry, and knowledge of terrain that are used to predict the effects of weapons. "The basic premise of geopairing is the calculation of the point of impact or detonation of a round based on knowledge of the position of the shooter and target, the time of trigger pull, the orientation vector of the weapon, and the characteristics of the weapon and round fire" (Trivette, Jr, Deres and Youmans 1999, 1). The intent of investigating this technology is to improve the performance of the I-TESS II system. In fact, the Army has already been integrating geopairing into its MILES based training system called OneTESS.

> One of [OneTESS'] novel features is the addition of geometric pairing to augment lasers and terrain dependent ordnance impact and explosion calculations required for realistic casualty assessment. (Baer et al. 2008, 1–2)

As previously noted, the variety of ground systems training used by the Army and Marine Corps which use MILES technology, all have common shortcomings as related to weapon fidelity. "Though laser-pairing systems have served the operational test community well for decades, problems in maintenance, accuracy, safety, (and) mismatch in obscurant specific bullet versus- pulse propagation characteristics…have led to the investigation of alternatives" (Baer, Baer, et al. 2005, 3). Nonetheless, the shortcomings noted by the MILES users have routinely included lack of weapon fidelity. "OneTESS will simulate a multitude of different engagements, proper doctrines, and weapon capabilities as well as stimulate detectors, sensors, monitors and countermeasures" (Schricker and Ford 2007, 3). The technology improvements proposed by OneTESS and geopairing solutions provide a way to simulate indirect fire and BLOS engagements. Furthermore, "GP enables the … system … to overcome most of the limitations of laser pairing, that is, engaging a target through smoke, rain, fog, and foliage and at longer ranges than are safe with a laser" (Baer, Baer, et al. 2005, 3-4).

Geopairing is not without drawbacks. With the amount of data required for a geopairing solution, there are many sources of potential data inaccuracies. These inaccuracies are more evident in larger range weapons; however, the errors do occur for all caliber weapons. There are several papers from the Program Executive Office for Simulation, Training, and Instrumentation that document and discuss these variances. In a paper from Shricker and Ford, the courses of action proposed include ignoring the problem, modeling the variances, and pursuing additional instrumentation on the weapons. They also go on to note that ignoring the problem may be an acceptable solution. Additional instrumentation on the weapon could provide the actual initial velocity of a projectile or virtual projectile. This data would be used by a geopairing system to improve the calculated results, providing more realistic values and modeling subtle variances between individual rounds and weapons.

> While producing the most realistic results in a laboratory setting, this method would also have numerous disadvantages. Most critically, added instrumentation would add weight to a system that already has strict weight requirements…. Further, such a solution would undoubtedly add complexity and communication latency to the geo-pairing solution. (Schricker and Ford 2007, 12)

The potential issues with geopairing technologies are subjective. Since the Army's and Marine's implementations are different than the Navy's, some issues may not be encountered for all three services; and if so, perhaps not to the same degree. That being said, there has been a large amount of effort already spent by other agencies on resolving their laser training system deficiencies. The Navy can benefit from these efforts. As discussed previously in this report, in order to determine weapon effects, the

Navy has requirements to capture data for aiming/heading (vectors), firing (velocities), position (GPS), and overall accurate weapons effect. These requirements have been noted as partially filled or not filled by the prototype I-TESS II system. A geopairing solution could be a gap filler for both the LOS and determining the effects of Red and Blue force weapons (more precision in determining impact). The remaining unfulfilled gaps are listed in Table 15, highlighted in red while the partially fulfilled gaps are highlighted yellow. As can be seen, except for the previously mentioned software development needed for scoring (highlighted red), the team believes that geopairing can at least partially fulfill the remaining functional gaps.

Table 15. Remaining FAC/FIAC Functional Gaps

Number	**Element**
1.1	Simulate Firing of Red Weapons
1.1.3	Communicate Red force Weapon Data
2.2	Simulate Effects of Red Weapons on Blue forces
2.2.1	Receive Red force Weapons Effects
2.2.2	Simulate Effects of Red RPG Weapons on Blue forces
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue forces
3.2.1	Determine Effects of Red Weapons
3.2.2	Determine Effects of Blue Weapons
4.1.1	Score Data Based on Metrics
4.1.2	Determine Readiness
4.2.1	Readiness Report

IV. ADDITIONAL CONSIDERATIONS WHEN USING LASER-BASED TRAINING

Paraphrasing the initial needs statement—the Navy needs to incorporate laser-based training into its training program—led to the development of research questions focused on laser-based technology. While the below items are not directly related to the requirements and functions of converting to a laser-based system, they are side effects of doing so and are therefore discussed here for overall reader awareness.

A. HUMAN FACTORS WHEN USING LASER-BASED TRAINING SYSTEMS

In addition to the technical approach the team looked at several other areas for shipboard compatibility, training realism, and laser hazards. Human factors assessment is part of sound engineering, and for this analysis is important due to the potential impacts of training realism, and laser hazards associated with laser-based training.

1. Training Realism

Among the drawbacks of laser-based training, in general, are the lack of weapon recoil (firing blanks is still lacking in comparison to training with live rounds) and the difficulties with getting a visual indication of impact points. The following notes the reaction from the demonstration team:

> Each operator stressed that the Navy's M2 normal mode of operation is to "walk into targets," not sighted in as in other services, USMC/US ARMY. Given the SATs inability to provide equivalent/modeled tracer or splash feedback, the primary operation use case cannot be modeled by MILES at this time. (Jauregui 2012, C-2,2)

2. Safety Concerns of Using Laser-Based Training Systems

The I-TESS II laser-based system uses an American National Standards Institute (ANSI) Class 3R laser (Jauregui 2012, 5). The system has been evaluated and results documented in Department of Army Memo dated 09 September 2009. The laser is considered safe for use without laser protective eyewear (unintentional eye exposure) and is not a skin or material burn hazard.

The OPNAVINST 5100.27B provides naval policy and guidance regarding laser systems, detailing the training, design, review and control requirements for laser systems. Additionally the instruction provides a list of applicable laser safety documentation for military laser systems and training. MIL_HDBK-828B w/CHANGE 1 provides guidelines for laser range operations, safety, and controls during laser system use.

B. ENVIRONMENTAL IMPACTS OF "LIVE" ORDNANCE TRAINING

Live ammunition can have severe consequences for the environment. Vieques, Puerto Rico, is the site of a former Navy training facility that has now been closed to operational training exercises. Table 16 shows the anticipated cost of the damage to be over $530 million. Some of the training activities conducted here in the past include naval gunfire training, air-to-ground ordnance delivery, amphibious landings, use of live ordnance, and ammunition storage (Department of the Navy [Vieques] 2012).

Table 16. Environmental Damages to Vieques Island

Fiscal Year	Environmental (52 Sites)	Munitions (18 Sites)	Totals
Through FY12	$27.6	$155.5	$183.1
FY13	$0.2	$19.5	$19.7
FY14 & Beyond	$0.6	$333.5	$334.1
Total Expenditure	$28.4	$508.5	$536.9
(Department of the Navy [Vieques] 2012)			

Laser-based training systems have inherent advantages over live ammunition base training: safety and cleanup cost have been discussed above. Additionally it is possible that laser-based training could be accomplished in locations that live ammunition training cannot be, such as, in port, in close proximity to other ships, and other areas that might have restriction on the usage of live ammunition due to safety and environmental concerns.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

After detailed analysis of laser-based FAC/FIAC training requirements and the Navy's prototype I-TESS II system, the limitations depicted in Table 15 still remain. The current system has a limited ability to detect both red and blue weapons lethality information and collect data for mission reconstruction. Some of the prototype's shortcomings could have potentially been induced by the limited scope of the demonstration in that it was primarily a FOT exercise. The team determined that both Blue and Red forces need to be fully instrumented (force and target) to determine outcomes in FoF engagements. The prototype's limited ability to collect data also needs to be improved in order to fulfill requirements.

Advancements in available technology are required before a single system will satisfy all of the FAC/FIAC training requirements for the Navy, as determined by the team. Laser-based systems have not successfully demonstrated effective control of spreading of the beam over distance, which limits its useful range. Incorporation of the FoF capabilities currently in use on the USMC laser system and geo-pairing technologies will minimize the remaining functional gaps. The identified shortfalls of the I-TESS II prototype systems do not preclude using the system in FoT training scenarios and in limited scenarios would provide better training than is currently available.

B. RECOMMENDATIONS

Force-on-Force training requires both Red and Blue forces to be fully implemented in order to facilitate FoF training. With this in mind the Naval Postgraduate School Systems Engineering Team for the laser-based simulated training capstone recommends the following 1) use the current prototype in limited FoT training scenarios, 2) blend laser-based training and geometric technology, and 3) additional follow-on research.

(1) Use the System in Limited Training Scenarios

Develop partial implementation of the system in testing scenarios where identified gaps are realized and without significant impact to the training mission. The equipment today is mature enough to incorporate in limited scale—three to four Red force players attacking one Blue force unit—training scenarios. This training could be conducted in local training areas that can be augmented with other instrumentation.

(2) Evaluate the Possibility of Blending Geometric Pairing and Simulated Rounds Technologies to Improve the Overall System

The shortcomings of traditional laser-based systems can be minimized through the application of terrain aided geopairing and the use of weapons with blanks or non-lethal projectiles (example: non-lethal marking rounds, tracers). For large surface vessels, the addition of advanced software can enhance the scenario realism. One example would be a detailed model of the ship (leveraging off of terrain aided geometric pairing technology) on a monitor with the capability to pin-point the hostile fire impact location.

(3) Recommendations for Follow-On Research

- Development of detailed CONOPs for the continued use of the prototype systems. Well-prepared CONOPs will set the expectations for both trainers and trainees in the use of the prototype system.
- Solicit more detailed feedback from the users of the prototype system. Any additional user evaluations should be developed based on the lessons learned from past evaluation efforts. Emphasis on gaining additional user feedback in the areas identified as gaps would be most beneficial.
- Conduct formal, well-focused and defined field user evaluations—structured to collect information such as the impacts of laser-energy spreading while at sea and in different sea states.
- Continue using the two procured prototype systems with the aim of developing a suitable training system.
- Conduct a detailed cost analysis (which can remain FOUO) to compare the cost of live ammunition training versus simulated training. There are

financial benefits to laser-based training that may offset any gaps depending on the fleet's prioritization of requirements.

- Collaborate with the Army and Marine Corps in the development of a common laser-based training system. The Army's OneTess is promising but not at full maturity and not ready for acquisition. The training mission for the three services will be similar and, by working together, costs and development resources can be shared.

These recommendations are provided for stakeholder consideration to further enhance Navy training. This system assessment and analysis can serve as a baseline to continue research and evaluation. The Laser-Based Training Assessment Team's analysis was conducted from an academic view point, with the assistance of non-tactical stakeholders. The requirements developed need to be reviewed by fleet representatives, preferably with experience in operational conditions associated with FAC/FIAC threats and with access to appropriate classified material, tactics, techniques and procedures.

C. SUMMARY

Based on the gap analysis and the technology assessment, the ideal FAC/FIAC training system would be a blend of technologies. Traditional laser-based systems shortcomings can be minimized through the application of geopairing. For large surface vessels, the addition of advanced software (detailed model of the ship) with the capability to pin-point hostile fire impact location is an area for further development and essential to increase the realism (unit suffering combat like casualties) during the training environment.

Figure 18 depicts notional HSMST integration of I-TESS II system. Existing MILES technology will require specific enhancements in order to be fully integrated within a Naval Shipboard/Maritime environment. Some of these enhancements include a command and control (C2) package with the capability to support the required six Blue force and 20 opposing force ships; the ability to operate in all maritime environments, inshore to open ocean, and in all expected weather/ocean conditions; and modification to allow for the use of an M2 and M240B weapons in a manner that allows for a visual indication of where the rounds are landing.

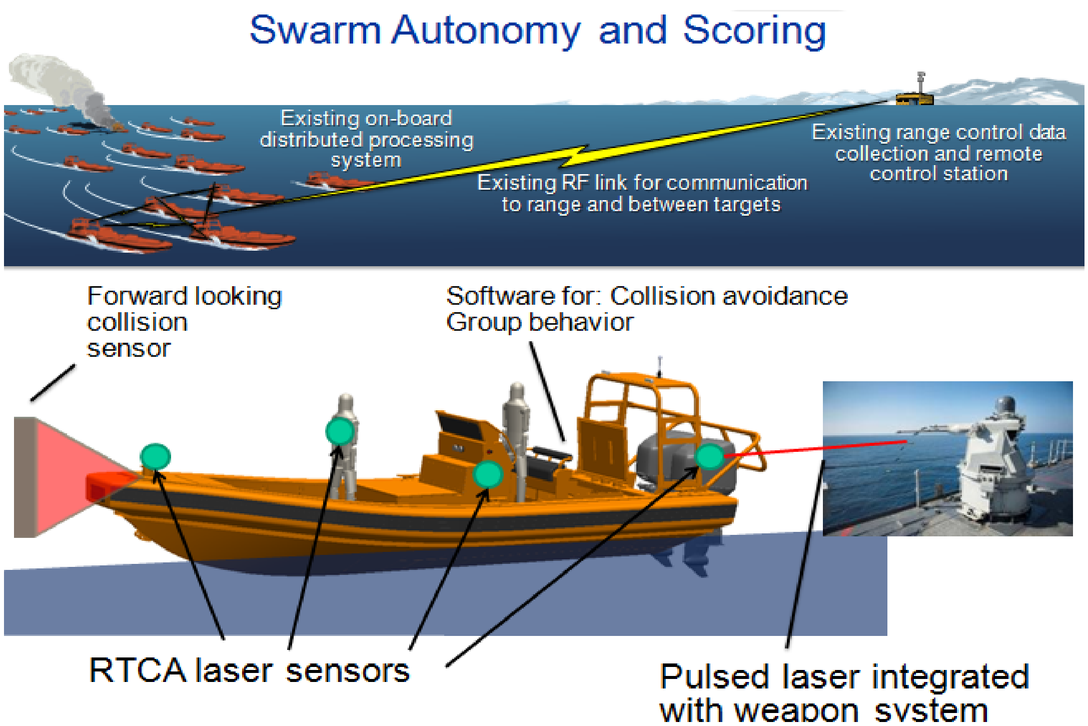

Figure 18. Notional HSMST MILES Integration

APPENDIX A. UNIT CREW SERVED WEAPONS (CSW) TRAINING

Table 17. Excerpt: Tab C of COMNAVSURFORINST 3502.1D (from Department of the Navy 2007)

2	Deter and Counter Terrorist Activities	All duty sections shall demonstrate proficiency in the execution of their Pre-Planned Response IAW their Force Protection (FP)/Inport Security Plan (ISP) (including transitions through FPCONs) to deter and counter the following terrorist activities quarterly: 1. Surveillance 2. Land Side 3. Water Side 4. OPSEC Probe 5. Entry Control Point (ECP) Threat 6. Pier penetration 7. Shipboard Intruder 8. Shipboard Penetration (Forced) 9. Improvised Explosive Device (IED) 10. Personnel 11. Vehicle 12. Suspicious Package 13. Pier side Small Boat Attack 14. Low, Slow Flyer 15. Telephonic Bomb Threat 16. Civil Disturbance (demonstration/protest on the pier) 17. Hostage situation 18. Seaborne Attack 19. Swimmer 20. Floating Object 21. Nighttime Small Boat Attack at Anchor
6	Weapons Qualifications	All armed watchstanders shall be personnel qualification standards (PQS) qualified and current with the weapon(s) required for the position that they are standing [in accordance with] IAW COMNAVFORINST 3300.1 (Series) Antiterrorism/Force Protection (AT/FP) program and OPNAVINST 3591.1 (Series) Small Arms Training and Qualification, including training in: 1. Weapon condition 2. Levels of Force training (Use of Force Cards)

		3. Quarterly Use of Deadly Force training. 4. Rules of Engagement (ROE) 5. All crew served watchstanders shall be PQS qualified. 6. Semi-annual sustainment training as outlined in OPNAVINST 3591.1 7. Designated personnel (IAW ship's instruction) shall be qualified (PQS/JQR) in use of flares. 8. Designated personnel (IAW ship's instruction) shall be qualified (PQS/JQR) in concussion grenades.
Note: In the interest of safety, simulated weapons (RED/BLUE GUNS) vice shipboard weapons shall be used during all training and assessment periods. All Crew Served Weapons (CSW) shall be verified "clear and safe" with no ammunition on deck, prior to conducting training or assessment. (Department of the Navy 2007)		

Some of the targets used for live ammunition training are described below.

The killer tomato is an inflatable orange cube that is deployed from the flight deck or missile deck of a destroyer. Once deployed the ship steams away from the float until it reaches an approximate range of 400 yards. Once that range is reached, the ship comes to all stop and CSW operators are allowed to complete range qualifications in accordance with the standards set forth in OPNAVINST 3591.1E. Not only does a killer tomato bear no resemblance to almost any other object that would normally be seen at sea, but its nearly stationary position does little to nothing to train CSW personnel to be able to engage inbound threat craft. Adequate as it may be for basic weapon proficiency and familiarization training, a more suitable training system must be implemented in the fleet for FIAC and swarm defense training. (Tiwari 2008)

Figure 19. Killer Tomato (from Tiwari 2008)

The following excerpts from Tiwari's and Conger's studies on small boat and swarm defense and prototype development of augmented reality trainer for CSW, respectively, provide explanations for this.

> There are several reasons for this including the inherent complexity of evaluating crews against actual targets, availability of targets, the cost of targets, and the fidelity of the data available for analysis. The only current measure of effectiveness would involve using actual ammunition on representative threat crafts operating in realistic ways. This would require a phenomenal allocation of funds to evaluate the numerous AT/FP crews in the multiple fleets. (Tiwari 2008)

> A significant emerging threat to coalition forces in littoral regions is from small craft such as jet skis, fast patrol boats, and speedboats. These craft, when armed, are categorized as Fast Inshore Attack Craft (FIAC), and their arsenal can contain an array of weapons to include suicide bombs, crew-served weapons, anti-tank or ship missiles, and torpedoes. While these craft often have crude weapon technologies, they use an asymmetric tactic of large numbers of small, cheap, poorly armed and armored units to overwhelm coalition defenses. (Conger 2008–09)

With a basic understanding of the threat, and initial stakeholder inputs, the team developed mission requirements. In an effort to more fully understand the mission the team developed use case one based on NAVSEA Corona 2012 trip report. After considering the stakeholder's goal of training the fleet, mission analysis provided the foundation for use case development. The initial use case was developed to refine stakeholder inputs and produce mission level requirement, by identifying the roles and communications required to execute the mission. A total of three unclassified use cases were developed to evaluate those functions based on potential tactical situations that might represent the FAC/FIAC threat:

1. Single Ship vs. Single Attacker
2. Multiple Attackers vs. Three-ship SAG
3. Multiple Attackers vs. two-Ship SAG at night in poor weather

The following section provides the first use case which, after analysis, enabled the development of mission requirements.

A. USE CASE ONE—SINGLE SHIP VS. SINGLE ATTACKER

During independent, detached operations, a Blue warship enters an area of operations with heightened tensions between countries Blue and Red. Based on prior information, upon entering this operating area the CO of Blue's warship sets a higher force protection condition enabling it to defend itself from small boat attacks.

Setting a higher force protection condition for this situation requires the crew served weapons teams make their weapons ready for action. Ready for action is reached when the weapon has been inspected, loaded with the appropriate ammunition, and the watch team has reported its status to the TAO, the officer on watch required to protect the ship. With the final watch station reporting in, the TAO reports to the CO that the appropriate force protection condition has been set and the watch teams are ready.

An unexpected attack commences when a small speedboat, armed with a .50-caliber weapon and a Rocket-Propelled Grenade (RPG), turns towards the warship and speeds up to reduce the range between the two vessels, Figure 20. The gunners report this reaction to the TAO who then orders a verbal warning to be issued via the ship communications system to the approaching speedboat. Observing that the speedboat has not heeded the verbal warning, the gunners report this observation to the TAO while aiming their weapons at the approaching speedboat.

The TAO, after updating the CO, orders warning shots to be fired at the approaching speedboat. Upon receipt of orders, the gunners proceed to fire warning shots at the approaching speedboat. Once again, observing that the speedboat does not alter its course or speed, they report their observation to the TAO.

After updating the CO, the TAO orders the gunners to destroy the approaching speedboat. The gunners aim, verify their target, and open fire. As the gunners fire their weapons, a constant cycle of aim, fire, assess continues until a direct hit is made which stops the speedboat or the engagement is terminated by CO or TAO. The gunners update the status of the speedboat to the TAO. After updating the CO, the TAO orders the gunners to maintain aim on the speedboat's driver, and, if they witnessed a hostile act, such as the driver or another occupant aiming a weapon at the ship, to sink it.

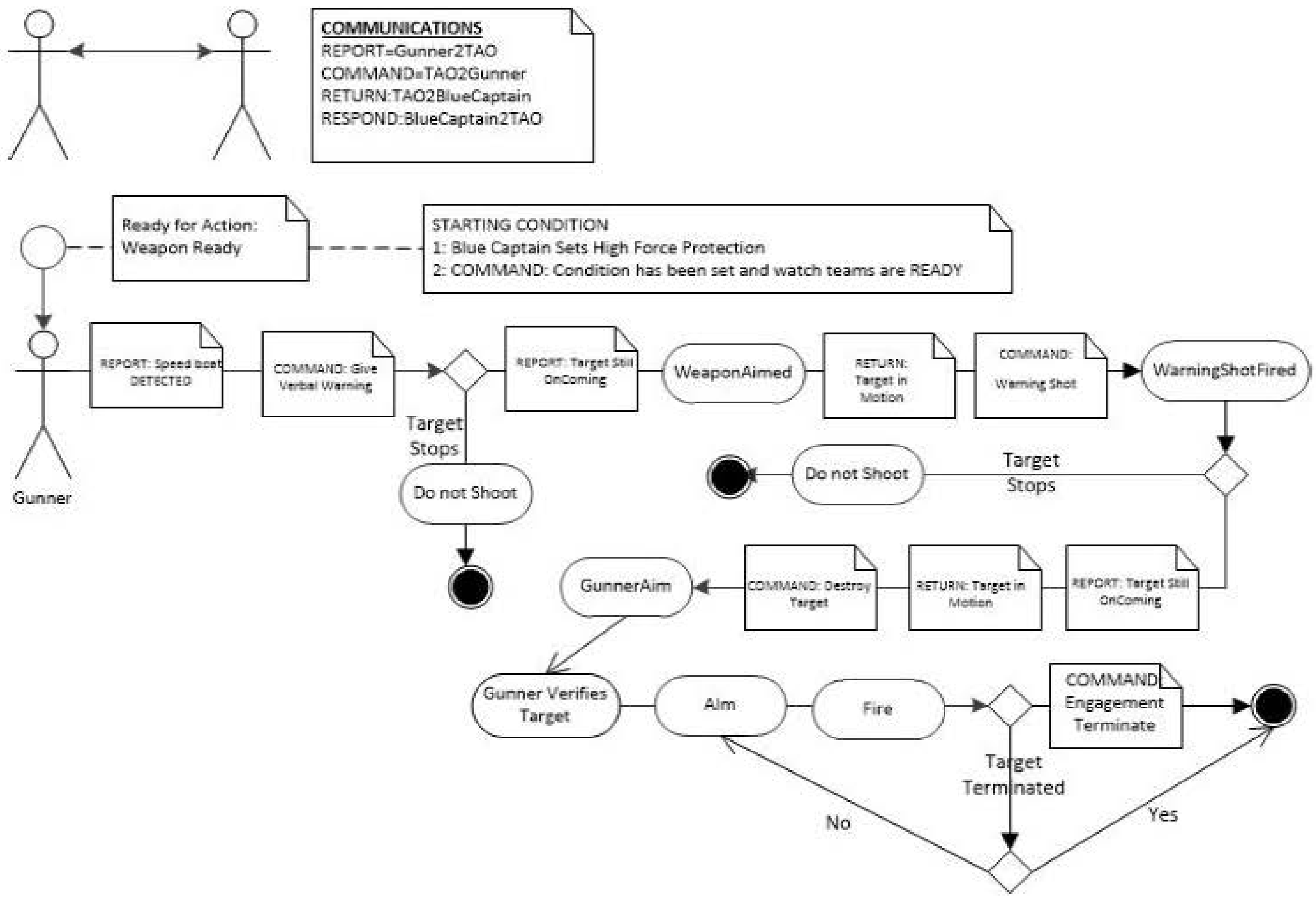

Figure 20. Use Case One

B. USE CASE TWO—MULTIPLE ATTACKERS VS. THREE-SHIP SURFACE ACTION GROUP

Three Blue force warships equipped with crew served weapons for force protection are assigned together as a SAG. As the Blue force SAG proceeds through a congested waterway, geographically confined and surrounded by several neutral ships, the TAO on each Blue force warship sets the restricted maneuvering detail and orders all force protection crews to man their stations. The restricted maneuvering detail is comprised of experienced ship handlers, extra lookout watchstanders, and force protection personnel. Upon receipt of this order, the gun crews (force protection personnel) proceed to make their weapons ready for action and proceed to their stations. Upon arrival to their stations, the crews inspect and load their weapon. Shortly after manning their stations, the crews observe and report small boat activity within 2,000 yards of their ship to their TAO.

Upon receipt of their crews' reports, the TAO of each ship notifies their ship's CO. Additionally, the TAO radios the other two ships in the SAG and relays the reports. This process continues for the next several hours.

After approximately four hours and just prior to exiting the congested waterway the gun crews report that several new visual contacts have been detected moving toward the ship at very high speeds (approximately 30kts), Figure 21.

Per the rules of engagement, the TAO sets a heightened alert status and notifies the other ships to do the same. The TAOs of the SAG confer, via secure chat, to arrange firing sectors and defensive actions. The TAOs order their gunners to prevent the potential hostile boats from closing within danger range, approximately 1000 yards.

The gunners, upon receipt of orders and coverage assignments, put their weapons in firing condition. They also turn on the CSW laser range finder and laser target marker. When the speedboats close within 1000 yards, the gunners proceed to fire warning shots near them and report their actions to their respective TAOs. Observing the approaching speedboats' reaction to the warning shots, the gunners report that the boats continue to close and are approaching extreme danger range, approximately 500 yards. The TAOs receive the reports, coordinate their response, and order the gunners to destroy the approaching speedboats.

Upon receipt of orders the gunners fire at the speedboats with the intention to destroy. The gunners destroy several boats in the first volley; however, a few boats turn away from the SAG. The gunners report the speedboats' change in actions to the TAOs.

The TAOs receive the reports, confer amongst themselves, and determine the gunners should hold fire and monitor the speedboats for further hostile actions. Additionally, they order the gunners to fire warning shots at any boat approaching closer than 1000 yards and if the boat does not turn away to destroy it. The SAG departs the constricted water way without further incidents and reports its actions to the fleet commander.

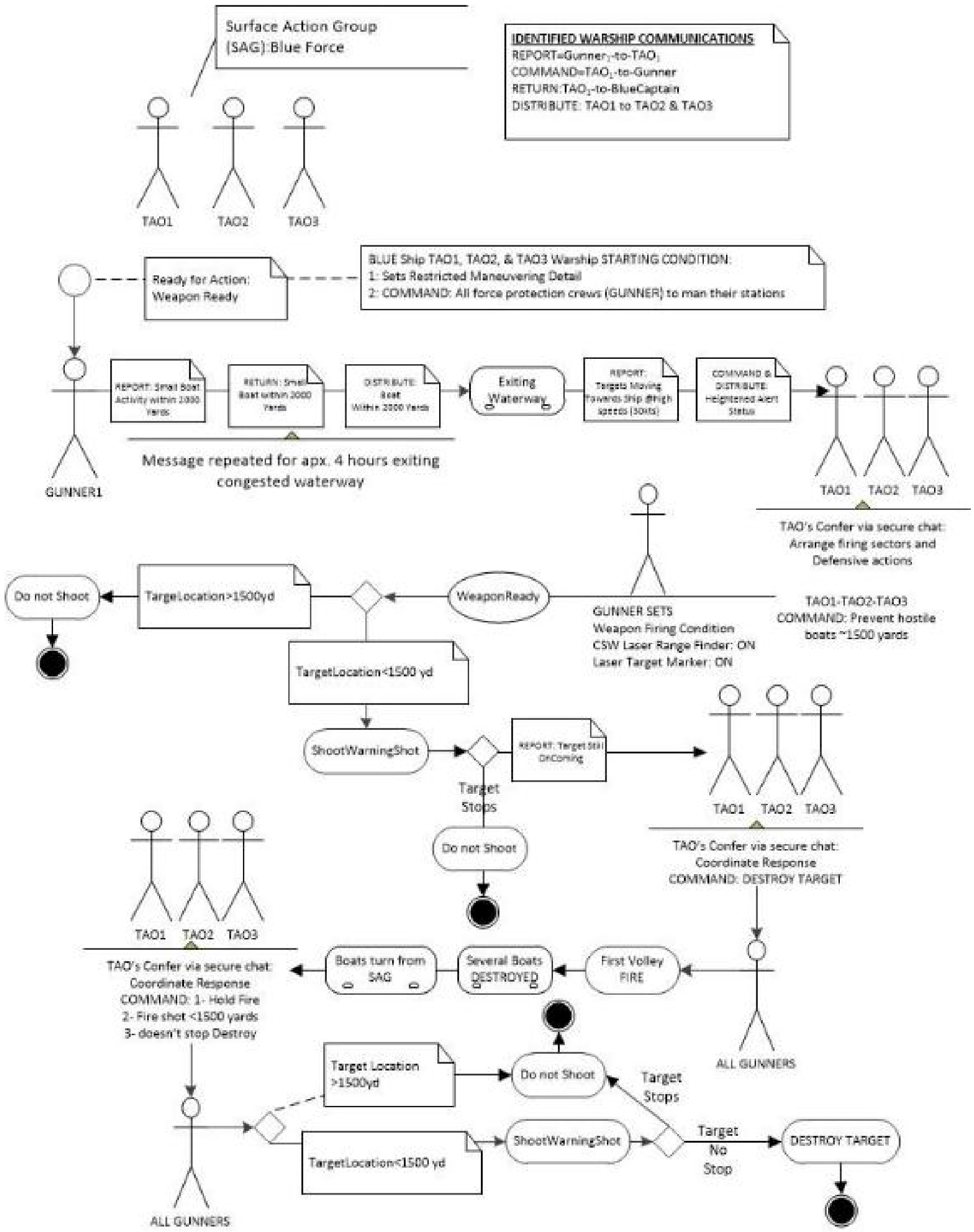

Figure 21. Use Case Two—Multiple Attackers vs. Three-ship SAG

C. USE CASE THREE—MULTIPLE ATTACKERS VS. TWO-SHIP SAG AT NIGHT IN POOR WEATHER

Use case three is provided as a verification process. The previously derived requirements were compared to the capabilities required to fulfil the requirements identified through analyzing use case three.

Two Blue force warships equipped with CSW for force protection are steaming in company. The Blue force SAG enters into a congested waterway (geographically confined and surrounded by several neutral ships) at night in stormy weather the TAO sets the restricted maneuvering detail and orders all force protection crews to man their stations.

Upon receipt of this order, the gun crews make their weapons ready for action and proceed to their stations. Another member of the crew retrieves night vision goggles (NVGs) from a storage locker. Upon arrival to their station, the crews inspect and load their weapons. Shortly after manning their stations and donning the NVGs, the crews observe and report five small boats in what appears to be a formation just outside 1000 yards of the ship to their TAO, Figure 22.

Upon receipt of their crews' reports, the TAO of the ship notifies their ship's CO. Additionally, the TAO radios the other ship in the SAG and relays the reports. The gunners observe the five small boats form into a staggered line abreast and appear to accelerate while turning toward the ships. The gunners update their respective TAOs on the activity of the small boats.

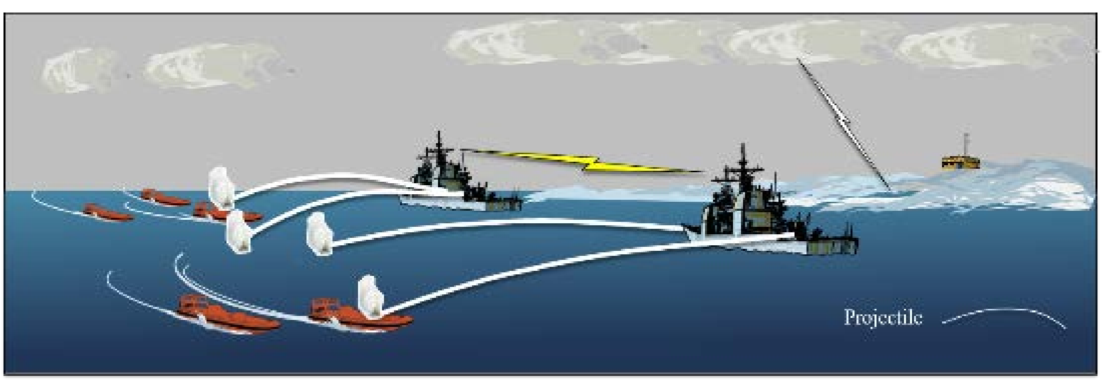

Figure 22. Use Case Three OV-1

Per the rules of engagement, the TAO of ship 1 sets a heightened alert status and notifies the other ship to do the same and sets them in the supporting role. The TAOs of the SAG confer, via secure communication, to arrange firing sectors and defensive actions. The TAOs order their gunners to prevent the potential hostile boats from closing within danger range, approximately 1000 yards.

The gunners, upon receipt of orders and coverage assignments, put their weapons in firing condition. They also turn on the CSW laser range finder and laser target marker, which is clearly visible while using NVGs. While the gunners are getting prepared, ship 1 issues a verbal warning over the loud speaker to the approaching small boats. When the small boats close within 500 yards the gunners proceed to fire warning shots near them and report their actions to their respective TAOs. Observing the approaching small boats' reactions to the warning shots, the gunners report that the boats continue to close and are approaching extreme danger range, approximately 500 yards.

The TAOs receive the reports, coordinate their response, and order the gunners to destroy the approaching speedboats. Upon receipt of orders, the gunners fire at the speedboats with the intention to destroy. The gunners destroy three of the small boats in the first volley; however, the remaining two continue to approach the ships. The gunners report the small boats' actions to the TAOs and, without waiting for further orders, continue to engage the small boats until they are destroyed. The SAG departs the constricted water way without further incidents and reports its actions to the fleet commander. The activity diagram for use case three is depicted in Figure 23.

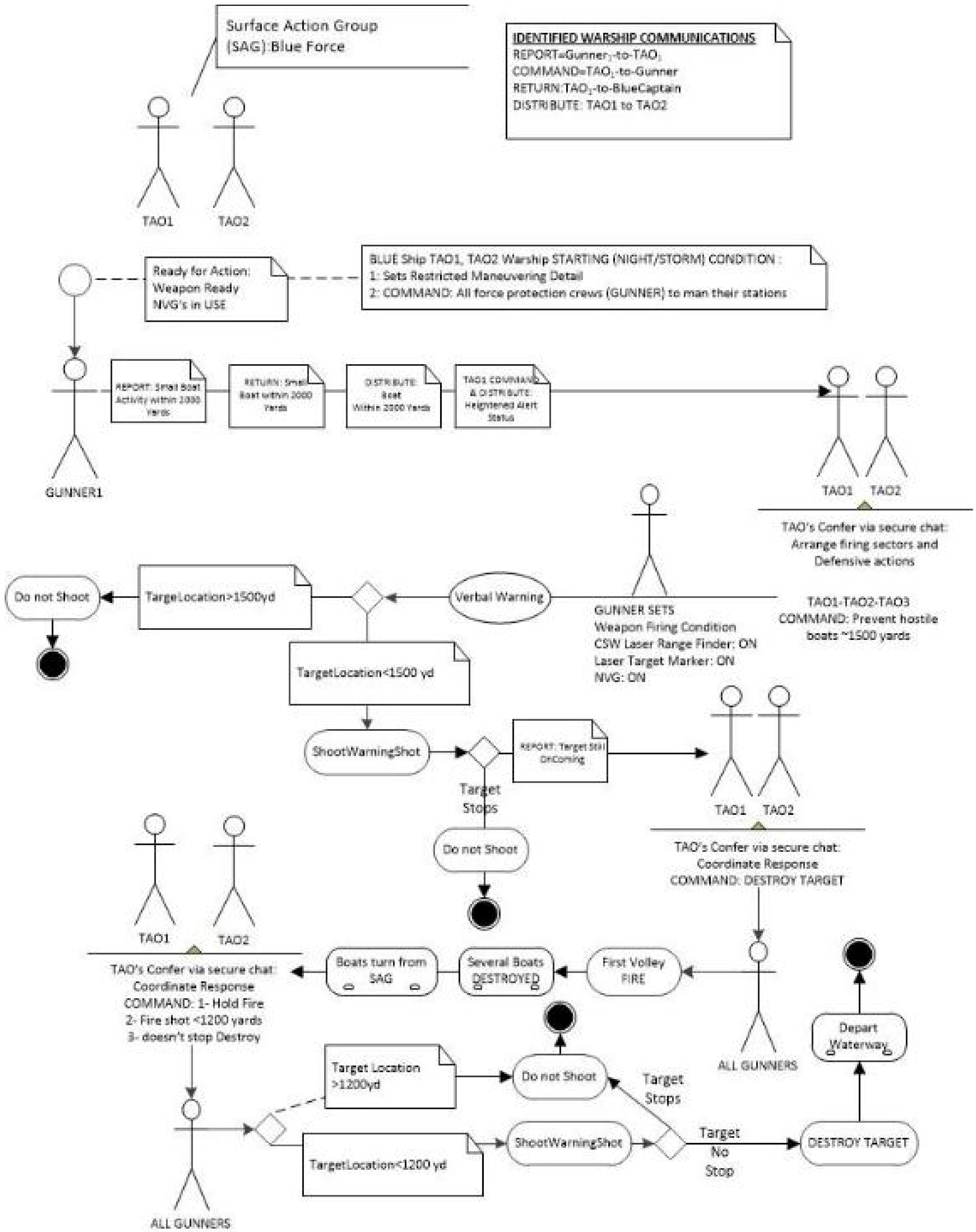

Figure 23. Use Case Three—Multiple Attackers vs. Two-Ship SAG at Night in Poor Weather

The capabilities identified in use case two's analysis fulfilled all of the requirements identified in use case three except for the usage of Night Vision Goggles. With the system level requirements the functions of the system were identified.

APPENDIX B. SEQUENCE DIAGRAMS

Figure 24 depicts the sequence of activities required for the Blue force units to complete their mission.

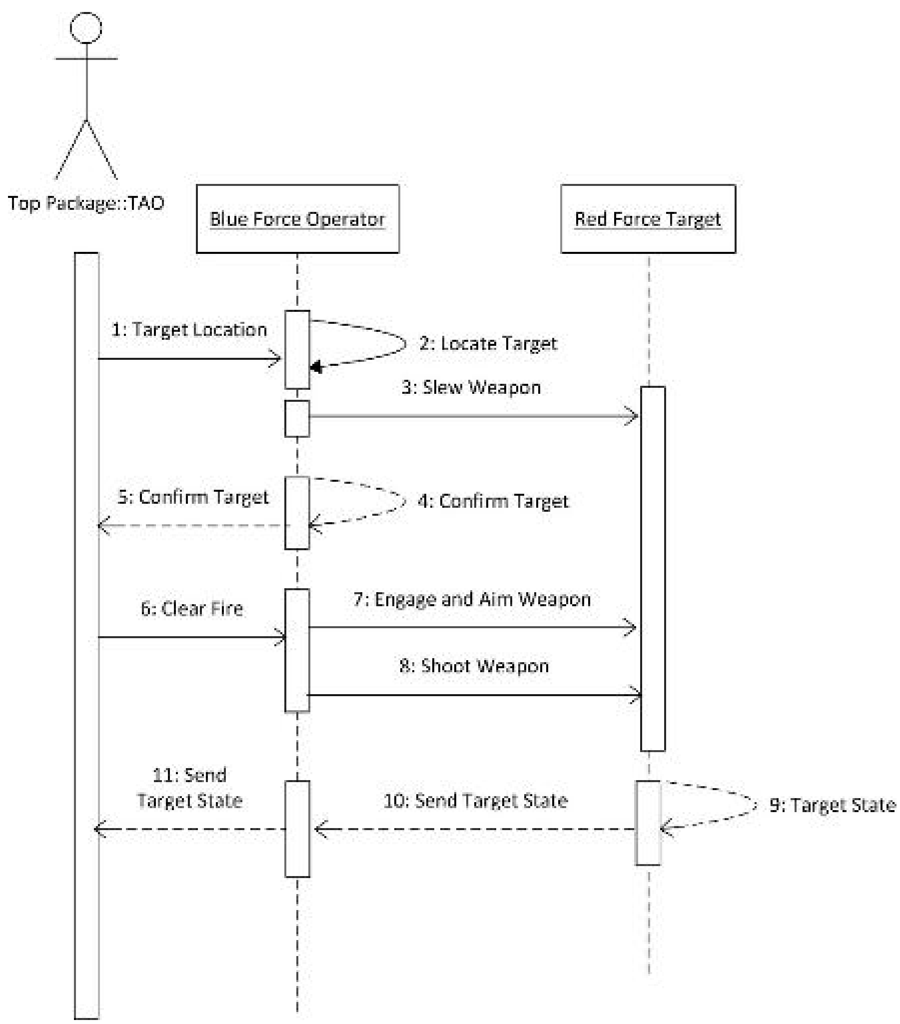

Figure 24. Blue Force Sequence

Blue force unit's basic activities: identify the target, aim a weapon, report target information, receive orders, and engage the target. The assumptions identified in the analysis of use case one still applied, along with the limitation of weapons for Blue forces. From the mission requirement of scenario fidelity, enable Blue forces additionally requires that weapons are able to be aimed, fired, and have the desired effects.

OPFOR or Red forces activities are depicted in Figure 25, are similar to the engagement sequence for Blue force units with the exception of command and control. Red forces requirements for weapons will need to fulfill the same requirements that Blue force weapons. For the purposes of this analysis, OPFOR/Red Forces are portrayed as operating independently with a common goal (i.e., units do not have to request permission to fire or to retreat).

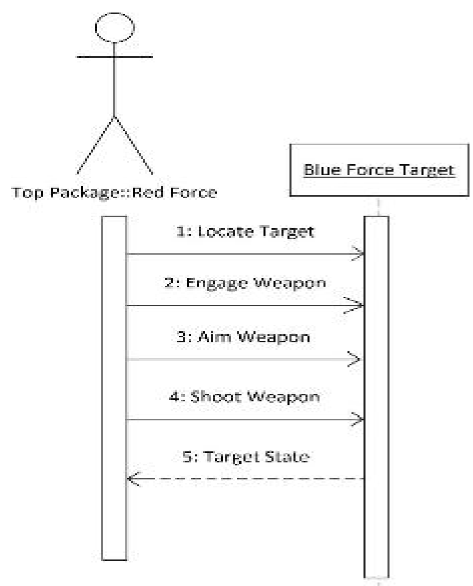

Figure 25. Red Force Sequence

Both Blue and Red forces require weapons and their associated functions in order to be useful in training units to execute FAC/FIAC defensive missions. Figure 26 depicts the firing of the weapon sequence identified, the next step was to determine the sequence of events required to simulate the effects of weapons on participating units. The system will need to provide the weapon state, identify the weapon, maintain ammo count, and determine projectile impact.

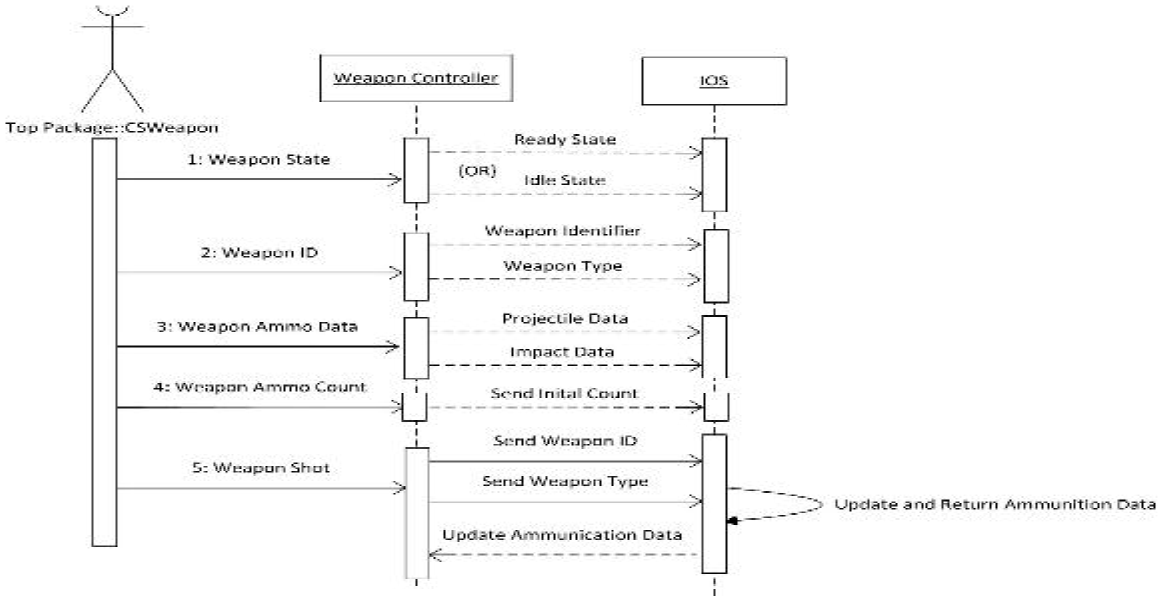

Figure 26. Weapon System Sequence

The receiver sequence is depicted in Figure 27, which depicts the receiver activities that the system will need to be able to accomplish. Receiver needs to detect that it has be fired at, transmit that information, and indicate that whether or not the associated unit has been damaged.

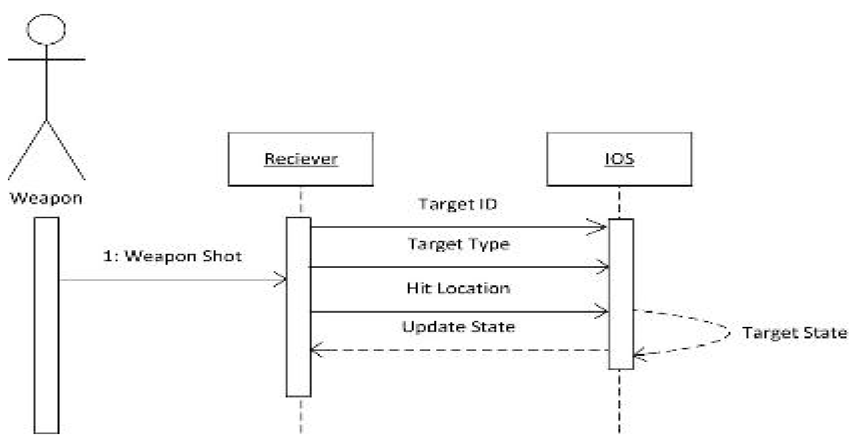

Figure 27. Receiver Sequence

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APPENDIX C. REQUIREMENTS

A. REQUIREMENTS TABLE

Table 18. Requirements List

Number	Requirement	Type	Description	Parent Requirement
0	Training System	nil	This system is needed in order to train surface ships force protection mission	
1	Shall provide Scenario Fidelity, 3 Blue units and 15 Red units.	nil	Shall provide Scenario Fidelity, 3 Blue units and 15 Red units.	0 Training System
1.1	Shall support Force-on-Force training	nil	Shall support Force-on-Force training	1 Shall provide Scenario Fidelity, 3 Blue units and 15 Red units.
1.1.1	Shall provide capability to have Red forces	nil	Shall provide capability to have Red forces	1.1 Shall support Force-on-Force training
1.1.1.1	Shall simulate Red force direct fire	nil	Shall simulate Red force direct fire	1.1.1 Shall provide capability to have Red forces
1.1.1.1.1	Red force .50-CAL Range	nil	Shall simulate Red force .50-CAL rifle firing characteristics for effective range	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.2	Red force .50-CAL accuracy	nil	Shall simulate Red force .50-CAL rifle firing characteristics for accuracy	1.1.1.1 Shall simulate Red force direct fire

Number	Requirement	Type	Description	Parent Requirement
1.1.1.1.3	Red force .50-CAL ballistics	nil	Shall simulate Red force .50-CAL rifle firing characteristics for ballistics	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.4	Red Force RPG range	nil	Shall simulate Red force RPG firing characteristics for effective firing range	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.5	Red Force RPG accuracy	nil	Shall simulate Red force RPG firing characteristics for accuracy	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.6	Red force RPG ballistics	nil	Shall simulate Red force RPG firing characteristics for ballistics	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.8	Red force weapon feedback	nil	Shall provide weapon feedback / action	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.9	Red force blanks	nil	Shall have the ability to shoot blanks	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.10	Red force limit weapons use	nil	Shall limit use of weapons and systems when kills are indicated	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.11	Red force normal weapon's functions	nil	Shall not prevent the weapon's normal functions (load, aim, fire, reload)	
1.1.1.1.12	Red force dry fire	nil	Shall have the ability to operate the system without firing rounds ("dry fire")	1.1.1.1 Shall simulate Red force direct fire
1.1.1.1.13	Red force transmit data	nil	Shall transmit Red force data to exercise control system	1.1.1.1 Shall simulate Red force direct fire

Number	Requirement	Type	Description	Parent Requirement
1.1.1.2	Shall simulate Red force receipt of fire from Blue force	nil	Shall simulate Red force receipt of fire from Blue force	1.1.1 Shall provide capability to have Red forces
1.1.1.2.1	Red force visual state	nil	Shall have visual target state for Red force	1.1.1.2 Shall simulate Red force receipt of fire from Blue force
1.1.1.2.2	Record Red force state	nil	Shall have capability to record Red force target state ability to show/display/report casualty assessment for Red forces	1.1.1.2 Shall simulate Red force receipt of fire from Blue force
1.1.1.2.3	Record Red force data	nil	Shall record Red force data (time, firings, position)	1.1.1.2 Shall simulate Red force receipt of fire from Blue force
1.1.2	Shall provide capability to have Blue forces	nil	Shall provide capability to have Blue forces	1.1 Shall support Force-on-Force training
1.1.2.1	Shall simulate the effects of Blue force direct fire weapons	nil	Shall simulate the effects of Blue force direct fire weapons	1.1.2 Shall provide capability to have Blue forces
1.1.2.1.1	Blue force .50-CAL range	nil	Shall simulate Blue force .50-CAL Rifle firing characteristics for effective range	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.2	Blue force .50-CAL accuracy	nil	Shall simulate Blue force .50-CAL Rifle firing characteristics for accuracy	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons

Number	Requirement	Type	Description	Parent Requirement
1.1.2.1.3	Blue force .50-CAL ballistics	nil	Shall simulate Blue force .50-CAL Rifle firing characteristics for ballistics	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.4	Blue force M240B range	nil	Shall simulate Blue force M240B machine gun firing characteristics for effective range	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.5	Blue force M240B accuracy	nil	Shall simulate Blue force M240B machine gun firing characteristics for accuracy	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.6	Blue force M240B ballistics	nil	Shall simulate Blue force M240B machine gun firing characteristics for ballistics	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.7	Blue force weapon feedback/action	nil	Shall provide weapon feedback / action	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.8	Blue force blanks	nil	Shall have the ability to shoot blanks	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.9	Limit Blue force weapons	nil	Shall limit use of weapons and systems when kills are indicated	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.10	Blue force weapons normal operations	nil	Shall not prevent the weapon's normal functions (load, aim, fire, reload)	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons

Number	Requirement	Type	Description	Parent Requirement
1.1.2.1.11	Blue force dry fire	nil	Shall have the ability to operate the system without firing rounds ("dry fire")	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.12	transmit Blue force data	nil	Shall transmit Blue force data to exercise control system	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.1.13	record Blue force data	nil	Shall record Blue force data (time, firings, position)	1.1.2.1 Shall simulate the effects of Blue force direct fire weapons
1.1.2.2	Shall simulate damage to Blue force due to receipt of fire from Red force	nil	Shall simulate damage to Blue force due to receipt of fire from Red force	1.1.2 Shall provide capability to have Blue forces
1.1.2.2.1	Blue force visual indicator	nil	Shall have visual target state for Blue force	1.1.2.2 Shall simulate damage to Blue force due to receipt of fire from Red force
1.1.2.2.2	Blue force casualty	nil	Shall have capability to show/display/report casualty assessment for Blue forces	1.1.2.2 Shall simulate damage to Blue force due to receipt of fire from Red force
1.1.2.2.3	record Blue force casualty data	nil	Shall have capability to record Blue force target state	1.1.2.2 Shall simulate damage to Blue force due to receipt of fire from Red force

Number	Requirement	Type	Description	Parent Requirement
1.1.2.2.4	Blue force instrumentation	nil	Shall provide instrumentation for Blue forces to detect and indicate hits	1.1.2.2 Shall simulate damage to Blue force due to receipt of fire from Red force
1.1.2.2.5	indication of Blue force being killed	nil	Shall provide indication of personnel and system kills	1.1.2.2 Shall simulate damage to Blue force due to receipt of fire from Red force
1.1.2.2.6	Blue force limit weapon	nil	Shall limit use of weapons and systems when kills are indicated	1.1.2.2 Shall simulate damage to Blue force due to receipt of fire from Red force
1.1.2.2.7	Blue force reset	nil	Shall have the ability to be "reset" at the direction of exercise control	1.1.2.2 Shall simulate damage to Blue force due to receipt of fire from Red force
1.2	Shall support Force-on-Target training	nil	Shall support Force-on-Target training	1 Shall provide Scenario Fidelity, 3 Blue units and 15 Red units.
1.2.1	FoT Shall simulate Red force	nil	Shall simulate Red force	1.2 Shall support Force-on-Target training
1.2.1.1	FoT-Shall simulate the effects on Red force due to receipt of fire from Blue force	nil	Shall simulate the effects on Red force due to receipt of fire from Blue force	1.2.1 FoT Shall simulate Red force
1.2.1.2	FoT Red force visual state	nil	Shall have visual target state for Red force	1.2.1 FoT Shall simulate Red force

Number	Requirement	Type	Description	Parent Requirement
1.2.1.3	FoT Record Red force state	nil	Shall have capability to record Red force target state ability to show/display/report casualty assessment for Red forces	1.2.1 FoT Shall simulate Red force
1.2.1.4	FoT Red force casualty individual	nil	Shall have capability to show/display/report casualty assessment for individual players	1.2.1 FoT Shall simulate Red force
1.2.1.5	FoT detect hits	nil	Shall provide instrumentation for Red forces to detect and indicate hits	1.2.1 FoT Shall simulate Red force
1.2.1.6	FoT Red force reset	nil	Shall have the ability to be "reset" at the direction of exercise control	1.2.1 FoT Shall simulate Red force
1.2.2	Shall enable Blue force(s) to conduct FoT training	nil	Shall enable Blue force(s) to conduct FoT training	1.2 Shall support Force-on-Target training
1.2.2.0	FoT Blue force fire	nil	Shall simulate Blue force direct fire	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.1	FoT Blue force .50-CAL range	nil	Shall simulate Blue force .50-CAL Rifle firing characteristics for effective range	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.2	FoT Blue force .50 accuracy	nil	Shall simulate Blue force .50-CAL Rifle firing characteristics for accuracy	1.2.2 Shall enable Blue force(s) to conduct FoT training

Number	Requirement	Type	Description	Parent Requirement
1.2.2.3	FoT Blue force .50-CAL ballistics	nil	Shall simulate Blue force .50-CAL Rifle firing characteristics for ballistics	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.4	FoT Blue force M240B range	nil	Shall simulate Blue force M240B machine gun firing characteristics for effective range	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.5	FoT Blue force M240B accuracy	nil	Shall simulate Blue force M240B machine gun firing characteristics for accuracy	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.6	FoT Blue force M240B ballistics	nil	Shall simulate Blue force M240B machine gun firing characteristics for ballistics	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.7	FoT Blue force weapon feedback	nil	Shall provide weapon feedback / action	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.8	FoT Blue force blanks	nil	Shall have the ability to shoot blanks	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.9	FoT Blue force normal weapon operations	nil	Shall not prevent the weapon's normal functions (load, aim, fire, reload)	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.10	FoT Blue force dry fire	nil	Shall have the ability to operate the system without firing rounds ("dry fire")	1.2.2 Shall enable Blue force(s) to conduct FoT training

Number	Requirement	Type	Description	Parent Requirement
1.2.2.11	FoT Blue force record data	nil	Shall transmit Blue force data to exercise control system	1.2.2 Shall enable Blue force(s) to conduct FoT training
1.2.2.12	FoT Blue force transmit data	nil	Shall record Blue force data (time, firings, position)	1.2.2 Shall enable Blue force(s) to conduct FoT training
2	Shall enable centralized command and control (C2) via LOS and Network	nil	Shall enable centralized command and control (C2) via LOS and Network	0 Training System
2.1	Shall provide LOS communications path (U/VHF)	nil	Shall provide LOS communications path (U/VHF)	2 Shall enable centralized command and control (C2) via LOS and Network
2.1.1	Exercise Voice LOS	nil	Shall provide exercise voice communications within LOS	2.1 Shall provide LOS communications path (U/VHF)
2.1.2	C2 of CSW positions	nil	Shall enable command and control of CSW positions	2.1 Shall provide LOS communications path (U/VHF)
2.1.3	Communications Relay	nil	Shall provide communications relay of exercise related unit's communications	2.1 Shall provide LOS communications path (U/VHF)
2.1.4	Maintain connectivity	nil	Shall maintain system connectivity / data availability to within 3% error rate	2.1 Shall provide LOS communications path (U/VHF)

Number	Requirement	Type	Description	Parent Requirement
2.2	Shall provide an exercise network for machine to machine data transfer	nil	Shall provide an exercise network for machine to machine data transfer	2 Shall enable centralized command and control (C2) via LOS and Network
2.2.1	1 Hz update rate	nil	Shall provide information updates at a rate of 1 sec (PLI and player status)	2.2 Shall provide an exercise network for machine to machine data transfer
2.2.2	Provide "gods eye" view	nil	Shall provide "Gods eye" view of the training exercise (live and playback)	2.2 Shall provide an exercise network for machine to machine data transfer
2.2.3	After action review	nil	Shall provide for network dissemination of AAR	2.2 Shall provide an exercise network for machine to machine data transfer
2.2.4	Digital Monitoring	nil	Shall enable digital monitoring of training	2.2 Shall provide an exercise network for machine to machine data transfer
2.2.5	Network storage of recordings	nil	Shall provide storage of recorded exercise related data	2.2 Shall provide an exercise network for machine to machine data transfer

Number	Requirement	Type	Description	Parent Requirement
2.3	Shall provide Command and Control function to the exercise (start, stop, and full control of players)	nil	Shall provide Command and Control function to the exercise (start, stop, and full control of players)	2 Shall enable centralized command and control (C2) via LOS and Network
2.3.1	Communications between participants	nil	Shall enable communications between exercise control and participating units	2.3 Shall provide Command and Control function to the exercise (start, stop, and full control of players)
2.3.2	Transmit of commands	nil	Shall enable transmission of commands via C2 system	2.3 Shall provide Command and Control function to the exercise (start, stop, and full control of players)
2.3.3	Receipt of commands	nil	Shall enable receipt of commands via C2 system	2.3 Shall provide Command and Control function to the exercise (start, stop, and full control of players)

Number	Requirement	Type	Description	Parent Requirement
2.3.4	C2 reset of players	nil	Shall provide provision to 'reset' dead players.	2.3 Shall provide Command and Control function to the exercise (start, stop, and full control of players)
2.3.5	Receipt of messages	nil	Shall enable receipt of status reports	2.3 Shall provide Command and Control function to the exercise (start, stop, and full control of players)
2.3.6	None interference with host platform C2	nil	Shall not interfere with host platform command and control systems	2.3 Shall provide Command and Control function to the exercise (start, stop, and full control of players)
3	Shall be compliant with applicable ESOH Rules and Regulations (MMPA, NEPA, Laser Use, et al.)	nil	Shall be compliant with applicable ESOH Rules and Regulations (MMPA, NEPA, Laser Use, et al.)	0 Training System
3.0.1	Shall be compliant with Marine Mammal Protection Act (MMPA)	nil	Shall be compliant with Marine Mammal Protection Act (MMPA)	3 Shall be compliant with applicable ESOH Rules and Regulations (MMPA, NEPA, Laser Use, et al.)

Number	Requirement	Type	Description	Parent Requirement
3.0.2	Shall be compliant with National Environmental Policy Act (NEPA)	nil	Shall be compliant with National Environmental Policy Act (NEPA)	3 Shall be compliant with applicable ESOH Rules and Regulations (MMPA, NEPA, Laser Use, et al.)
3.0.3	Shall be compliant with Laser safety regulations	nil	Shall be compliant with Laser safety regulations	3 Shall be compliant with applicable ESOH Rules and Regulations (MMPA, NEPA, Laser Use, et al.)
4	Operational Availability	nil	Shall be Operational Available	0 Training System
4.1	Reliability	nil	Shall provide a Reliable System	4 Operational Availability
4.1.1	Environmentally qualified	nil	Shall be operable in all environments representative of Navy training Areas (compliant with MIL-STD 810G)	4.1 Reliability
4.2	Useable	nil	Shall provide a Useable System	4 Operational Availability
4.3	Portable	nil	Shall provide a Portable System	4 Operational Availability
4.4	Accurate	nil	Shall provide an Accurate System	4 Operational Availability
4.5	Maintainability	nil	Shall provide a Maintainable System	4 Operational Availability
4.6	Sustainable	nil	Shall provide a Sustainable System	4 Operational Availability

Number	**Requirement**	**Type**	**Description**	**Parent Requirement**
5	System shall automatically determine readiness	nil	System shall automatically determine readiness of a unit to defend itself form damage when faced with a FAC/FIAC threat based on recorded information and TTPs/ROE.	
5.1	Record exercise data	nil	System shall automatically record exercise data	5 System shall automatically determine readiness
5.2	Store data	nil	The system shall store all recorded data on removable media.	5 System shall automatically determine readiness
5.3	Evaluate performance	nil	The system shall evaluate performance based on TTPs and ROE	5 System shall automatically determine readiness
5.4	Produce reports	nil	The system shall produce after action reports and readiness evaluation reports	5 System shall automatically determine readiness

B. SYSTEM REQUIREMENTS HIERARCHY

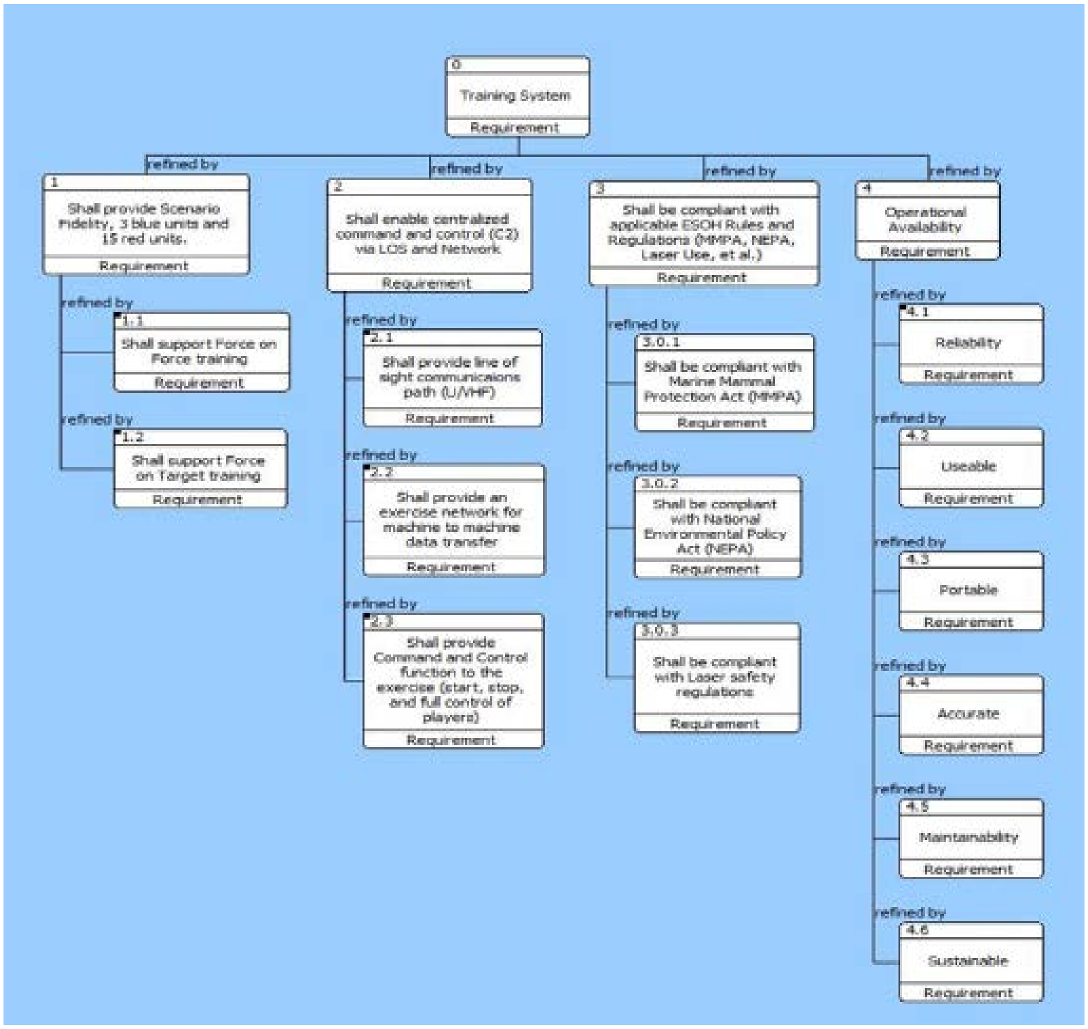

Figure 28. Level 1-2 System Requirements Hierarchy

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APPENDIX D. FUNCTIONAL FLOW BLOCK DIAGRAMS

A. FUNCTION DESCRIPTION TABLES

Table 19. Training System Derived Functions

Number	Element	description
0	Conduct FAC/FIAC Training	This is the overall system function of supporting both Blue force training and Red force units
1	Simulate Red Forces	The system's ability to identify Red forces and enable participation in training.
1.1	Simulate Firing of Red Weapons	The system's ability to simulate the firing of Red Force Weapons
1.1.1	Simulate Red .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon
1.1.1.1	Simulate Loading of Red Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's loading process
1.1.1.2	Simulate Aiming of Red Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's aiming process
1.1.1.3	Simulate Firing of Red Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's firing process
1.1.2	Simulate Red RPG Weapons	The system's ability to simulate a RPG weapon
1.1.2.1	Simulate Loading of Red Force RPG Weapons	The system's ability to simulate a RPG weapon's loading process
1.1.2.2	Simulate Aiming of Red Force RPG Weapons	The system's ability to simulate a RPG weapon's aiming process
1.1.2.3	Simulate Firing of Red Force RPG Weapons	The system's ability to simulate a RPG weapon's firing process
1.1.3	Communicate Red Force Weapon Data	The system's ability to transmit Red Force weapon related data to a collection system
1.1.3.1	Transmit Aiming Data for Red Force Weapons	The system's ability to transmit Red Force Aiming data to a data collection system
1.1.3.2	Transmit Firing Data for Red Force Weapons	The system's ability to transmit Red Force Firing data to a data collection system
1.2	Simulate Effects of Blue Weapons on Red Forces	The system's ability to simulated the lethal effects of Blue force weapons on Red Force participants

Number	**Element**	**description**
1.2.1	Receive Blue Forces Weapons effects	The system's ability to receive Blue Force weapons calculated effects
1.2.2	Simulate Effects of Blue .50-CAL Weapons on Red Forces	The system's ability to simulate the lethal effects of Blue Force .50-CAL weapons on Red Forces
1.2.3	Simulate Effects of Blue M240B Weapons on Red Forces	The system's ability to simulate the lethal effects of Blue Force M240B Cal weapons on Red Forces
1.2.4	Simulate Effects of Blue Mrk 19 Weapons on Red Forces	The system's ability to simulate the lethal effects of Blue Force Mrk 19 weapons on Red Forces
1.3	Communicate Position Data from Red Platforms	The system's ability to collect and transmit Positional information from Red force Platforms
1.3.1	Transmit Position Information from Red Platforms	The system's ability to collect and transmit Position information from Red force Platforms
1.3.2	Transmit Heading Information from Red Platforms	The system's ability to collect and transmit Heading information from Red force Platforms
1.3.3	Transmit Velocity Information from Red Platforms	The system's ability to collect and transmit velocity information from Red force Platforms
2	Simulate Blue Forces	The system's ability to identify Blue forces and enable participation in training
2.1	Simulate Firing Blue Crew Served Weapons	The system's ability to simulate the firing of Blue Force Crew Served Weapons
2.1.1	Simulate Blue .50 Weapons	The system's ability to simulate a .50-CAL weapon
2.1.1.1	Simulate Loading of Blue Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's loading process
2.1.1.2	Simulate Aiming of Blue Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's aiming process
2.1.1.3	Simulate Firing of Blue Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's firing process
2.1.2	Simulate Blue M240B Weapons	The system's ability to simulate a M240B weapon
2.1.2.1	Simulate Loading of Blue Force M240B Weapons	The system's ability to simulate a M240B weapon's loading process
2.1.2.2	Simulate Aiming of Blue Force M240B Weapons	The system's ability to simulate a M240B weapon's aiming process

Number	Element	description
2.1.2.3	Simulate Firing of Blue Force M240B Weapons	The system's ability to simulate a M240B weapon's firing process
2.1.3	Simulate Blue Mrk 19 Weapons	The system's ability to simulate a Mrk 19 weapon
2.1.3.1	Simulate Loading of Blue Force Mrk 19 Weapons	The system's ability to simulate a Mrk 19 weapon's loading process
2.1.3.2	Simulate Aiming of Blue Force Mrk 19 Weapons	The system's ability to simulate a Mrk 19 weapon's aiming process
2.1.3.3	Simulate Firing of Blue Force Mrk 19 Weapons	The system's ability to simulate a Mrk 19 weapon's firing process
2.1.4	Communicate Blue Force Weapon Data	The system's ability to transmit Blue Force weapon related data to a collection system
2.1.4.1	Transmit Aiming Data for Blue Force Weapons	The system's ability to transmit Blue Force Aiming data to a data collection system
2.1.4.2	Transmit Firing Data for Blue Force Weapons	The system's ability to transmit Blue Force Firing data to a data collection system
2.2	Simulate Effects of Red Weapons on Blue Forces	The system's ability to simulated the lethal effects of Red force weapons on Blue Force participants
2.2.1	Receive Red Force Weapons Effects	The system's ability to receive Red Force weapons calculated effects
2.2.2	Simulate Effects of Red RPG Weapons on Blue Forces	The system's ability to simulated the lethal effects of Red force RPG on Blue Force participants
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue Forces	The system's ability to simulate the lethal effects of Red Force .50-CAL weapons on Blue Forces
2.3	Communicate Position Data from Blue Platforms	The system's ability to collect and transmit Positional information from Blue Force Platforms
2.3.1	Transmit Position Information from Blue Platforms	The system's ability to collect and transmit Position information from Blue Force Platforms
2.3.2	Transmit Heading Information from Blue Platforms	The system's ability to collect and transmit Heading information from Blue Force Platforms
2.3.3	Transmit Velocity Information from Blue Platforms	The system's ability to collect and transmit velocity information from Blue Force Platforms

Number	Element	description
3	Manage Information	High level function of managing inputs from participating units and the dissemination of processed data
3.1	Receive Information	The system's ability to receive transmitted data from participants, store that data, and allow that data to be analyzed
3.1.1	Receive Information From Red Weapons	The system's ability to receive transmitted data from Red Force participants
3.1.1.1	Receive Red Weapon Aiming Data	The system's ability to receive Red Weapon Aiming Data
3.1.1.2	Receive Red Weapon Firing Data	The system's ability to receive Red Weapon Firing Data
3.1.2	Receive Information From Blue Weapons	The system's ability to receive transmitted data from Blue Force participants
3.1.2.1	Receive Blue Weapon Aiming Data	The system's ability to receive Blue Weapon Aiming Data
3.1.2.2	Receive Blue Weapon Firing Data	The system's ability to receive Blue Weapon Firing Data
3.1.3	Receive Information From Red Platforms	The system's ability to receive information from Red Force platforms
3.1.3.1	Receive Position Information from Red Platforms	The system's ability to receive Red Force Platform position information
3.1.3.2	Receive Heading Information from Red Platforms	The system's ability to receive Red Force Platform Heading information
3.1.3.3	Receive Velocity Information from Red Platforms	The system's ability to receive Red Force Platform Velocity information
3.1.4	Receive Information from Blue Platforms	The system's ability to receive information from Blue Force platforms
3.1.4.1	Receive Position Information from Blue Platforms	The system's ability to receive Blue Force Platform position information
3.1.4.2	Receive Heading Information from Blue Platforms	The system's ability to receive Blue Force Platform Heading information
3.1.4.3	Receive Velocity Information from Blue Platforms	The system's ability to receive Blue Force Platform Velocity information
3.2	Process Information	The system's ability to process received information

Number	Element	description
3.2.1	Determine Effects of Red Weapons	The system's ability to determine the effects of Red Force weapons based on received data and system software
3.2.1.1	Determine Effects of Red Weapons on Blue Platforms	The system's ability to determine the effects of Red Force weapons on Blue Force Platforms based on received data and system software
3.2.1.2	Determine Effects of Red Weapons on Blue Weapons	The system's ability to determine the effects of Red Force weapons on Blue Force Weapons based on received data and system software
3.2.2	Determine Effects of Blue Weapons	The system's ability to determine the effects of Blue Force weapons based on received data and system software
3.2.2.1	Determine Effects of Blue Weapons on Red Platforms	The system's ability to determine the effects of Blue Force weapons on Red Force Platforms based on received data and system software
3.2.2.2	Determine Effects of Blue Weapons on Red Weapons	The system's ability to determine the effects of Blue Force weapons on Red Force Weapons based on received data and system software
3.3	Transmit Information	The system's ability to transmit participant data to support the execution of the training event
3.3.1	Transmit Red Platform Status Information	The system's ability to transmit Red Platform Status data to support the execution of the training event
3.3.2	Transmit Red Weapon Status Information	The system's ability to transmit Red Weapon Status data to support the execution of the training event
3.3.3	Transmit Blue Platform Status Information	The system's ability to transmit Blue Platform Status data to support the execution of the training event
3.3.4	Transmit Blue Weapon Status Information	The system's ability to transmit Blue Weapon Status data to support the execution of the training event
3.4	Record Data	The system's ability to record received information
3.4.1	Record Red Weapon Data	The system's ability to record Red Force Weapons received information

Number	Element	description
3.4.1.1	Record Red Weapon Aiming Data	The system's ability to record received Red Force Weapons Aiming information
3.4.1.2	Record Red Weapon Firing Data	The system's ability to record received Red Force Weapons Firing information
3.4.1.3	Record Red Weapon Effects on Blue Platforms	The system's ability to record received Red Force Weapons Effects on Blue Force Platform information
3.4.1.4	Record Red Weapon Effects on Blue Weapons	The system's ability to record received Red Force Weapons Effects on Blue Force Weapons information
3.4.1.5	Record Red Force Weapons Status	The system's ability to record received Red Force Weapons status
3.4.2	Record Red Platform Data	The system's ability to record received Red Force Platform Data
3.4.2.1	Record Red Platform Position Data	The system's ability to record received Red Force Position Data
3.4.2.2	Record Red Platform Status Information	The system's ability to record received Red Force Platform status information
3.4.3	Record Blue Weapon Data	The system's ability to record Blue Force Weapons received information
3.4.3.1	Record Blue Weapon Aiming Data	The system's ability to record received Blue Force Weapons Aiming information
3.4.3.2	Record Blue Weapon Firing Data	The system's ability to record received Blue Force Weapons Firing information
3.4.3.3	Record Blue Weapon Effects on Red Platforms	The system's ability to record received Blue Force Weapons Effects on Red Force Platform information
3.4.3.4	Record Blue Weapons Effects on Red Weapons	The system's ability to record received Blue Force Weapons Effects on Red Force Weapons information
3.4.3.5	Record Blue Force Weapons Status	The system's ability to record received Blue Force Weapons status
3.4.4	Record Blue Platform Data	The system's ability to record received Blue Force Platform Data
3.4.4.1	Record Blue Platform Position Data	The system's ability to record received Blue Force Position Data

Number	Element	description
3.4.4.2	Record Blue Platform Status Information	The system's ability to record received Blue Force Platform status information
4	Evaluate Performance	The system's ability to evaluate training relate information and produce an after action report
4.1	Evaluate Data	The system's ability to evaluate received data against established grading criteria
4.1.1	Score Data Based on Metrics	The system's ability to determine a participating units score based on the evaluation of data compared to a predetermined performance metrics
4.1.2	Determine Readiness	The system's ability to determine readiness of a participating unit to execute mission based on approve assessment criteria
4.2	Generate Reports	The ability of the system to generate tailored reports
4.2.1	Readiness Report	The ability of the system to generate Readiness reports
4.2.2	After Action Report	The ability of the system to generate After Action reports

Table 20. Prototype System Derived Functions

Number	Element	description
0	Conduct FAC/FIAC Training	This is the overall system function of supporting both Blue force training and Red force units
1	Simulate Red Forces	The system's ability to identify Red forces and enable participation in training.
1.2.1	Receive Blue Forces Weapons effects	The system's ability to receive Blue Force weapons calculated effects
1.2.2	Simulate Effects of Blue .50-CAL Weapons on Red Forces	The system's ability to simulate the lethal effects of Blue Force .50-CAL weapons on Red Forces

Number	Element	description
1.2.3	Simulate Effects of Blue M240B Weapons on Red Forces	The system's ability to simulate the lethal effects of Blue Force M240B Cal weapons on Red Forces
1.3	Communicate Position Data from Red Platforms	The system's ability to collect and transmit Positional information from Red force Platforms
1.3.1	Transmit Position Information from Red Platforms	The system's ability to collect and transmit Position information from Red force Platforms
1.3.2	Transmit Heading Information from Red Platforms	The system's ability to collect and transmit Heading information from Red force Platforms
1.3.3	Transmit Velocity Information from Red Platforms	The system's ability to collect and transmit velocity information from Red force Platforms
2	Simulate Blue Forces	The system's ability to identify Blue forces and enable participation in training
2.1	Simulate Firing Blue Crew Served Weapons	The system's ability to simulate the firing of Blue Force Crew Served Weapons
2.1.1	Simulate Blue .50 Weapons	The system's ability to simulate a .50-CAL weapon
2.1.1.2	Simulate Aiming of Blue Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's aiming process
2.1.1.3	Simulate Firing of Blue Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's firing process
2.1.2	Simulate Blue M240B Weapons	The system's ability to simulate a M240B weapon
2.1.2.2	Simulate Aiming of Blue Force M240B Weapons	The system's ability to simulate a M240B weapon's aiming process
2.1.2.3	Simulate Firing of Blue Force M240B Weapons	The system's ability to simulate a M240B weapon's firing process
2.1.4	Communicate Blue Force Weapon Data	The system's ability to transmit Blue Force weapon related data to a collection system
2.1.4.1	Transmit Aiming Data for Blue Force Weapons	The system's ability to transmit Blue Force Aiming data to a data collection system
2.1.4.2	Transmit Firing Data for Blue Force Weapons	The system's ability to transmit Blue Force Firing data to a data collection system

Number	Element	description
2.3	Communicate Position Data from Blue Platforms	The system's ability to collect and transmit Positional information from Blue Force Platforms
2.3.1	Transmit Position Information from Blue Platforms	The system's ability to collect and transmit Position information from Blue Force Platforms
2.3.2	Transmit Heading Information from Blue Platforms	The system's ability to collect and transmit Heading information from Blue Force Platforms
2.3.3	Transmit Velocity Information from Blue Platforms	The system's ability to collect and transmit velocity information from Blue Force Platforms
3	Manage Information	High level function of managing inputs from participating units and the dissemination of processed data
3.1	Receive Information	The system's ability to receive transmitted data from participants, store that data, and allow that data to be analyzed
3.1.2	Receive Information From Blue Weapons	The system's ability to receive transmitted data from Blue Force participants
3.1.2.1	Receive Blue Weapon Aiming Data	The system's ability to receive Blue Weapon Aiming Data
3.1.2.2	Receive Blue Weapon Firing Data	The system's ability to receive Blue Weapon Firing Data
3.1.3	Receive Information From Red Platforms	The system's ability to receive information from Red Force platforms
3.1.3.1	Receive Position Information from Red Platforms	The system's ability to receive Red Force Platform position information
3.1.3.2	Receive Heading Information from Red Platforms	The system's ability to receive Red Force Platform Heading information
3.1.3.3	Receive Velocity Information from Red Platforms	The system's ability to receive Red Force Platform Velocity information
3.1.4	Receive Information from Blue Platforms	The system's ability to receive information from Blue Force platforms
3.1.4.1	Receive Position Information from Blue Platforms	The system's ability to receive Blue Force Platform position information
3.1.4.2	Receive Heading Information from Blue Platforms	The system's ability to receive Blue Force Platform Heading information

Number	Element	description
3.1.4.3	Receive Velocity Information from Blue Platforms	The system's ability to receive Blue Force Platform Velocity information
3.2	Process Information	The system's ability to process received information
3.2.2	Determine Effects of Blue Weapons	The system's ability to determine the effects of Blue Force weapons based on received data and system software
3.2.2.1	Determine Effects of Blue Weapons on Red Platforms	The system's ability to determine the effects of Blue Force weapons on Red Force Platforms based on received data and system software
3.2.2.2	Determine Effects of Blue Weapons on Red Weapons	The system's ability to determine the effects of Blue Force weapons on Red Force Weapons based on received data and system software
3.3	Transmit Information	The system's ability to transmit participant data to support the execution of the training event
3.3.1	Transmit Red Platform Status Information	The system's ability to transmit Red Platform Status data to support the execution of the training event
3.3.3	Transmit Blue Platform Status Information	The system's ability to transmit Blue Platform Status data to support the execution of the training event
3.3.4	Transmit Blue Weapon Status Information	The system's ability to transmit Blue Weapon Status data to support the execution of the training event
3.4	Record Data	The system's ability to record received information
3.4.2	Record Red Platform Data	The system's ability to record received Red Force Platform Data
3.4.2.1	Record Red Platform Position Data	The system's ability to record received Red Force Position Data
3.4.2.2	Record Red Platform Status Information	The system's ability to record received Red Force Platform status information
3.4.3	Record Blue Weapon Data	The system's ability to record Blue Force Weapons received information
3.4.3.1	Record Blue Weapon Aiming Data	The system's ability to record received Blue Force Weapons Aiming information

Number	Element	description
3.4.3.2	Record Blue Weapon Firing Data	The system's ability to record received Blue Force Weapons Firing information
3.4.3.3	Record Blue Weapon Effects on Red Platforms	The system's ability to record received Blue Force Weapons Effects on Red Force Platform information
3.4.3.4	Record Blue Weapons Effects on Red Weapons	The system's ability to record received Blue Force Weapons Effects on Red Force Weapons information
3.4.3.5	Record Blue Force Weapons Status	The system's ability to record received Blue Force Weapons status
3.4.4	Record Blue Platform Data	The system's ability to record received Blue Force Platform Data
3.4.4.1	Record Blue Platform Position Data	The system's ability to record received Blue Force Position Data
3.4.4.2	Record Blue Platform Status Information	The system's ability to record received Blue Force Platform status information
4	Evaluate Performance	The system's ability to evaluate training relate information and produce an after action report
4.1	Evaluate Data	The system's ability to evaluate received data against established grading criteria
4.2	Generate Reports	The ability of the system to generate tailored reports
4.2.2	After Action Report	The ability of the system to generate After Action reports

Table 21. Training System Derived Functions

Number	Element	description
0	Conduct FAC/FIAC Training	This is the overall system function of supporting both Blue force training and Red force units
1	Simulate Red Forces	The system's ability to identify Red forces and enable participation in training.
1.1	Simulate Firing of Red Weapons	The system's ability to simulate the firing of Red Force Weapons

Number	Element	description
1.1.1	Simulate Red .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon
1.1.1.1	Simulate Loading of Red Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's loading process
1.1.1.2	Simulate Aiming of Red Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's aiming process
1.1.1.3	Simulate Firing of Red Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's firing process
1.1.2	Simulate Red RPG Weapons	The system's ability to simulate a RPG weapon
1.1.2.1	Simulate Loading of Red Force RPG Weapons	The system's ability to simulate a RPG weapon's loading process
1.1.2.2	Simulate Aiming of Red Force RPG Weapons	The system's ability to simulate a RPG weapon's aiming process
1.1.2.3	Simulate Firing of Red Force RPG Weapons	The system's ability to simulate a RPG weapon's firing process
1.1.3	Communicate Red Force Weapon Data	The system's ability to transmit Red Force weapon related data to a collection system
1.1.3.1	Transmit Aiming Data for Red Force Weapons	The system's ability to transmit Red Force Aiming data to a data collection system
1.1.3.2	Transmit Firing Data for Red Force Weapons	The system's ability to transmit Red Force Firing data to a data collection system
1.2	Simulate Effects of Blue Weapons on Red Forces	The system's ability to simulated the lethal effects of Blue force weapons on Red Force participants
1.2.1	Receive Blue Forces Weapons effects	The system's ability to receive Blue Force weapons calculated effects
1.2.2	Simulate Effects of Blue .50-CAL Weapons on Red Forces	The system's ability to simulate the lethal effects of Blue Force .50-CAL weapons on Red Forces
1.2.3	Simulate Effects of Blue M240B Weapons on Red Forces	The system's ability to simulate the lethal effects of Blue Force M240B Cal weapons on Red Forces
1.2.4	Simulate Effects of Blue Mrk 19 Weapons on Red Forces	The system's ability to simulate the lethal effects of Blue Force Mrk 19 weapons on Red Forces
1.3	Communicate Position Data from Red Platforms	The system's ability to collect and transmit Positional information from Red force Platforms

Number	Element	description
1.3.1	Transmit Position Information from Red Platforms	The system's ability to collect and transmit Position information from Red force Platforms
1.3.2	Transmit Heading Information from Red Platforms	The system's ability to collect and transmit Heading information from Red force Platforms
1.3.3	Transmit Velocity Information from Red Platforms	The system's ability to collect and transmit velocity information from Red force Platforms
2	Simulate Blue Forces	The system's ability to identify Blue forces and enable participation in training
2.1	Simulate Firing Blue Crew Served Weapons	The system's ability to simulate the firing of Blue Force Crew Served Weapons
2.1.1	Simulate Blue .50 Weapons	The system's ability to simulate a .50-CAL weapon
2.1.1.1	Simulate Loading of Blue Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's loading process
2.1.1.2	Simulate Aiming of Blue Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's aiming process
2.1.1.3	Simulate Firing of Blue Force .50-CAL Weapons	The system's ability to simulate a .50-CAL weapon's firing process
2.1.2	Simulate Blue M240B Weapons	The system's ability to simulate a M240B weapon
2.1.2.1	Simulate Loading of Blue Force M240B Weapons	The system's ability to simulate a M240B weapon's loading process
2.1.2.2	Simulate Aiming of Blue Force M240B Weapons	The system's ability to simulate a M240B weapon's aiming process
2.1.2.3	Simulate Firing of Blue Force M240B Weapons	The system's ability to simulate a M240B weapon's firing process
2.1.3	Simulate Blue Mrk 19 Weapons	The system's ability to simulate a Mrk 19 weapon
2.1.3.1	Simulate Loading of Blue Force Mrk 19 Weapons	The system's ability to simulate a Mrk 19 weapon's loading process
2.1.3.2	Simulate Aiming of Blue Force Mrk 19 Weapons	The system's ability to simulate a Mrk 19 weapon's aiming process
2.1.3.3	Simulate Firing of Blue Force Mrk 19 Weapons	The system's ability to simulate a Mrk 19 weapon's firing process
2.1.4	Communicate Blue Force Weapon Data	The system's ability to transmit Blue Force weapon related data to a collection system

Number	Element	description
2.1.4.1	Transmit Aiming Data for Blue Force Weapons	The system's ability to transmit Blue Force Aiming data to a data collection system
2.1.4.2	Transmit Firing Data for Blue Force Weapons	The system's ability to transmit Blue Force Firing data to a data collection system
2.2	Simulate Effects of Red Weapons on Blue Forces	The system's ability to simulated the lethal effects of Red force weapons on Blue Force participants
2.2.1	Receive Red Force Weapons Effects	The system's ability to receive Red Force weapons calculated effects
2.2.2	Simulate Effects of Red RPG Weapons on Blue Forces	The system's ability to simulated the lethal effects of Red force RPG on Blue Force participants
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue Forces	The system's ability to simulate the lethal effects of Red Force .50-CAL weapons on Blue Forces
2.3	Communicate Position Data from Blue Platforms	The system's ability to collect and transmit Positional information from Blue Force Platforms
2.3.1	Transmit Position Information from Blue Platforms	The system's ability to collect and transmit Position information from Blue Force Platforms
2.3.2	Transmit Heading Information from Blue Platforms	The system's ability to collect and transmit Heading information from Blue Force Platforms
2.3.3	Transmit Velocity Information from Blue Platforms	The system's ability to collect and transmit velocity information from Blue Force Platforms
3	Manage Information	High level function of managing inputs from participating units and the dissemination of processed data
3.1	Receive Information	The system's ability to receive transmitted data from participants, store that data, and allow that data to be analyzed
3.1.1	Receive Information From Red Weapons	The system's ability to receive transmitted data from Red Force participants
3.1.1.1	Receive Red Weapon Aiming Data	The system's ability to receive Red Weapon Aiming Data
3.1.1.2	Receive Red Weapon Firing Data	The system's ability to receive Red Weapon Firing Data

Number	Element	description
3.1.2	Receive Information From Blue Weapons	The system's ability to receive transmitted data from Blue Force participants
3.1.2.1	Receive Blue Weapon Aiming Data	The system's ability to receive Blue Weapon Aiming Data
3.1.2.2	Receive Blue Weapon Firing Data	The system's ability to receive Blue Weapon Firing Data
3.1.3	Receive Information From Red Platforms	The system's ability to receive information from Red Force platforms
3.1.3.1	Receive Position Information from Red Platforms	The system's ability to receive Red Force Platform position information
3.1.3.2	Receive Heading Information from Red Platforms	The system's ability to receive Red Force Platform Heading information
3.1.3.3	Receive Velocity Information from Red Platforms	The system's ability to receive Red Force Platform Velocity information
3.1.4	Receive Information from Blue Platforms	The system's ability to receive information from Blue Force platforms
3.1.4.1	Receive Position Information from Blue Platforms	The system's ability to receive Blue Force Platform position information
3.1.4.2	Receive Heading Information from Blue Platforms	The system's ability to receive Blue Force Platform Heading information
3.1.4.3	Receive Velocity Information from Blue Platforms	The system's ability to receive Blue Force Platform Velocity information
3.2	Process Information	The system's ability to process received information
3.2.1	Determine Effects of Red Weapons	The system's ability to determine the effects of Red Force weapons based on received data and system software
3.2.1.1	Determine Effects of Red Weapons on Blue Platforms	The system's ability to determine the effects of Red Force weapons on Blue Force Platforms based on received data and system software
3.2.1.2	Determine Effects of Red Weapons on Blue Weapons	The system's ability to determine the effects of Red Force weapons on Blue Force Weapons based on received data and system software
3.2.2	Determine Effects of Blue Weapons	The system's ability to determine the effects of Blue Force weapons based on received data and system software

Number	Element	description
3.2.2.1	Determine Effects of Blue Weapons on Red Platforms	The system's ability to determine the effects of Blue Force weapons on Red Force Platforms based on received data and system software
3.2.2.2	Determine Effects of Blue Weapons on Red Weapons	The system's ability to determine the effects of Blue Force weapons on Red Force Weapons based on received data and system software
3.3	Transmit Information	The system's ability to transmit participant data to support the execution of the training event
3.3.1	Transmit Red Platform Status Information	The system's ability to transmit Red Platform Status data to support the execution of the training event
3.3.2	Transmit Red Weapon Status Information	The system's ability to transmit Red Weapon Status data to support the execution of the training event
3.3.3	Transmit Blue Platform Status Information	The system's ability to transmit Blue Platform Status data to support the execution of the training event
3.3.4	Transmit Blue Weapon Status Information	The system's ability to transmit Blue Weapon Status data to support the execution of the training event
3.4	Record Data	The system's ability to record received information
3.4.1	Record Red Weapon Data	The system's ability to record Red Force Weapons received information
3.4.1.1	Record Red Weapon Aiming Data	The system's ability to record received Red Force Weapons Aiming information
3.4.1.2	Record Red Weapon Firing Data	The system's ability to record received Red Force Weapons Firing information
3.4.1.3	Record Red Weapon Effects on Blue Platforms	The system's ability to record received Red Force Weapons Effects on Blue Force Platform information
3.4.1.4	Record Red Weapon Effects on Blue Weapons	The system's ability to record received Red Force Weapons Effects on Blue Force Weapons information
3.4.1.5	Record Red Force Weapons Status	The system's ability to record received Red Force Weapons status
3.4.2	Record Red Platform Data	The system's ability to record received Red Force Platform Data

Number	Element	description
3.4.2.1	Record Red Platform Position Data	The system's ability to record received Red Force Position Data
3.4.2.2	Record Red Platform Status Information	The system's ability to record received Red Force Platform status information
3.4.3	Record Blue Weapon Data	The system's ability to record Blue Force Weapons received information
3.4.3.1	Record Blue Weapon Aiming Data	The system's ability to record received Blue Force Weapons Aiming information
3.4.3.2	Record Blue Weapon Firing Data	The system's ability to record received Blue Force Weapons Firing information
3.4.3.3	Record Blue Weapon Effects on Red Platforms	The system's ability to record received Blue Force Weapons Effects on Red Force Platform information
3.4.3.4	Record Blue Weapons Effects on Red Weapons	The system's ability to record received Blue Force Weapons Effects on Red Force Weapons information
3.4.3.5	Record Blue Force Weapons Status	The system's ability to record received Blue Force Weapons status
3.4.4	Record Blue Platform Data	The system's ability to record received Blue Force Platform Data
3.4.4.1	Record Blue Platform Position Data	The system's ability to record received Blue Force Position Data
3.4.4.2	Record Blue Platform Status Information	The system's ability to record received Blue Force Platform status information
4	Evaluate Performance	The system's ability to evaluate training relate information and produce an after action report
4.1	Evaluate Data	The system's ability to evaluate received data against established grading criteria
4.1.1	Score Data Based on Metrics	The system's ability to determine a participating units score based on the evaluation of data compared to a predetermined performance metrics
4.1.2	Determine Readiness	The system's ability to determine readiness of a participating unit to execute mission based on approve assessment criteria

Number	**Element**	**description**
4.2	Generate Reports	The ability of the system to generate tailored reports
4.2.1	Readiness Report	The ability of the system to generate Readiness reports
4.2.2	After Action Report	The ability of the system to generate After Action reports

B. FUNCTIONAL FLOW BLOCK DIAGRAMS (FFBD)

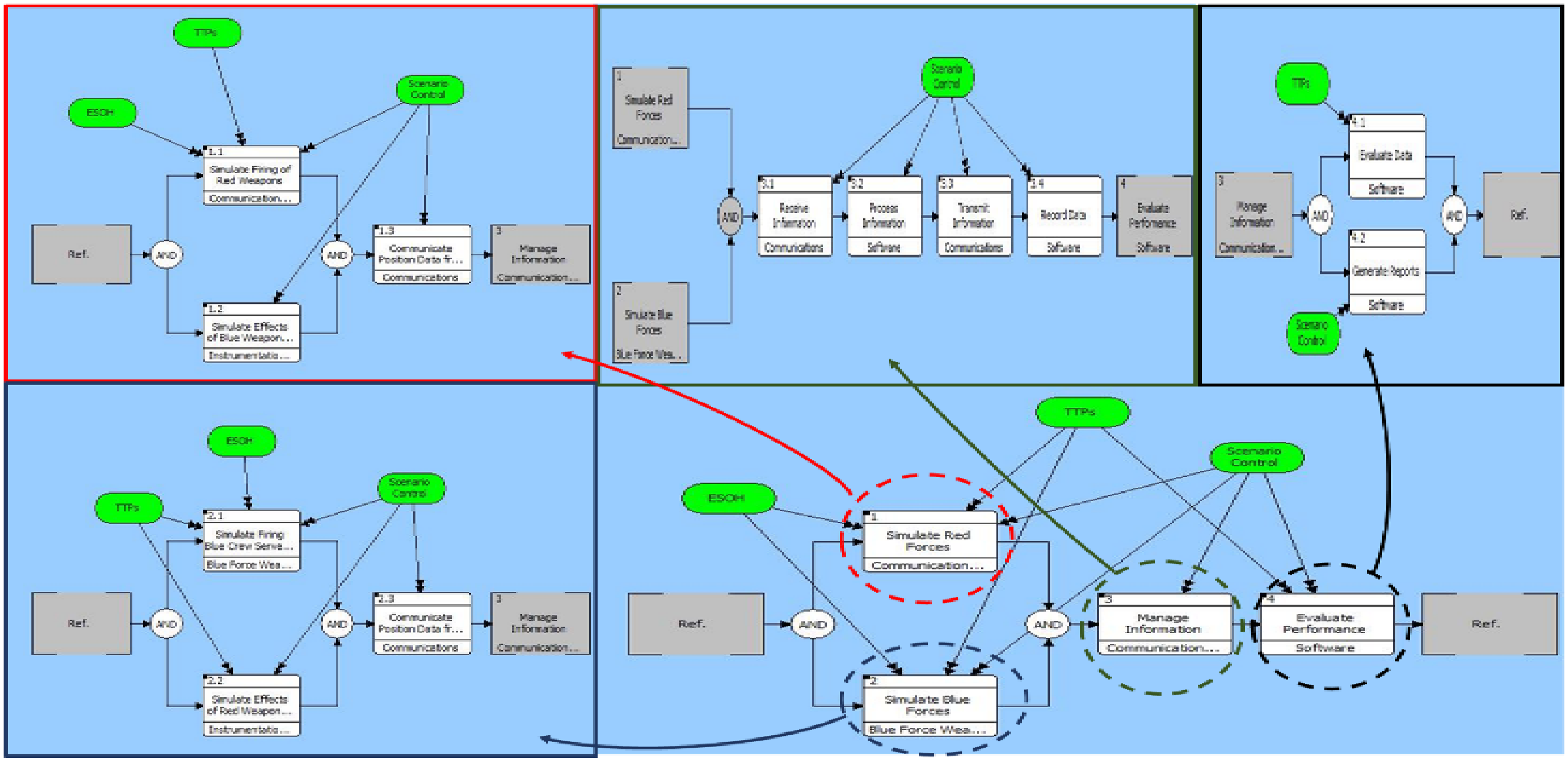

Figure 29. FAC/FIAC Training System Functions to level 2 FFBD

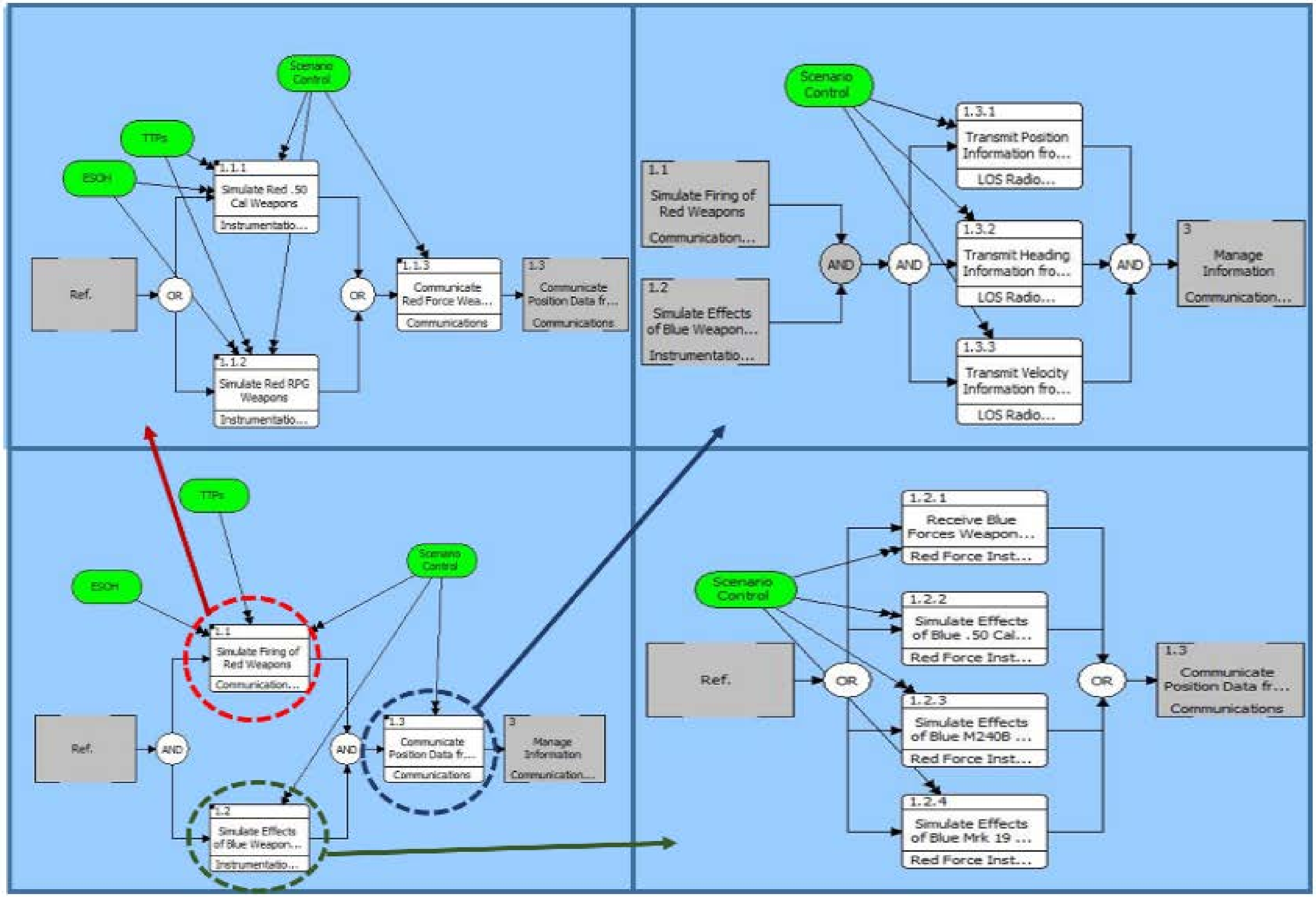

Figure 30. Simulate Red Forces (1.0) Levels 2 and 3 FFBD

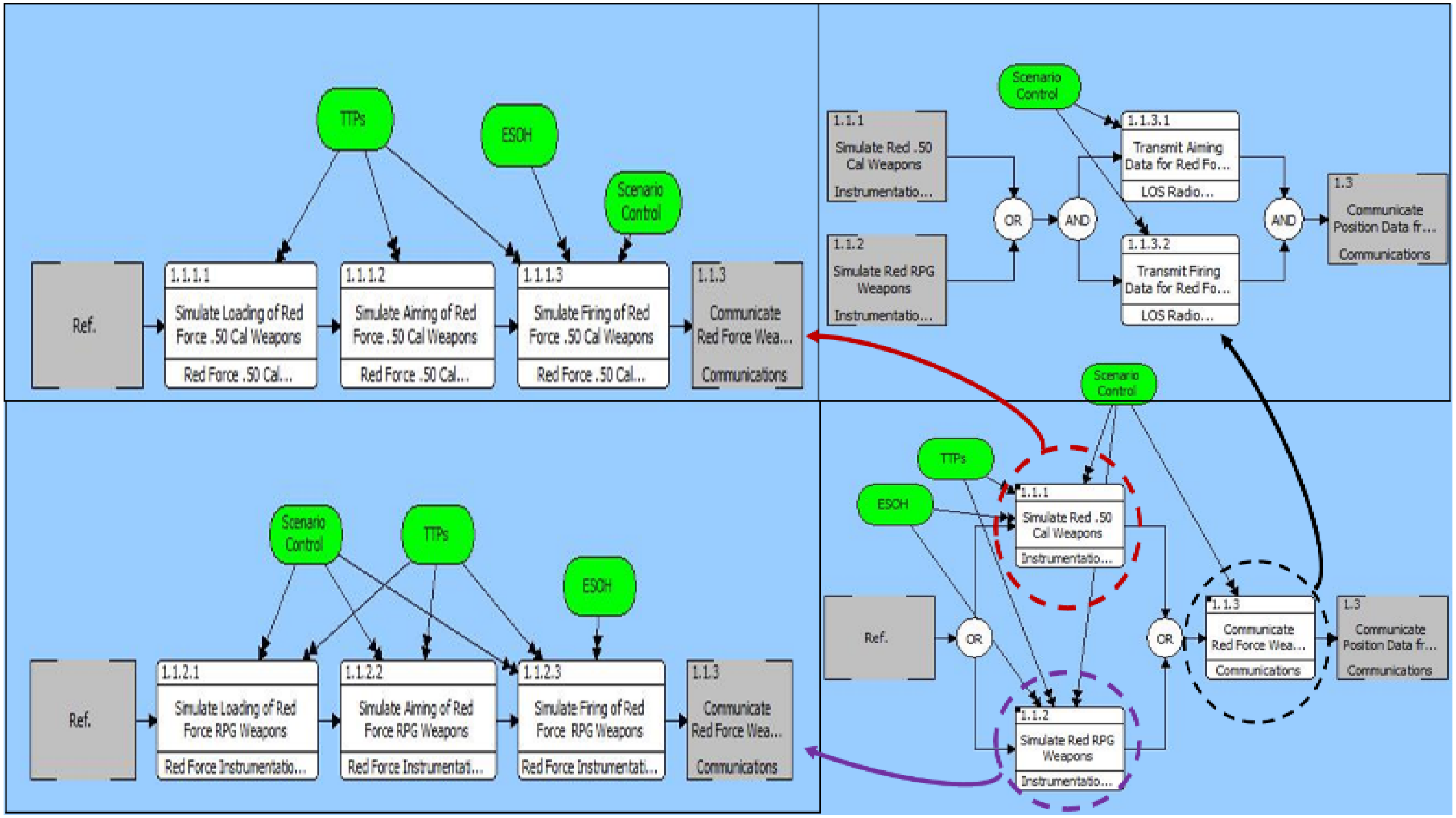

Figure 31. Simulate Red Forces (1.0) Levels 3 and 4 FFBD

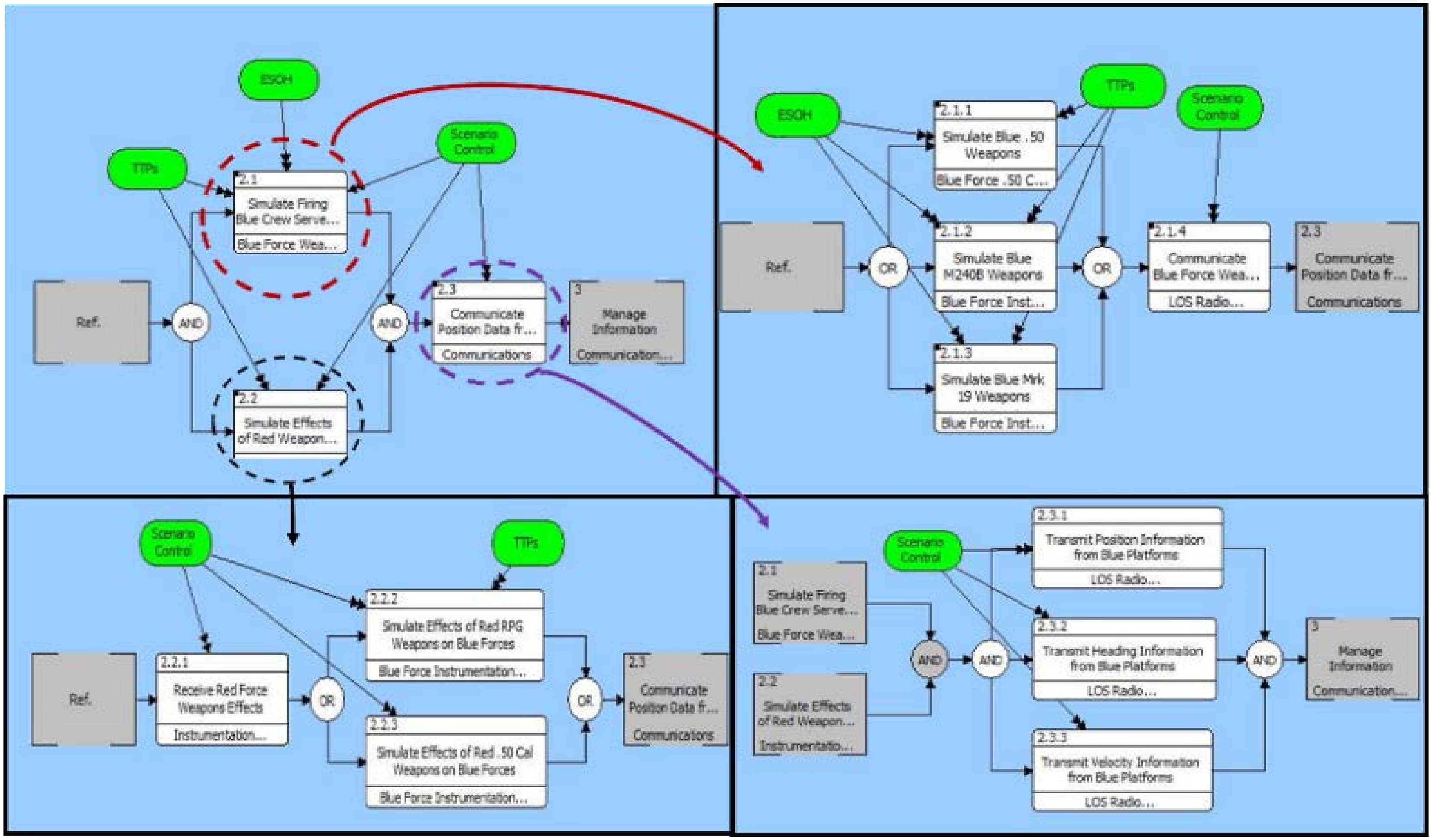

Figure 32. Simulate Blue Forces (2.0) Levels 2 and 3 FFBD

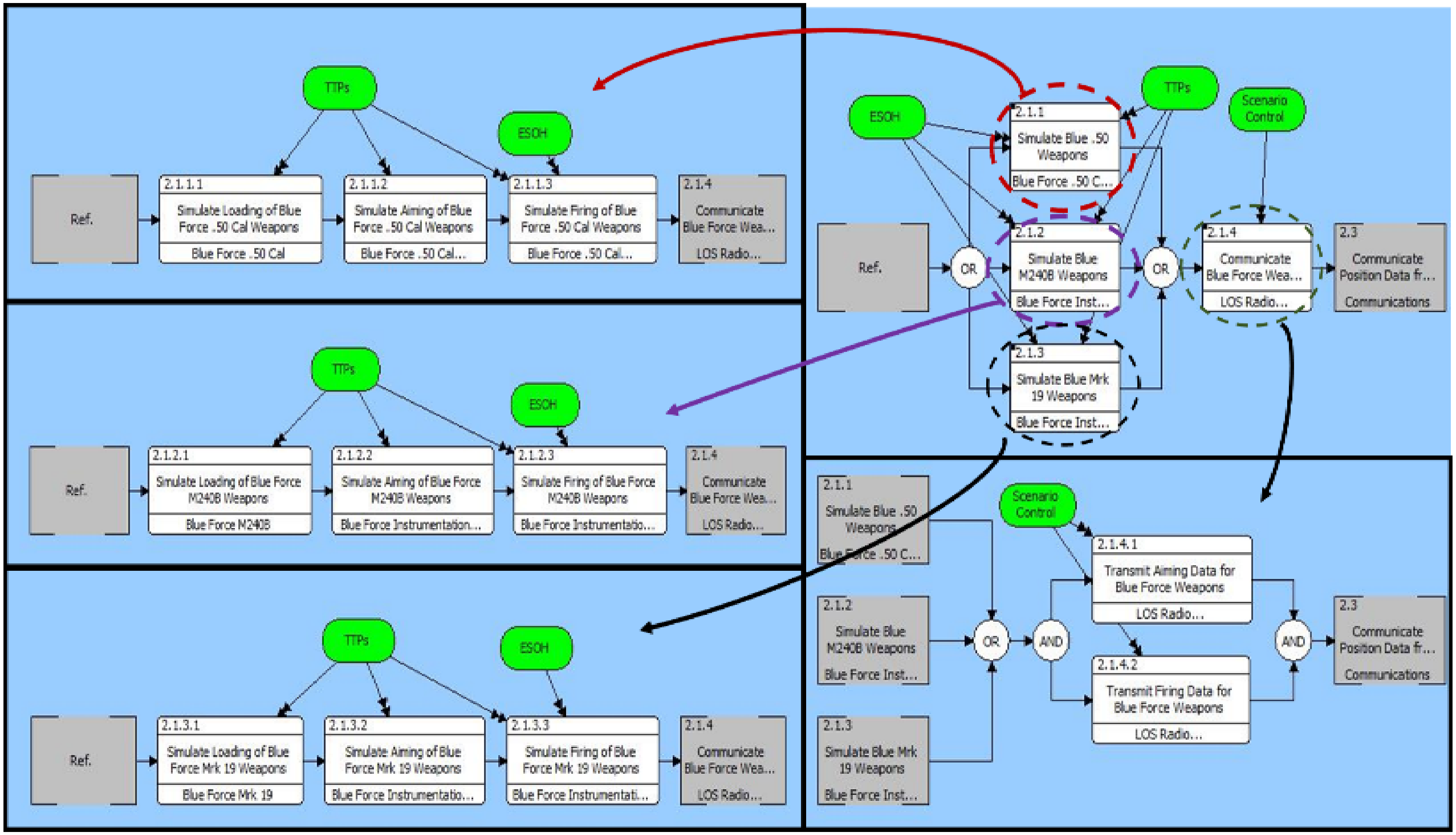

Figure 33. Simulate Blue Forces (2.0) Levels 3 and 4 FFBD

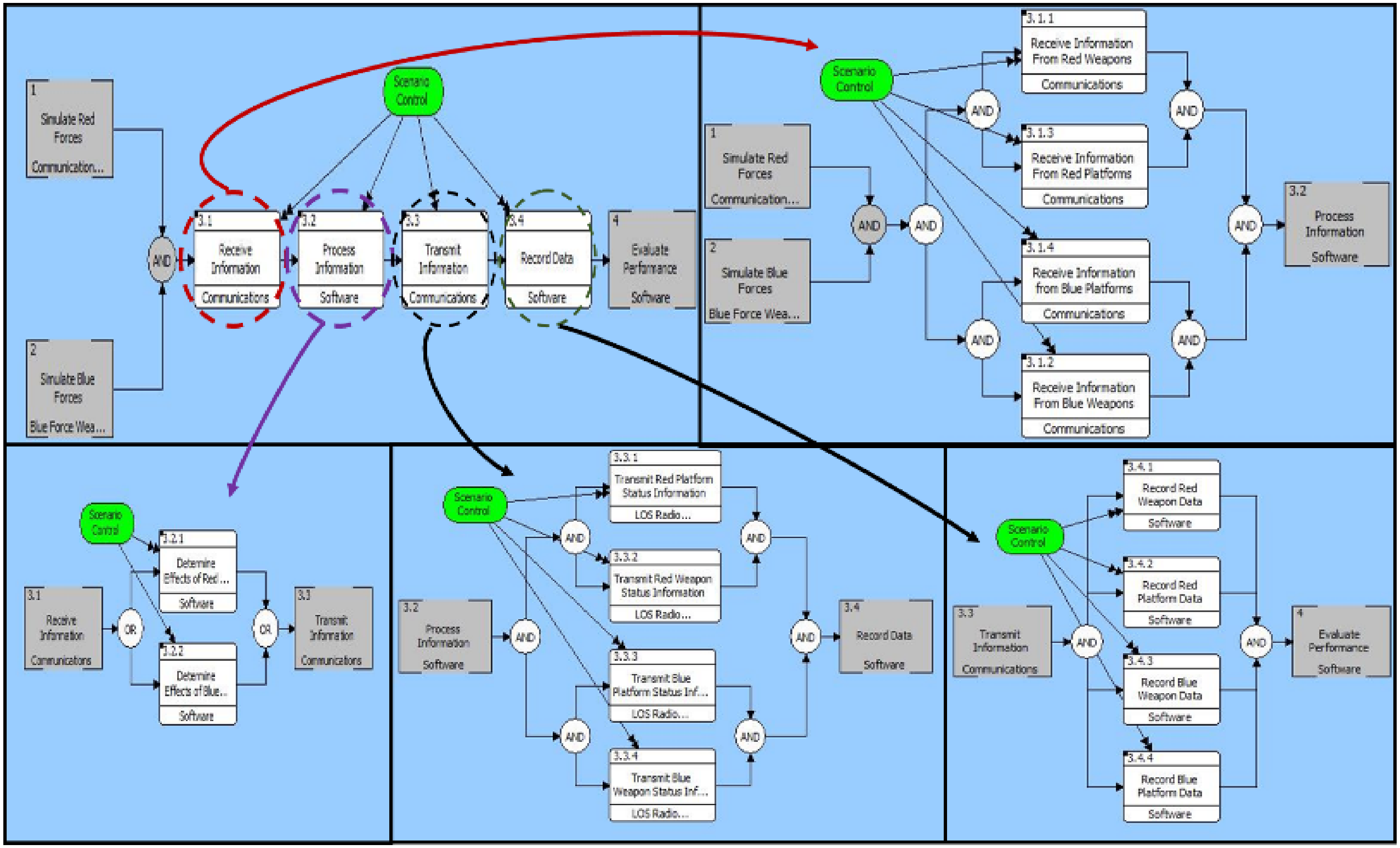

Figure 34. Manage Information (3.0) Levels 2 and 3 FFBD

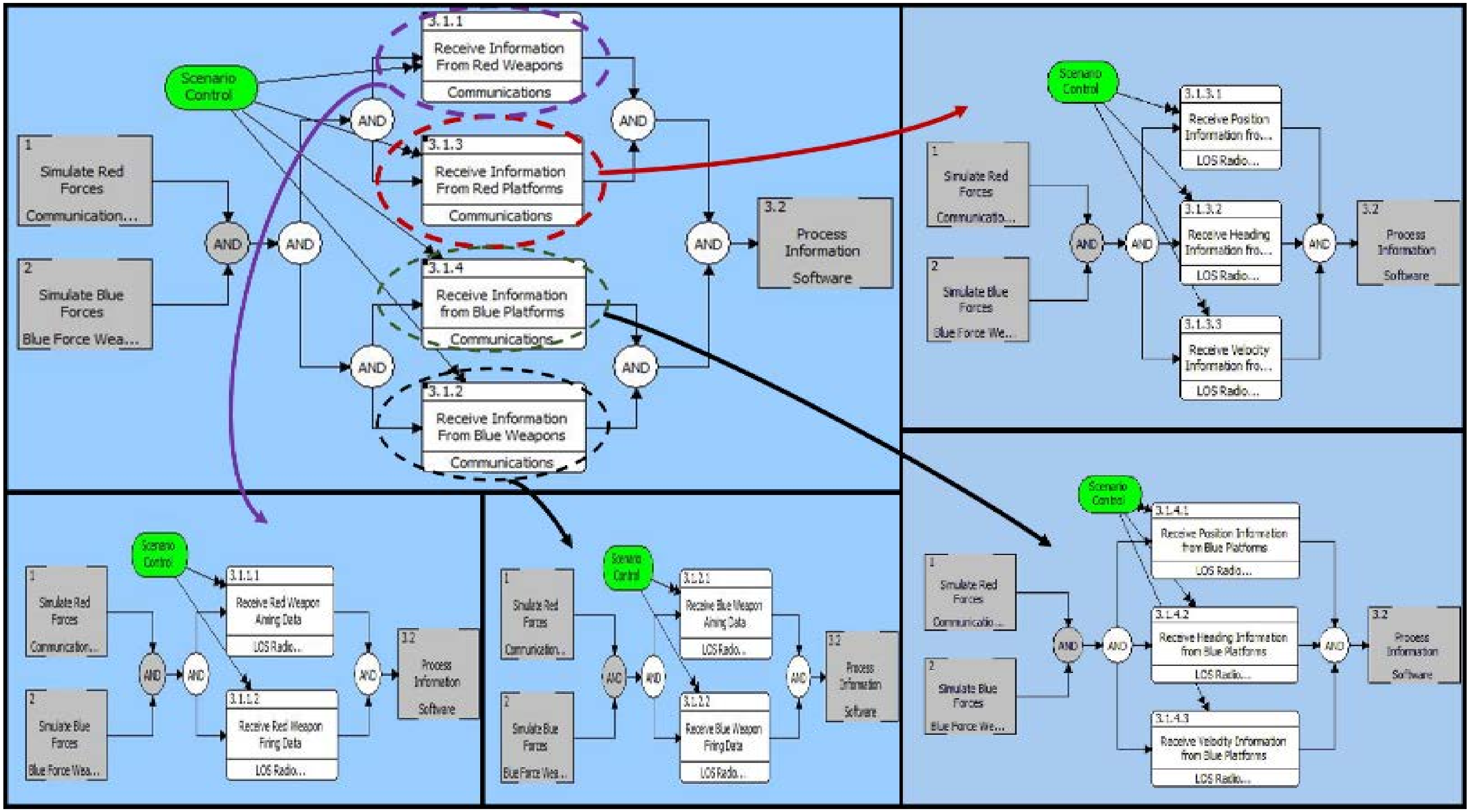

Figure 35. Manage Information (3.0) Level 3 (3.1.1) and Level 4 FFBD

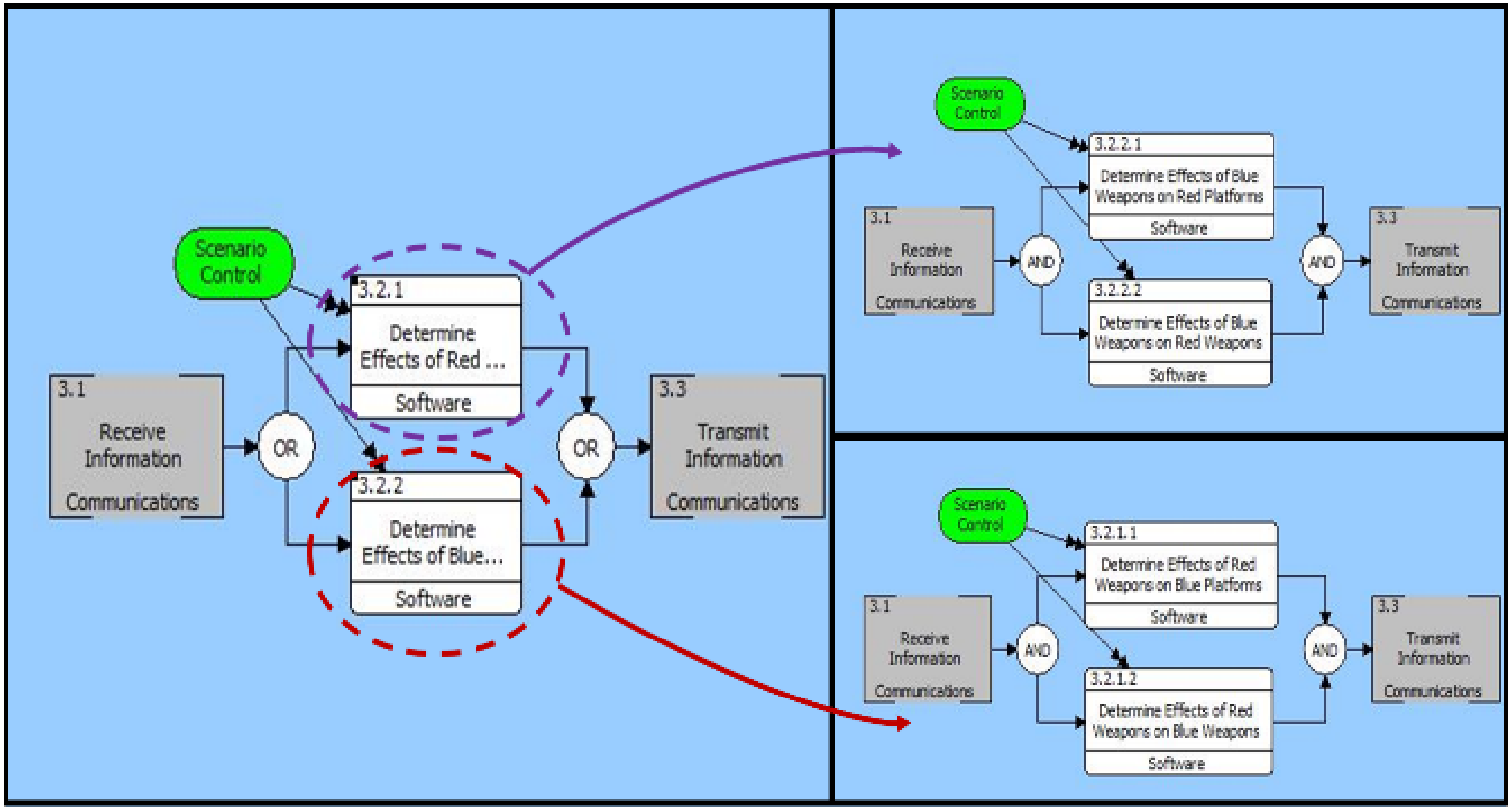

Figure 36. Manage Information (3.0) Level 3s (3.2.X) and Level 4 FFBDs

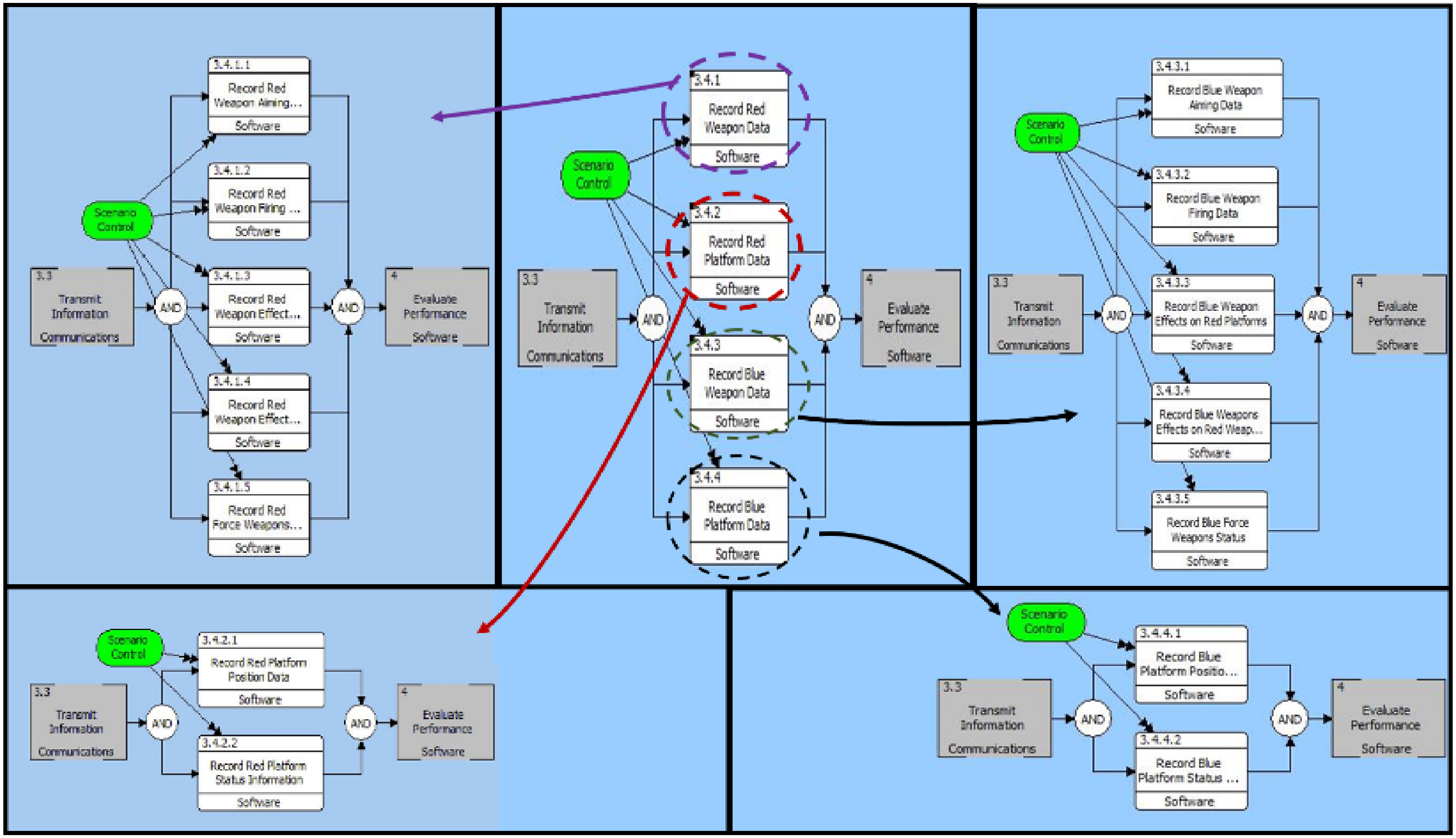

Figure 37. Manage Information (3.0) Level 3 (3.4.X) and Level 4 FFBDs

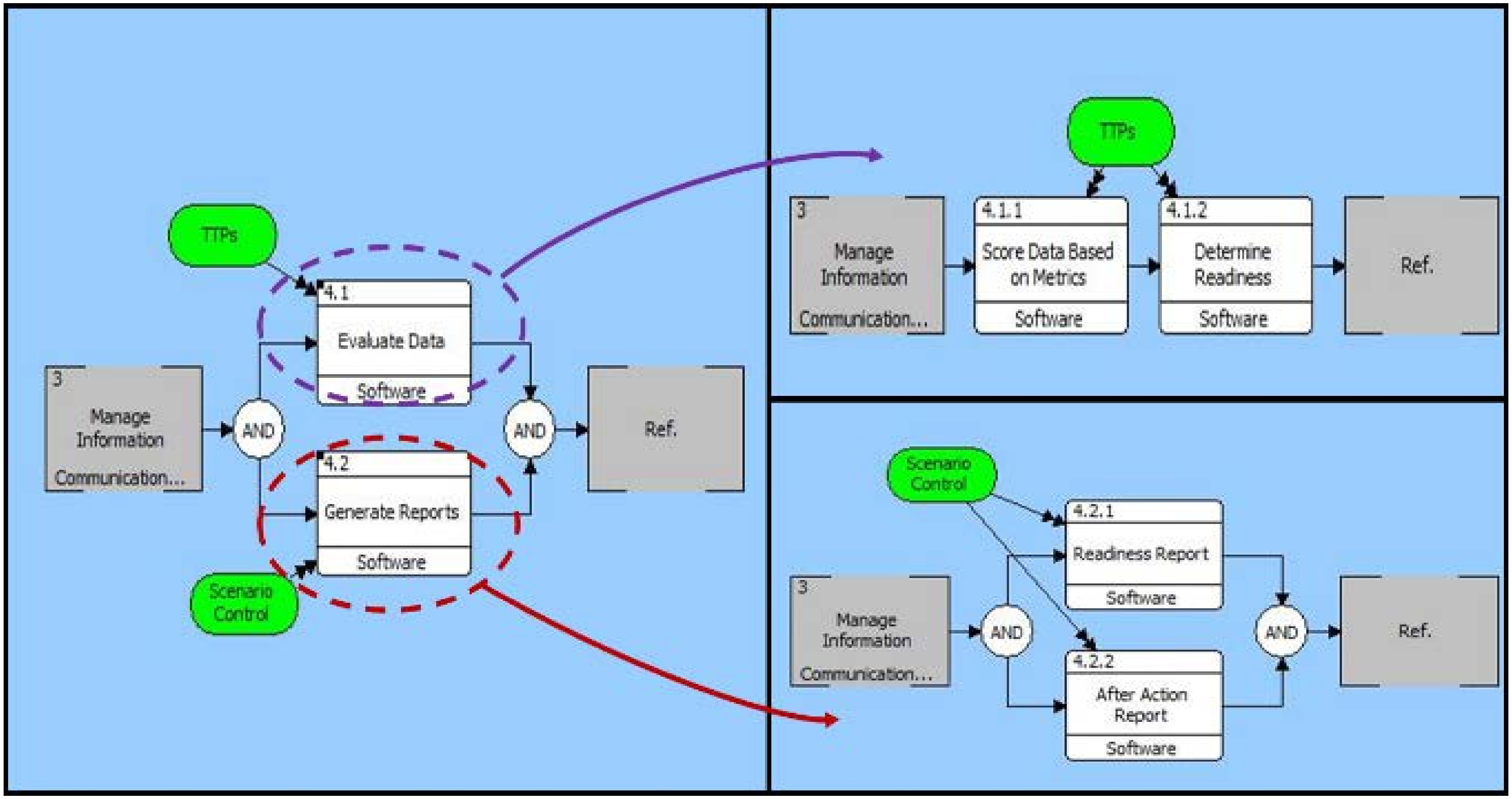

Figure 38. Process Information (4.0) Level 2 (4.X) and Level 3 FFBDs

APPENDIX E. IDEF0 TABLES AND DIAGRAMS

A. INPUTS, CONTROLS, OUTPUTS, AND MECHANISMS TABLE

Table 22. Inputs, Controls, Outputs, and Mechanisms

Number	Function	Inputs	Controls	Outputs	Mechanism
0	Conduct FAC/FIAC Training	Blue Forces Operator Red Forces	ESOH Scenario Control TTPs	Reports Trained Crew Unit Readiness	Blue Force Weapons Communications Instrumentation Red Force Weapons Software
1	Simulate Red Forces	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data Operator Red Forces	ESOH Scenario Control TTPs	Red Force Heading Red Force Platform Status Red Force Position Red Force Velocity Red Force Weapon Aiming Data Red Force Weapon Firing Data Red Force Weapons Status	Communications Instrumentation Red Force Weapons Software
1.1	Simulate Firing of Red Weapons	Operator Red Force Weapons Information	ESOH Scenario Control TTPs	Red Force Weapon Aiming Data Red Force Weapon Firing Data	Communications Instrumentation Red Force Weapons Software

Number	Function	Inputs	Controls	Outputs	Mechanism
1.1.1	Simulate Red .50-CAL Weapons	Operator Red Force .50-CAL	ESOH Scenario Control TTPs	Red Force .50-CAL Aiming Red Force .50-CAL Firing data	Instrumentation Red Force .50-CAL Software
1.1.1.1	Simulate Loading of Red Force .50-CAL Weapons	Operator Red Force .50-CAL	TTPs	Red Force loaded .50-CAL	Red Force .50-CAL Red Force Instrumentation Software
1.1.1.2	Simulate Aiming of Red Force .50-CAL Weapons	Operator	TTPs	Red Force .50-CAL Aiming	Red Force .50-CAL Red Force Instrumentation Software
1.1.1.3	Simulate Firing of Red Force .50-CAL Weapons	Operator Red Force loaded .50-CAL	ESOH Scenario Control TTPs	Red Force .50-CAL Firing data	Red Force .50-CAL Red Force Instrumentation Software
1.1.2	Simulate Red RPG Weapons	Operator Red Force RPG	ESOH Scenario Control TTPs	Red Force RPG Aiming Data Red Force RPG Firing Data	Instrumentation Red Force RPG Software
1.1.2.1	Simulate Loading of Red Force RPG Weapons	Operator Red Force RPG	Scenario Control TTPs	Red Force Loaded RPG	Red Force Instrumentation Red Force RPG
1.1.2.2	Simulate Aiming of Red Force RPG Weapons	Operator	Scenario Control TTPs	Red Force RPG Aiming Data Red Force RPG Firing solution	Red Force Instrumentation Red Force RPG

Number	Function	Inputs	Controls	Outputs	Mechanism
1.1.2.3	Simulate Firing of Red Force RPG Weapons	Operator Red Force Loaded RPG Red Force RPG Red Force RPG Firing solution	ESOH Scenario Control TTPs	Red Force RPG Firing Data	Red Force Instrumentation Red Force RPG RPG Software
1.1.3	Communicate Red Force Weapon Data	Red Force .50-CAL Aiming Red Force .50-CAL Firing data Red Force RPG Aiming Data Red Force RPG Firing Data	Scenario Control	Red Force Weapon Aiming Data Red Force Weapon Firing Data	Communications
1.1.3.1	Transmit Aiming Data for Red Force Weapons	Red Force .50-CAL Aiming Red Force RPG Aiming Data	Scenario Control		LOS Radio Network
1.1.3.2	Transmit Firing Data for Red Force Weapons	Red Force .50-CAL Firing data Red Force RPG Firing Data	Scenario Control	Red Force Weapon Aiming Data Red Force Weapon Firing Data	LOS Radio Network
1.2	Simulate Effects of Blue Weapons on Red Forces	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data	Scenario Control	Red Force Platform Status Red Force Weapons Status	Instrumentation Software
1.2.1	Receive Blue Forces Weapons effects	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data	Scenario Control	Blue Force Weapons Effects on Red Platforms Blue Force Weapons Effects on Red Weapons	Red Force Instrumentation Software

Number	Function	Inputs	Controls	Outputs	Mechanism
1.2.2	Simulate Effects of Blue .50-CAL Weapons on Red Forces	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data Blue Force Weapons Effects on Red Platforms Blue Force Weapons Effects on Red Weapons	Scenario Control	Red Force Platform Status Red Force Weapons Status	Red Force Instrumentation Software
1.2.3	Simulate Effects of Blue M240B Weapons on Red Forces	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data Blue Force Weapons Effects on Red Platforms Blue Force Weapons Effects on Red Weapons	Scenario Control	Red Force Platform Status Red Force Weapons Status	Red Force Instrumentation Software
1.2.4	Simulate Effects of Blue Mrk 19 Weapons on Red Forces	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data Blue Force Weapons Effects on Red Platforms Blue Force Weapons Effects on Red Weapons	Scenario Control	Red Force Platform Status Red Force Weapons Status	Red Force Instrumentation Software
1.3	Communicate Position Data from Red Platforms	Red Force Platform information	Scenario Control	Red Force Heading Red Force Position Red Force Velocity	Communications

Number	Function	Inputs	Controls	Outputs	Mechanism
1.3.1	Transmit Position Information from Red Platforms	Red Force Platform information	Scenario Control	Red Force Position	LOS Radio Network
1.3.2	Transmit Heading Information from Red Platforms	Red Force Platform information	Scenario Control	Red Force Heading	LOS Radio Network
1.3.3	Transmit Velocity Information from Red Platforms	Red Force Platform information	Scenario Control	Red Force Velocity	LOS Radio Network
2	Simulate Blue Forces	Blue Forces Operator Red Force Weapon Aiming Data Red Force Weapon Firing Data	ESOH Scenario Control TTPs	Blue Force Heading Blue Force Position Blue Force Velocity Blue Force Weapon Aiming Data Blue Force Weapon Firing Data Blue Platform Status Blue Weapons Status	Blue Force Weapons Communications Instrumentation Software
2.1	Simulate Firing Blue Crew Served Weapons	Blue Force Information Operator	ESOH Scenario Control TTPs	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data	Blue Force Weapons Communications Instrumentation

Number	Function	Inputs	Controls	Outputs	Mechanism
2.1.1	Simulate Blue .50 Weapons	Blue Force Information Operator	ESOH TTPs	Blue Force .50-CAL Aiming Blue Force .50-CAL Firing data	Blue Force .50-CAL Blue Force Instrumentation
2.1.1.1	Simulate Loading of Blue Force .50-CAL Weapons	Blue Force Information Operator	TTPs	Blue Force loaded .50-CAL	Blue Force .50-CAL
2.1.1.2	Simulate Aiming of Blue Force .50-CAL Weapons	Operator	TTPs	Blue Force .50-CAL Aiming Blue Force .50-CAL Firing Solution	Blue Force .50-CAL Blue Force Instrumentation
2.1.1.3	Simulate Firing of Blue Force .50-CAL Weapons	Blue Force .50-CAL Firing Solution Blue Force loaded .50-CAL Operator	ESOH TTPs	Blue Force .50-CAL Firing data	Blue Force .50-CAL Blue Force Instrumentation
2.1.2	Simulate Blue M240B Weapons	Blue Force Information Operator	ESOH TTPs	Blue Force M240B Aiming Blue Force M240B Firing data	Blue Force Instrumentation Blue Force M240B
2.1.2.1	Simulate Loading of Blue Force M240B Weapons	Blue Force Information Operator	TTPs	Blue Force loaded M240B	Blue Force M240B
2.1.2.2	Simulate Aiming of Blue Force M240B Weapons	Operator	TTPs	Blue Force M240B Aiming Blue Force M240B Firing Solution	Blue Force Instrumentation Blue Force M240B
2.1.2.3	Simulate Firing of Blue Force M240B Weapons	Blue Force loaded M240B Blue Force M240B Firing Solution Operator	ESOH TTPs	Blue Force M240B Firing data	Blue Force Instrumentation Blue Force M240B

Number	Function	Inputs	Controls	Outputs	Mechanism
2.1.3	Simulate Blue Mrk 19 Weapons	Blue Force Information Operator	ESOH TTPs	Blue Force Mrk 19 Aiming Data Blue Force Mrk 19 Firing Data	Blue Force Instrumentation Blue Force Mrk 19
2.1.3.1	Simulate Loading of Blue Force Mrk 19 Weapons	Blue Force Information Operator	TTPs	Blue Force Loaded Mrk 19	Blue Force Mrk 19
2.1.3.2	Simulate Aiming of Blue Force Mrk 19 Weapons	Operator	TTPs	Blue Force Mrk 19 Aiming Data Blue Force Mrk 19 Firing solution	Blue Force Instrumentation Blue Force Mrk 19
2.1.3.3	Simulate Firing of Blue Force Mrk 19 Weapons	Blue Force Loaded Mrk 19 Blue Force Mrk 19 Firing solution Operator	ESOH TTPs	Blue Force Mrk 19 Firing Data	Blue Force Instrumentation Blue Force Mrk 19
2.1.4	Communicate Blue Force Weapon Data	Blue Force .50-CAL Aiming Blue Force .50-CAL Firing data Blue Force M240B Aiming Blue Force M240B Firing data Blue Force Mrk 19 Aiming Data Blue Force Mrk 19 Firing Data	Scenario Control	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data	LOS Radio Network
2.1.4.1	Transmit Aiming Data for Blue Force Weapons	Blue Force .50-CAL Aiming Blue Force M240B Aiming Blue Force Mrk 19 Aiming Data	Scenario Control	Blue Force Weapon Aiming Data	LOS Radio Network

Number	Function	Inputs	Controls	Outputs	Mechanism
2.1.4.2	Transmit Firing Data for Blue Force Weapons	Blue Force .50-CAL Firing data Blue Force M240B Firing data Blue Force Mrk 19 Firing Data	Scenario Control	Blue Force Weapon Firing Data	LOS Radio Network
2.2	Simulate Effects of Red Weapons on Blue Forces	Red Force Weapon Aiming Data Red Force Weapon Firing Data	Scenario Control TTPs	Blue Platform Status Blue Weapons Status	Instrumentation Software
2.2.1	Receive Red Force Weapons Effects	Red Force Weapon Aiming Data Red Force Weapon Firing Data	Scenario Control	Red Force Weapons Effects on Blue Platforms Red Force Weapons Effects on Blue Weapons	Instrumentation Software
2.2.2	Simulate Effects of Red RPG Weapons on Blue Forces	Red Force Weapons Effects on Blue Platforms Red Force Weapons Effects on Blue Weapons	Scenario Control TTPs	Blue Platform Status Blue Weapons Status	Blue Force Instrumentation Software
2.2.3	Simulate Effects of Red .50-CAL Weapons on Blue Forces	Red Force Weapons Effects on Blue Platforms Red Force Weapons Effects on Blue Weapons	Scenario Control	Blue Platform Status Blue Weapons Status	Blue Force Instrumentation Software
2.3	Communicate Position Data from Blue Platforms	Blue Force Information	Scenario Control	Blue Force Heading Blue Force Position Blue Force Velocity	Communications

Number	Function	Inputs	Controls	Outputs	Mechanism
2.3.1	Transmit Position Information from Blue Platforms	Blue Force Information	Scenario Control	Blue Force Position	LOS Radio Network
2.3.2	Transmit Heading Information from Blue Platforms	Blue Force Information	Scenario Control	Blue Force Heading	LOS Radio Network
2.3.3	Transmit Velocity Information from Blue Platforms	Blue Force Information	Scenario Control	Blue Force Velocity	LOS Radio Network

Numb er	Function	Inputs	Controls	Outputs	Mechanism
3	Manage Informatio n	Blue Force Heading Blue Force Position Blue Force Velocity Blue Force Weapon Aiming Data Blue Force Weapon Firing Data Blue Platform Status Blue Weapons Status Red Force Heading Red Force Platform Status Red Force Position Red Force Velocity Red Force Weapon Aiming Data Red Force Weapon Firing Data Red Force Weapons Status	Scenario Control	Recorded Data	Communicati ons Software

Number	Function	Inputs	Controls	Outputs	Mechanism
3.1	Receive Information	Blue Force Heading Blue Force Position Blue Force Velocity Blue Force Weapon Aiming Data Blue Force Weapon Firing Data Red Force Heading Red Force Position Red Force Velocity Red Force Weapon Aiming Data Red Force Weapon Firing Data	Scenario Control	Blue Force Platform information Blue Force Weapons Information Red Force Platform information Red Force Weapons Information	Communications
3.1.1	Receive Information From Red Weapons	Red Force Weapon Aiming Data Red Force Weapon Firing Data	Scenario Control	Red Force Weapons Information	Communications
3.1.1.1	Receive Red Weapon Aiming Data	Red Force Weapon Aiming Data	Scenario Control	Red Force Weapons Information	LOS Radio Network
3.1.1.2	Receive Red Weapon Firing Data	Red Force Weapon Firing Data	Scenario Control	Red Force Weapons Information	LOS Radio Network
3.1.2	Receive Information From Blue Weapons	Blue Force Weapon Aiming Data Blue Force Weapon Firing Data	Scenario Control	Blue Force Weapons Information	Communications

Number	Function	Inputs	Controls	Outputs	Mechanism
3.1.2.1	Receive Blue Weapon Aiming Data	Blue Force Weapon Aiming Data	Scenario Control	Blue Force Weapons Information	LOS Radio Network
3.1.2.2	Receive Blue Weapon Firing Data	Blue Force Weapon Firing Data	Scenario Control	Blue Force Weapons Information	LOS Radio Network
3.1.3	Receive Information From Red Platforms	Red Force Heading Red Force Position Red Force Velocity	Scenario Control	Red Force Platform information	Communications
3.1.3.1	Receive Position Information from Red Platforms	Red Force Position	Scenario Control	Red Force Platform information	LOS Radio Network
3.1.3.2	Receive Heading Information from Red Platforms	Red Force Heading	Scenario Control	Red Force Platform information	LOS Radio Network
3.1.3.3	Receive Velocity Information from Red Platforms	Red Force Velocity	Scenario Control	Red Force Platform information	LOS Radio Network
3.1.4	Receive Information from Blue Platforms	Blue Force Heading Blue Force Position Blue Force Velocity	Scenario Control	Blue Force Platform information	Communications

Number	Function	Inputs	Controls	Outputs	Mechanism
3.1.4.1	Receive Position Information from Blue Platforms	Blue Force Position	Scenario Control	Blue Force Platform information	LOS Radio Network
3.1.4.2	Receive Heading Information from Blue Platforms	Blue Force Heading	Scenario Control	Blue Force Platform information	LOS Radio Network
3.1.4.3	Receive Velocity Information from Blue Platforms	Blue Force Velocity	Scenario Control	Blue Force Platform information	LOS Radio Network
3.2	Process Information	Blue Force Platform information Blue Force Weapons Information Red Force Platform information Red Force Weapons Information	Scenario Control	Blue Force Weapons Effects on Red Platforms Blue Force Weapons Effects on Red Weapons Red Force Weapons Effects on Blue Platforms Red Force Weapons Effects on Blue Weapons	Software
3.2.1	Determine Effects of Red Weapons	Blue Force Platform information Red Force Weapons Information	Scenario Control	Red Force Weapons Effects on Blue Platforms Red Force Weapons Effects on Blue Weapons	Software

Number	Function	Inputs	Controls	Outputs	Mechanism
3.2.1.1	Determine Effects of Red Weapons on Blue Platforms	Blue Force Platform information Red Force Weapons Information	Scenario Control	Red Force Weapons Effects on Blue Platforms	Software
3.2.1.2	Determine Effects of Red Weapons on Blue Weapons	Blue Force Platform information Red Force Weapons Information	Scenario Control	Red Force Weapons Effects on Blue Weapons	Software
3.2.2	Determine Effects of Blue Weapons	Blue Force Weapons Information Red Force Platform information	Scenario Control	Blue Force Weapons Effects on Red Platforms Blue Force Weapons Effects on Red Weapons	Software
3.2.2.1	Determine Effects of Blue Weapons on Red Platforms	Blue Force Weapons Information Red Force Platform information	Scenario Control	Blue Force Weapons Effects on Red Platforms	Software
3.2.2.2	Determine Effects of Blue Weapons on Red Weapons	Blue Force Weapons Information Red Force Platform information	Scenario Control	Blue Force Weapons Effects on Red Weapons	Software

Number	Function	Inputs	Controls	Outputs	Mechanism
3.3	Transmit Information	Blue Force Weapons Effects on Red Platforms Blue Force Weapons Effects on Red Weapons Red Force Weapons Effects on Blue Platforms Red Force Weapons Effects on Blue Weapons	Scenario Control	Blue Platform Status Blue Weapons Status Red Force Platform Status Red Force Weapons Status	Communications
3.3.1	Transmit Red Platform Status Information	Blue Force Weapons Effects on Red Platforms	Scenario Control	Red Force Platform Status	LOS Radio Network
3.3.2	Transmit Red Weapon Status Information	Blue Force Weapons Effects on Red Weapons	Scenario Control	Red Force Weapons Status	LOS Radio Network
3.3.3	Transmit Blue Platform Status Information	Red Force Weapons Effects on Blue Platforms	Scenario Control	Blue Platform Status	LOS Radio Network
3.3.4	Transmit Blue Weapon Status Information	Red Force Weapons Effects on Blue Weapons	Scenario Control	Blue Weapons Status	LOS Radio Network

Number	Function	Inputs	Controls	Outputs	Mechanism
3.4	Record Data	Blue Force Platform information Blue Force Weapons Information Blue Platform Status Blue Weapons Status Red Force Platform information Red Force Platform Status Red Force Weapons Information Red Force Weapons Status	Scenario Control	Recorded Data	Software
3.4.1	Record Red Weapon Data	Red Force Weapons Information Red Force Weapons Status	Scenario Control	Recorded Data	Software
3.4.1.1	Record Red Weapon Aiming Data	Red Force Weapons Information	Scenario Control	Recorded Data	Software
3.4.1.2	Record Red Weapon Firing Data	Red Force Weapons Information	Scenario Control	Recorded Data	Software
3.4.1.3	Record Red Weapon Effects on Blue Platforms	Red Force Weapons Information	Scenario Control	Recorded Data	Software

Number	Function	Inputs	Controls	Outputs	Mechanism
3.4.1.4	Record Red Weapon Effects on Blue Weapons	Red Force Weapons Information	Scenario Control	Recorded Data	Software
3.4.1.5	Record Red Force Weapons Status	Red Force Weapons Status	Scenario Control	Recorded Data	Software
3.4.2	Record Red Platform Data	Red Force Platform information Red Force Platform Status	Scenario Control	Recorded Data	Software
3.4.2.1	Record Red Platform Position Data	Red Force Platform information	Scenario Control	Recorded Data	Software
3.4.2.2	Record Red Platform Status Information	Red Force Platform Status	Scenario Control	Recorded Data	Software
3.4.3	Record Blue Weapon Data	Blue Force Weapons Information Blue Weapons Status	Scenario Control	Recorded Data	Software
3.4.3.1	Record Blue Weapon Aiming Data	Blue Force Weapons Information	Scenario Control	Recorded Data	Software
3.4.3.2	Record Blue Weapon Firing Data	Blue Force Weapons Information	Scenario Control	Recorded Data	Software

Number	Function	Inputs	Controls	Outputs	Mechanism
3.4.3.3	Record Blue Weapon Effects on Red Platforms	Blue Force Weapons Information	Scenario Control	Recorded Data	Software
3.4.3.4	Record Blue Weapons Effects on Red Weapons	Blue Force Weapons Information	Scenario Control	Recorded Data	Software
3.4.3.5	Record Blue Force Weapons Status	Blue Weapons Status	Scenario Control	Recorded Data	Software
3.4.4	Record Blue Platform Data	Blue Force Platform information Blue Platform Status	Scenario Control	Recorded Data	Software
3.4.4.1	Record Blue Platform Position Data	Blue Force Platform information	Scenario Control	Recorded Data	Software
3.4.4.2	Record Blue Platform Status Information	Blue Platform Status	Scenario Control	Recorded Data	Software
4	Evaluate Performance	Recorded Data	Scenario Control TTPs	Reports Trained Crew Unit Readiness	Software
4.1	Evaluate Data	Recorded Data	TTPs	Evaluated Data Trained Crew Unit Readiness	Software
4.1.1	Score Data Based on Metrics	Recorded Data	TTPs	Scored data	Software

Number	Function	Inputs	Controls	Outputs	Mechanism
4.1.2	Determine Readiness	Scored data	TTPs	Evaluated Data Trained Crew Unit Readiness	Software
4.2	Generate Reports	Evaluated Data Recorded Data	Scenario Control	Reports	Software
4.2.1	Readiness Report	Evaluated Data Recorded Data	Scenario Control	Reports	Software
4.2.2	After Action Report	Evaluated Data Recorded Data	Scenario Control	Reports	Software

B. IDEF0 DIAGRAMS

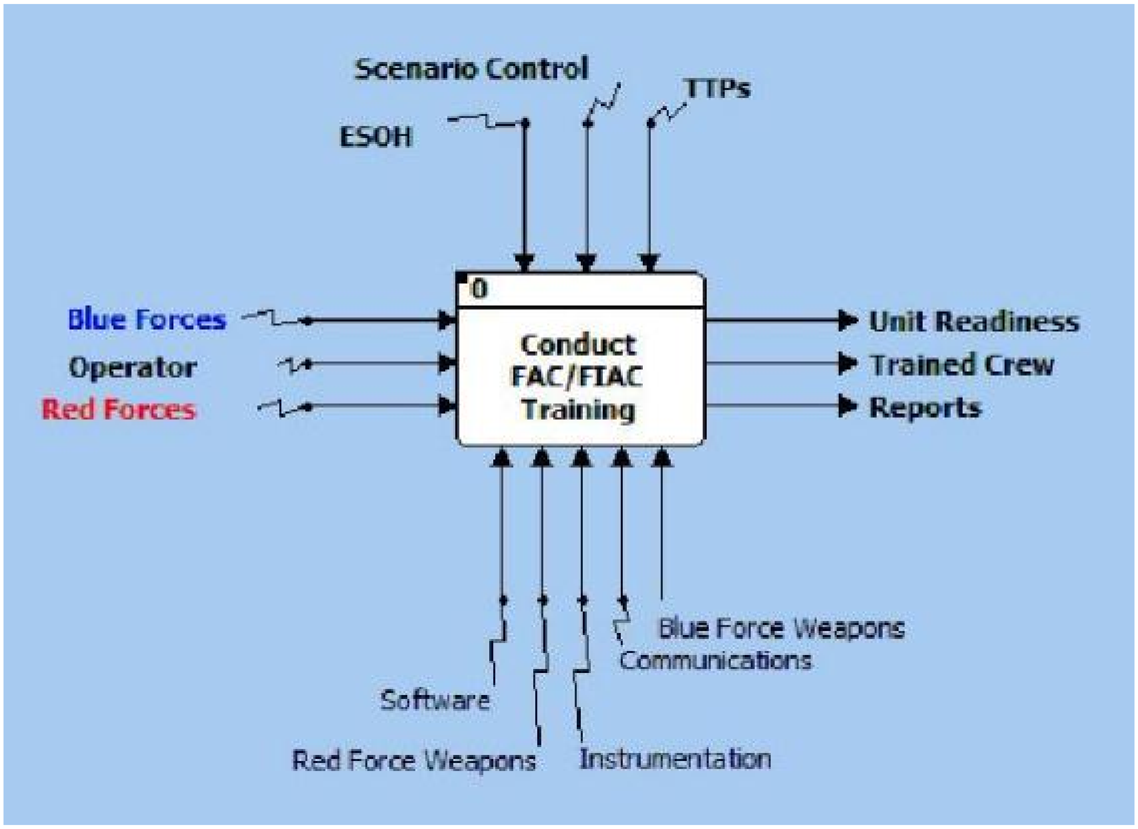

Figure 39. A0 FAC/FIAC Training IDEF0

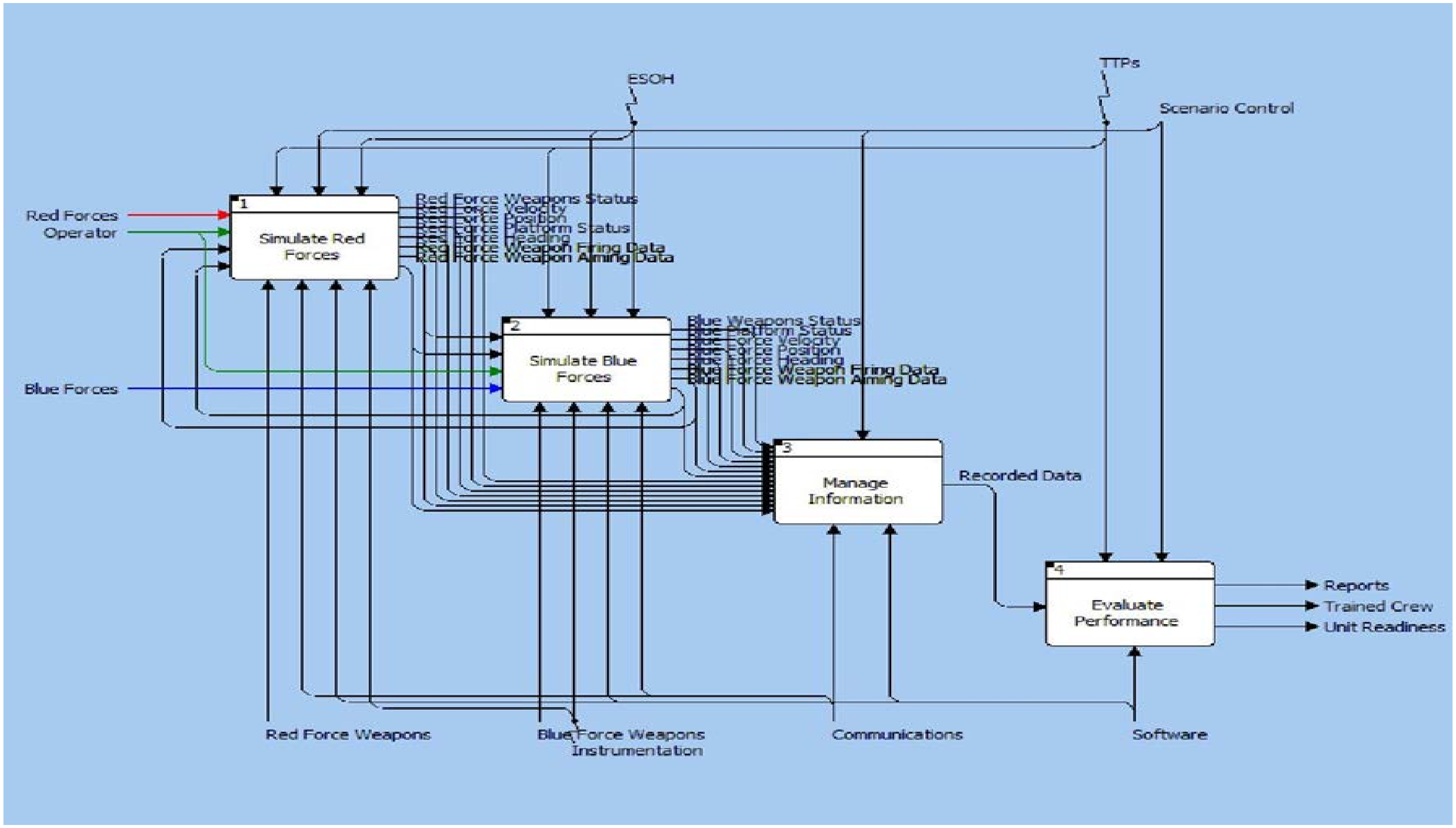

Figure 40. 0-Conduct FAC/FIAC Training

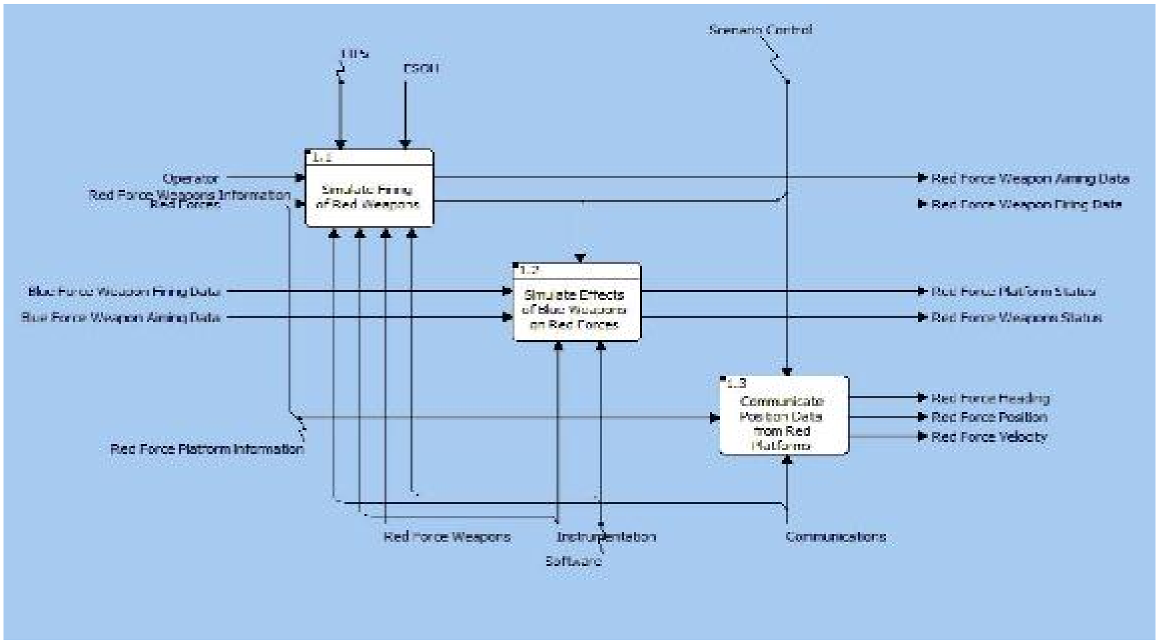

Figure 41. 1-Simulate Red Forces FAC/FIAC IDEF0

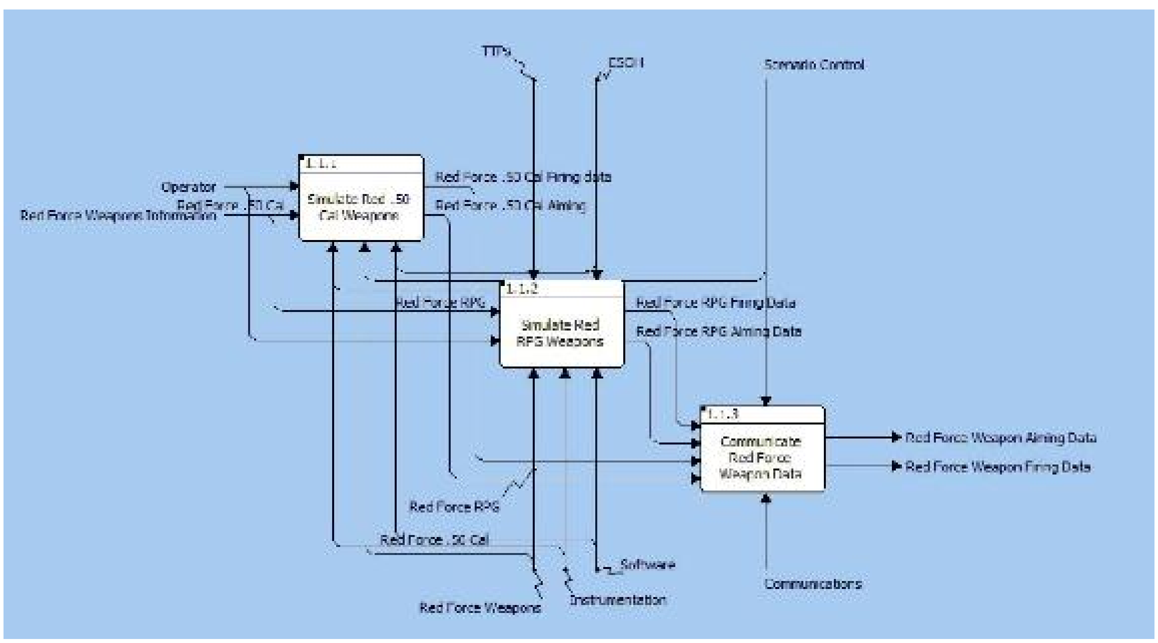

Figure 42. 1.1-Simulate Firing of Red Forces Weapons FAC/FIAC IDEF0

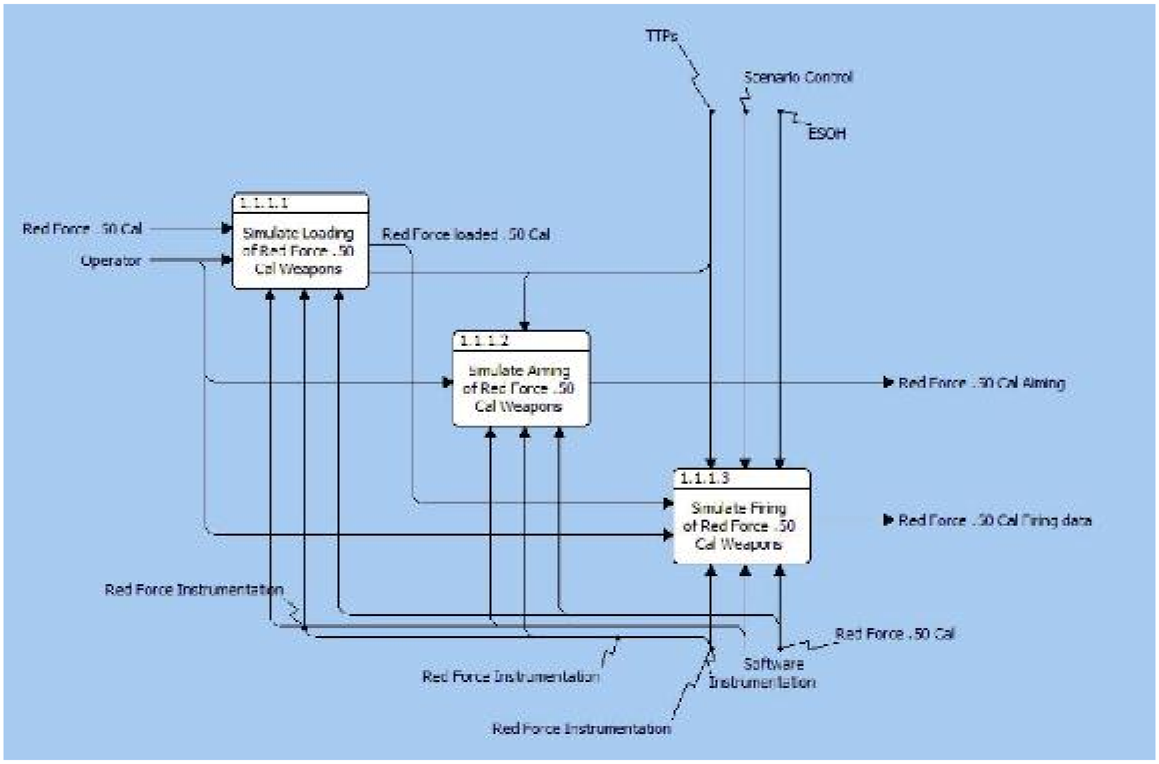

Figure 43. 1.1.1-Simulate Red Forces .50-CAL Weapon IDEF0

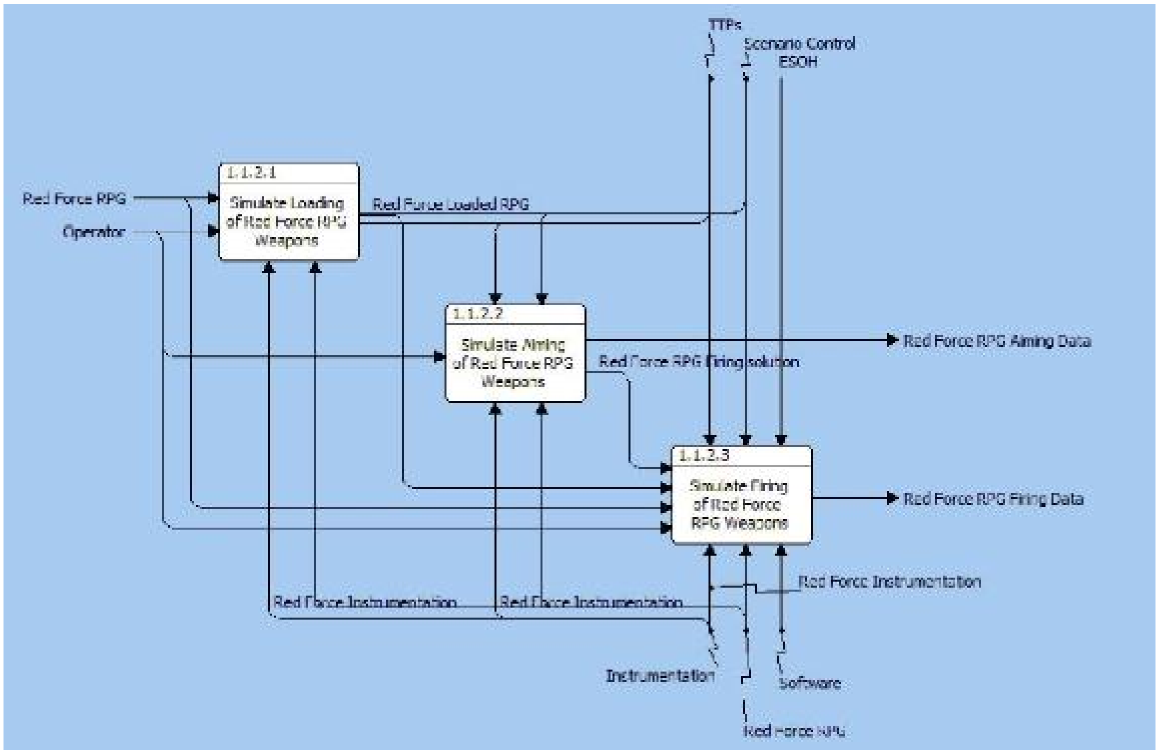

Figure 44. 1.1.2-Simulate Red Forces RPG Weapon IDEF0

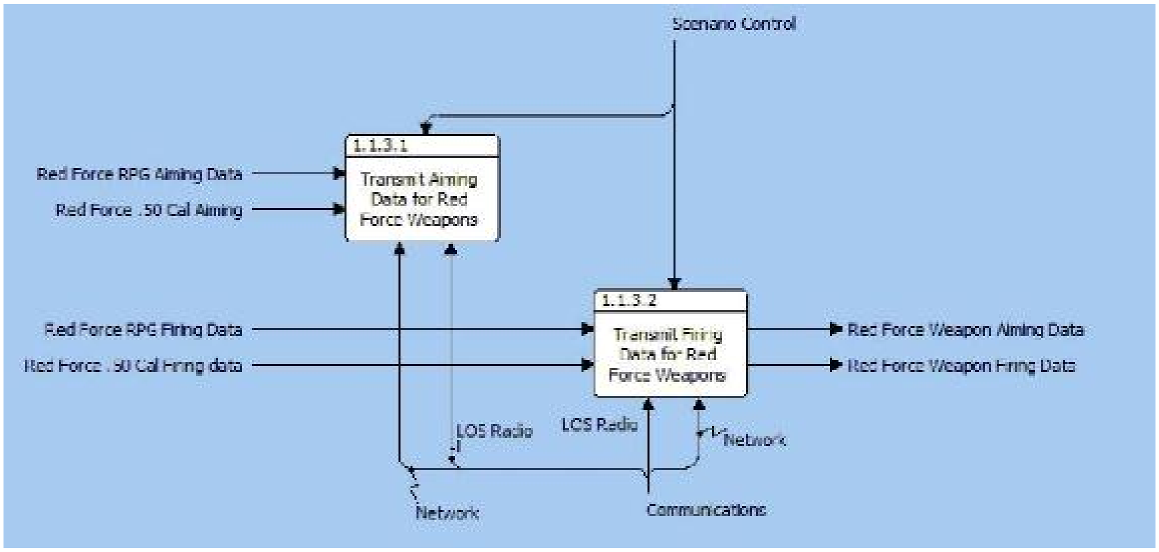

Figure 45. 1.1.3-Transmit Red Forces Weapon's data IDEF0

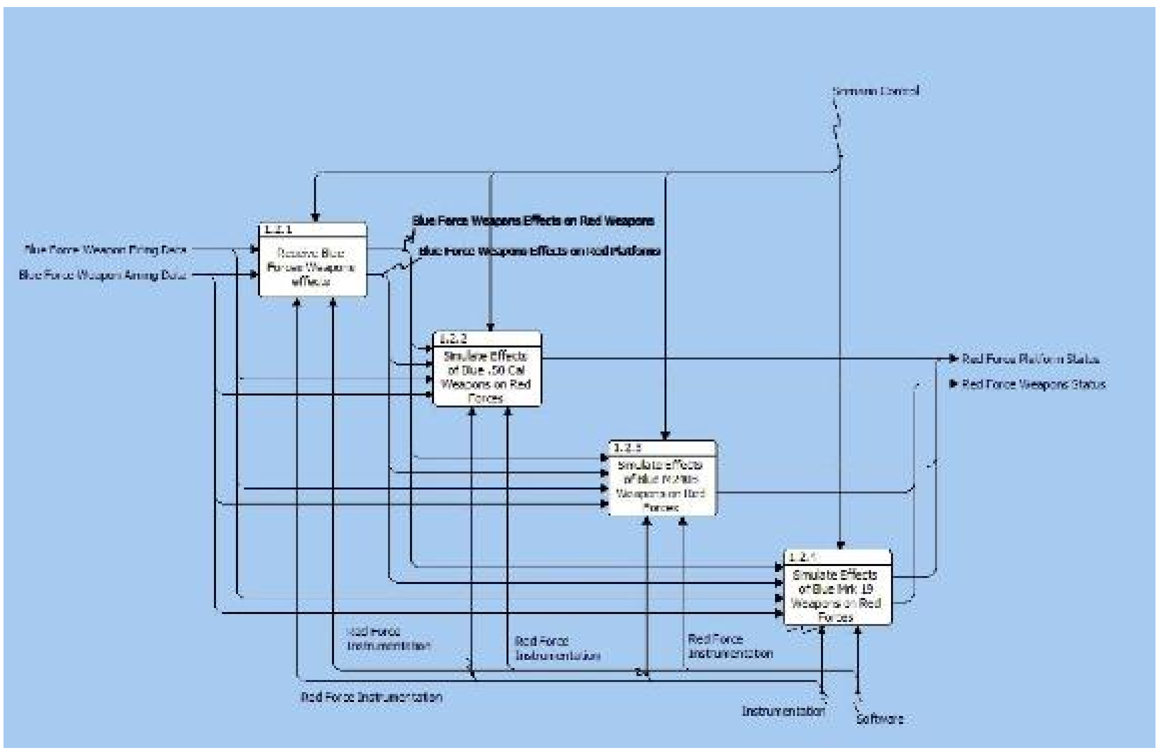

Figure 46. 1.2-Simulate Blue Forces Weapons Effects IDEF0

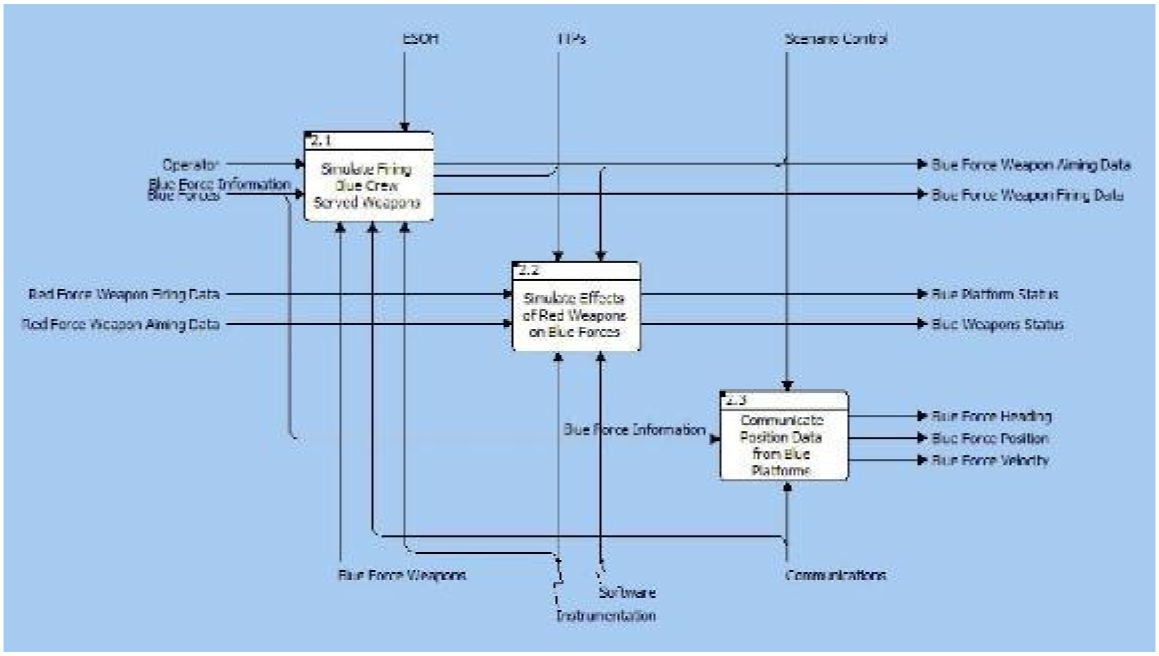

Figure 47. 2-Simulate Blue Forces IDEF0

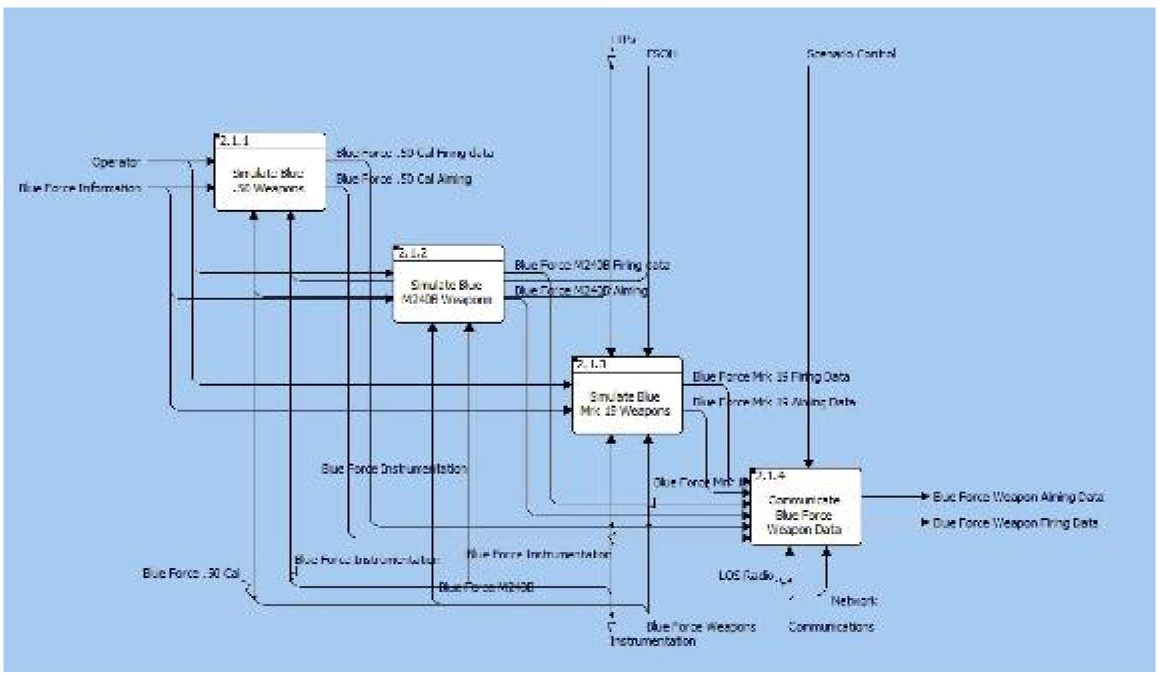

Figure 48. 2.1-Simulate Blue Forces Weapons IDEF0

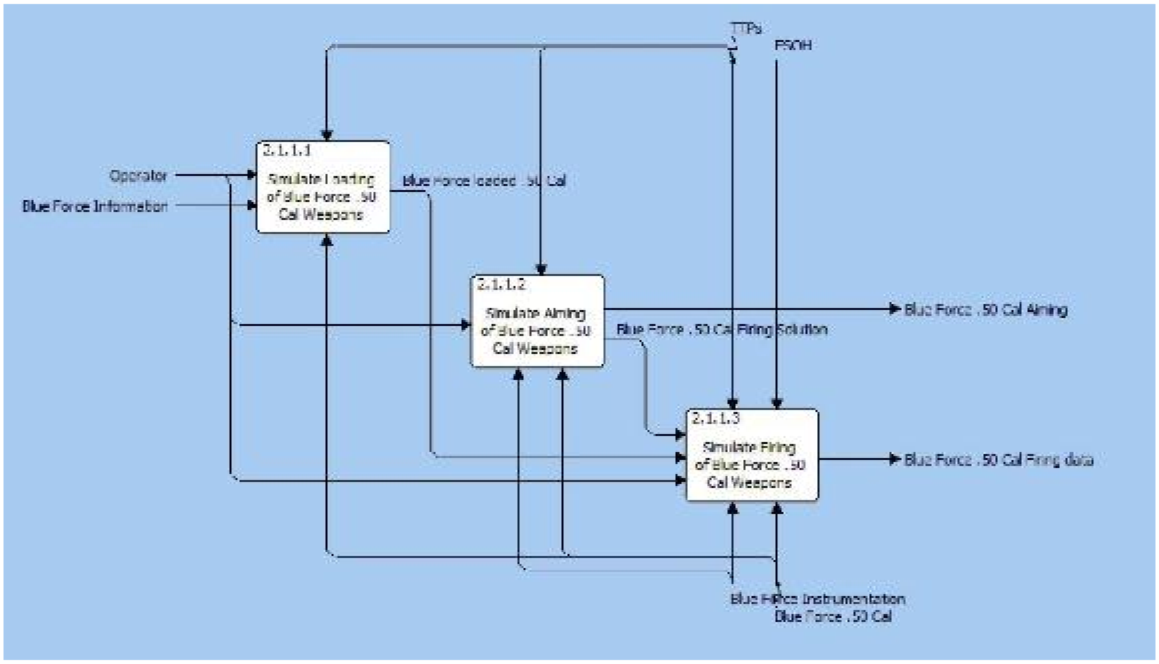

Figure 49. 2.1.1-Simulate Blue Forces .50-CAL Weapon IDEF0

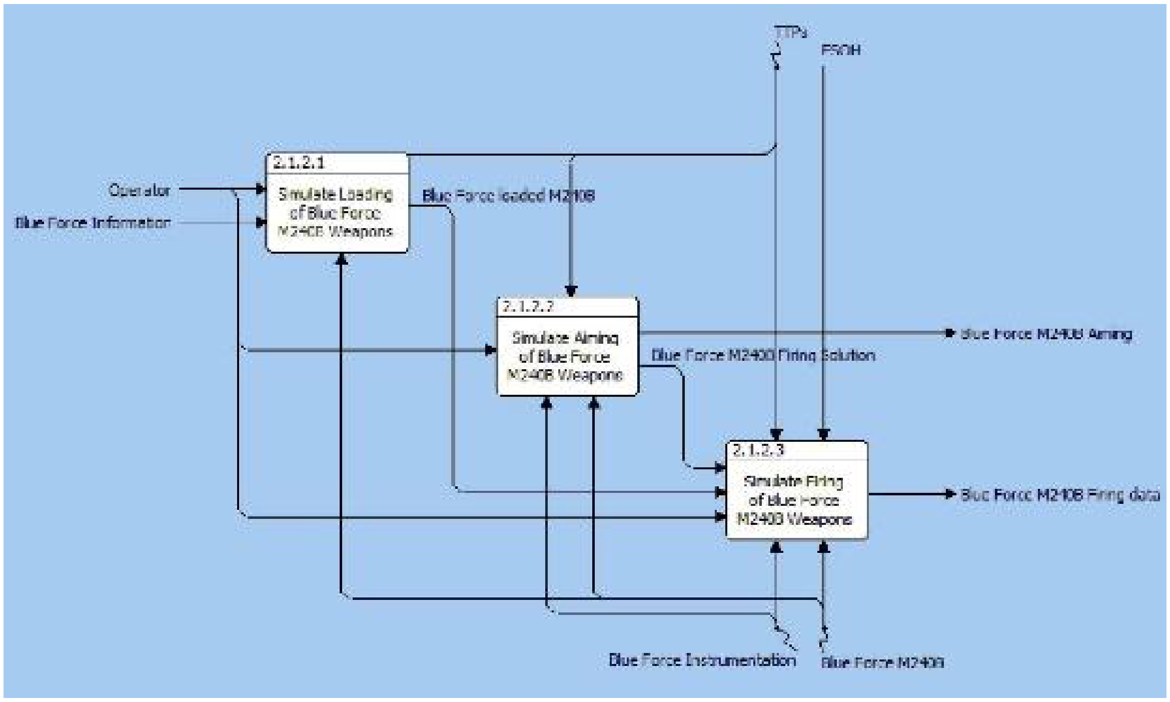

Figure 50. 2.1.2-Simulate Blue Forces M240B Weapon IDEF0

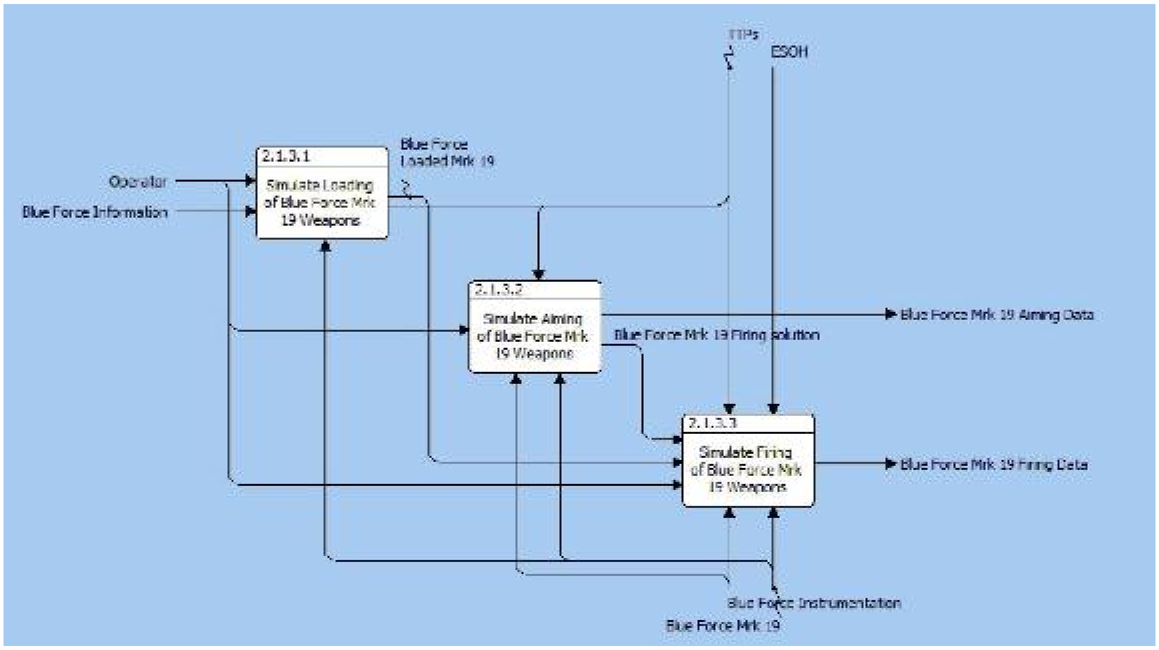

Figure 51. 2.1.3-Simulate Blue Forces MK19 Weapon IDEF0

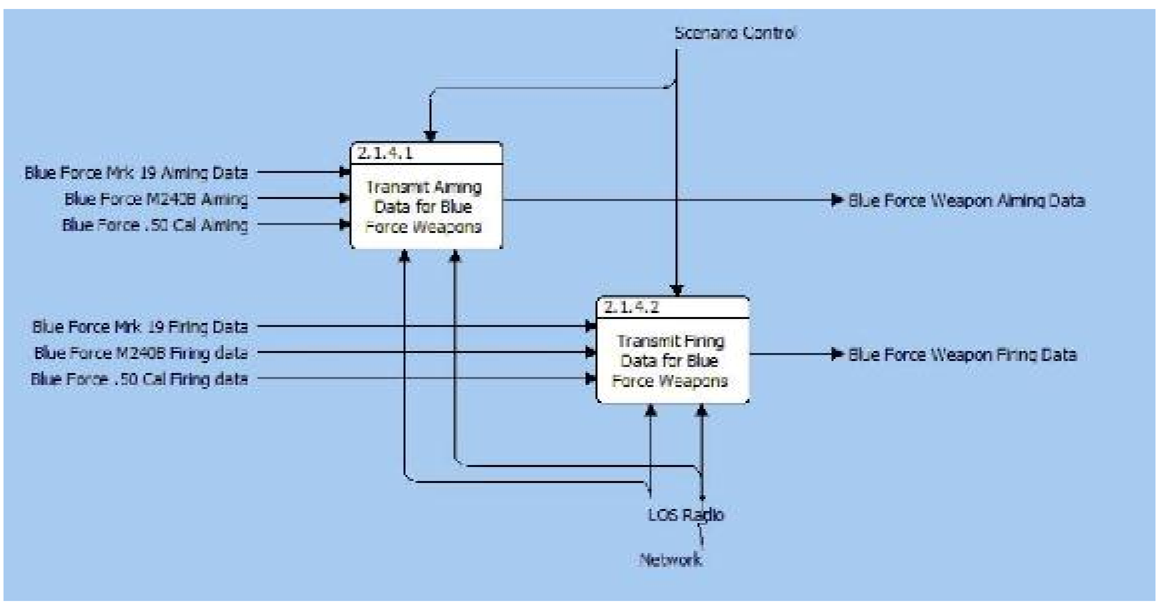

Figure 52. 2.1.4-Transmit Blue Forces Weapon data IDEF0

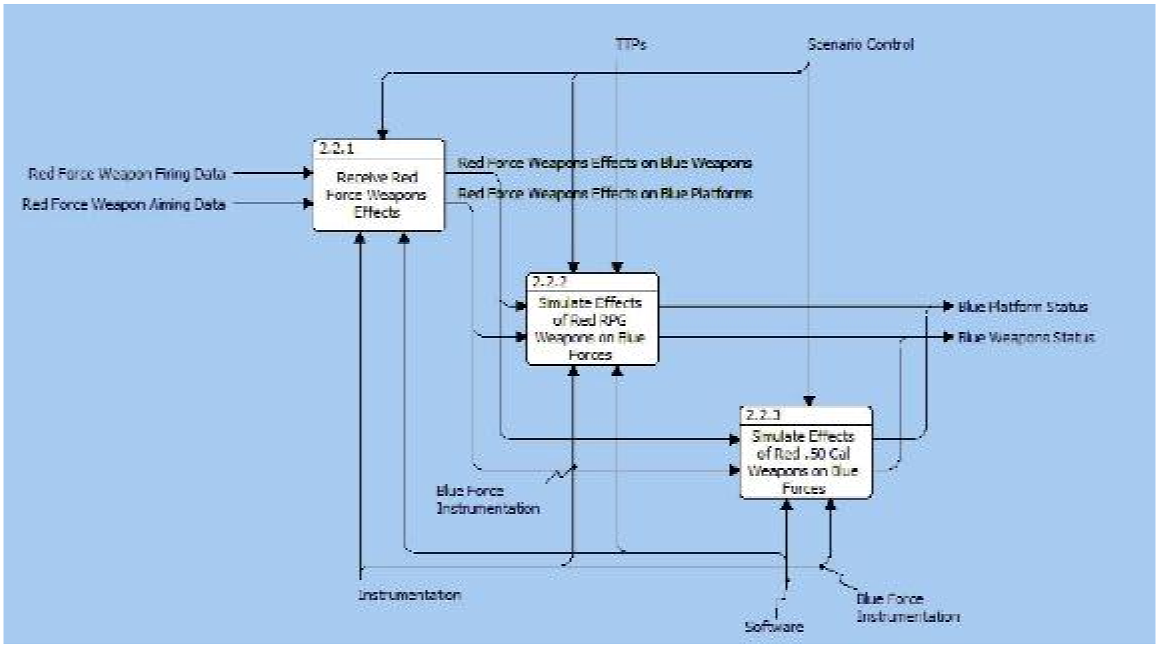

Figure 53. 2.2-Simulate Effects of Red Force Weapons on Blue Forces IDEF0

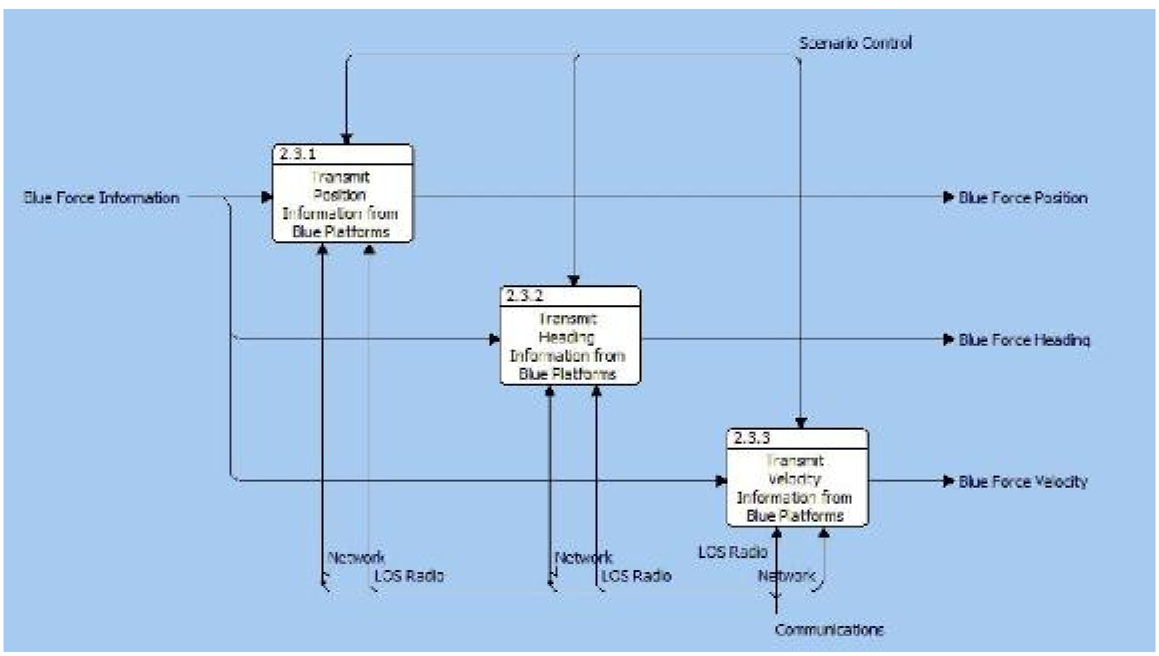

Figure 54. 2.3-Transmit Blue Positional Information IDEF0

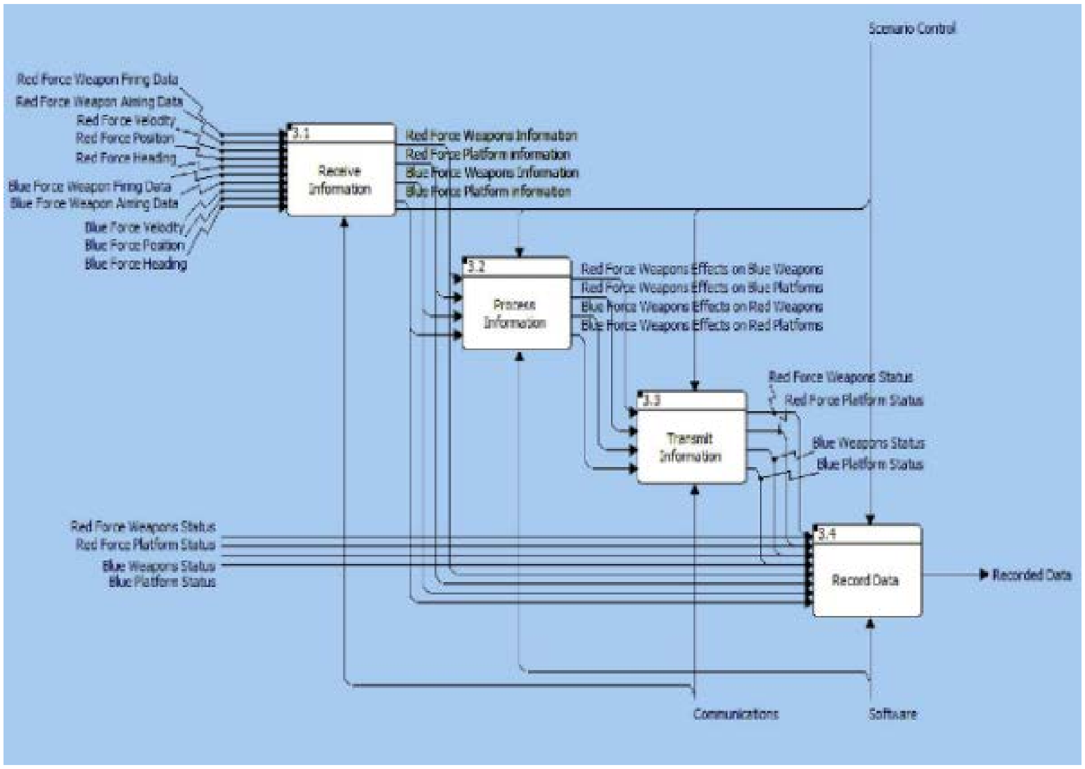

Figure 55. 3-Process Information IDEF0

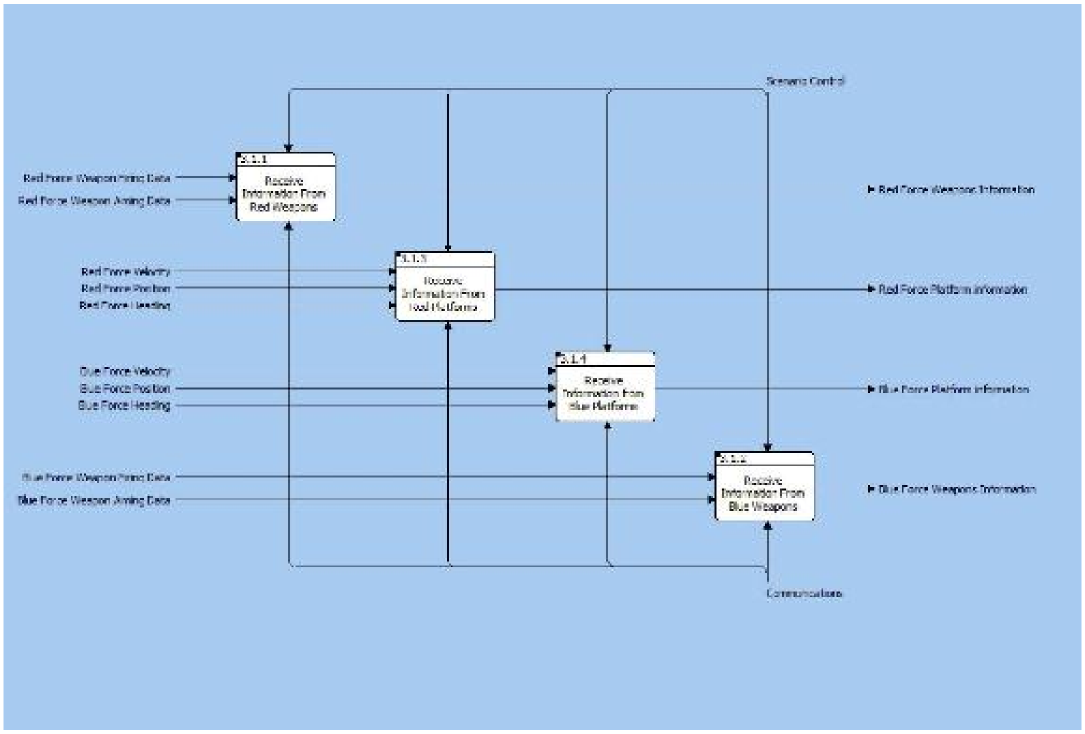

Figure 56. 3.1-Receive Information IDEF0

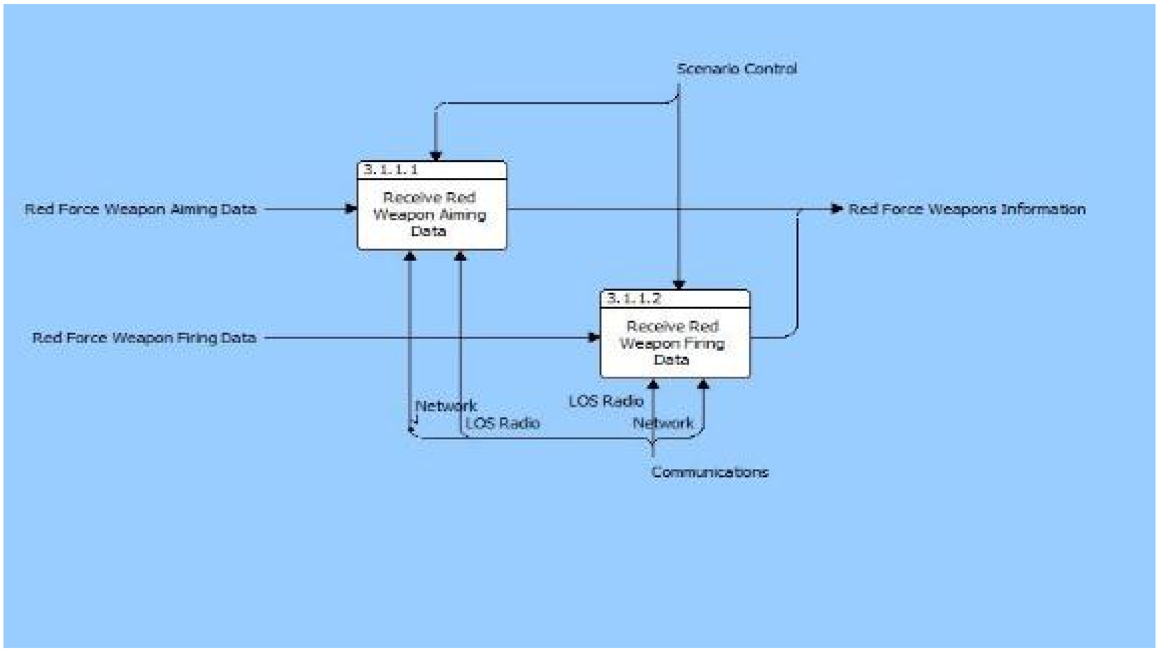

Figure 57. 3.1.1-Receive Red Force Weapons Information IDEF0

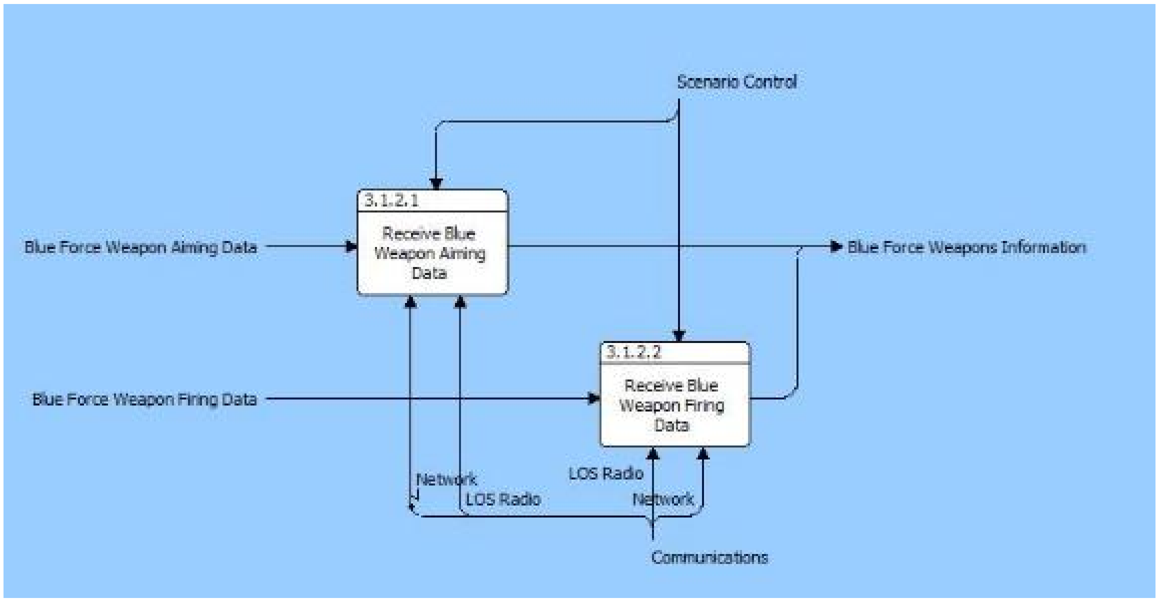

Figure 58. 3.1.2-Receive Blue Force Weapons Information IDEF0

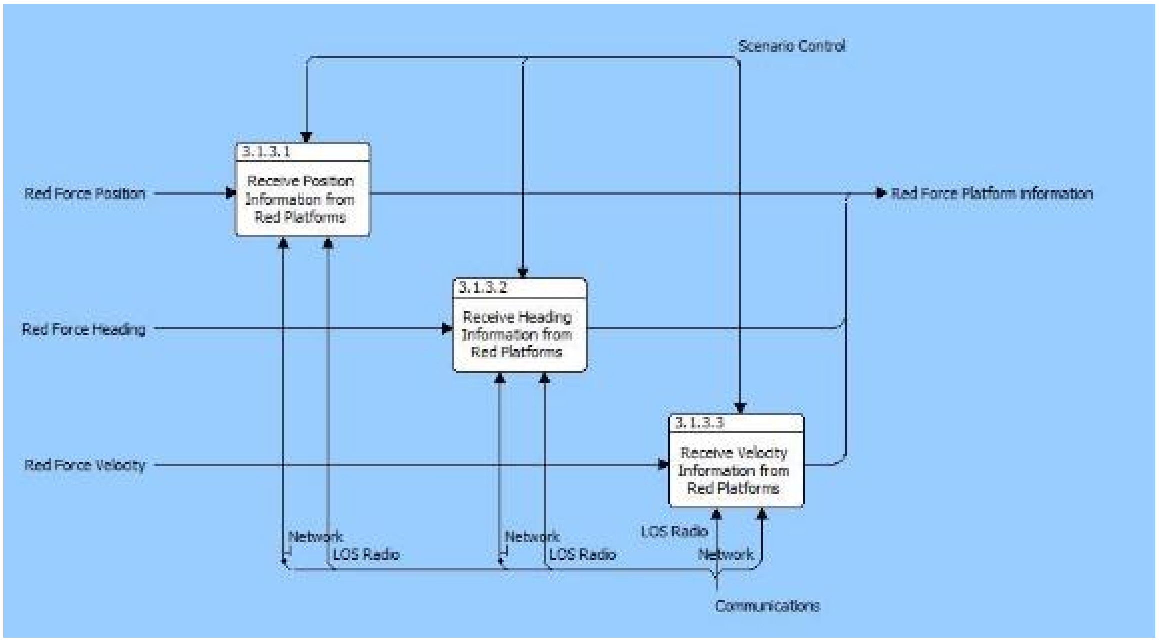

Figure 59. 3.1.3-Receive Red Force Positional Information IDEF0

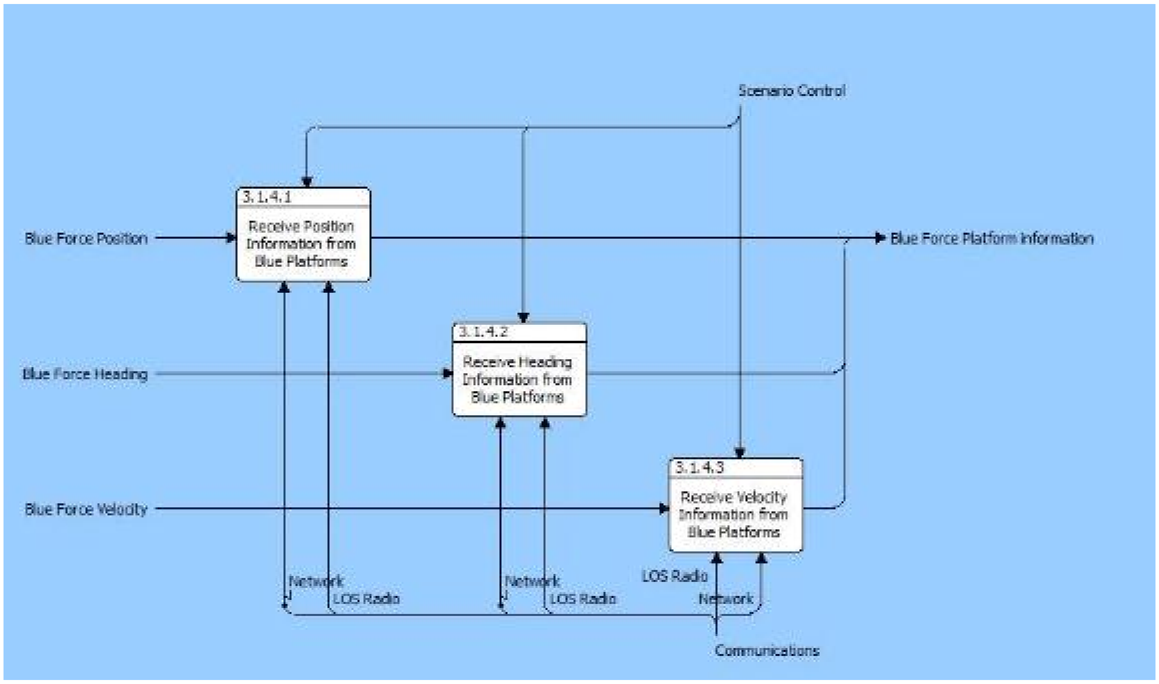

Figure 60. 3.1.4-Receive Blue Force Positional Information IDEF0

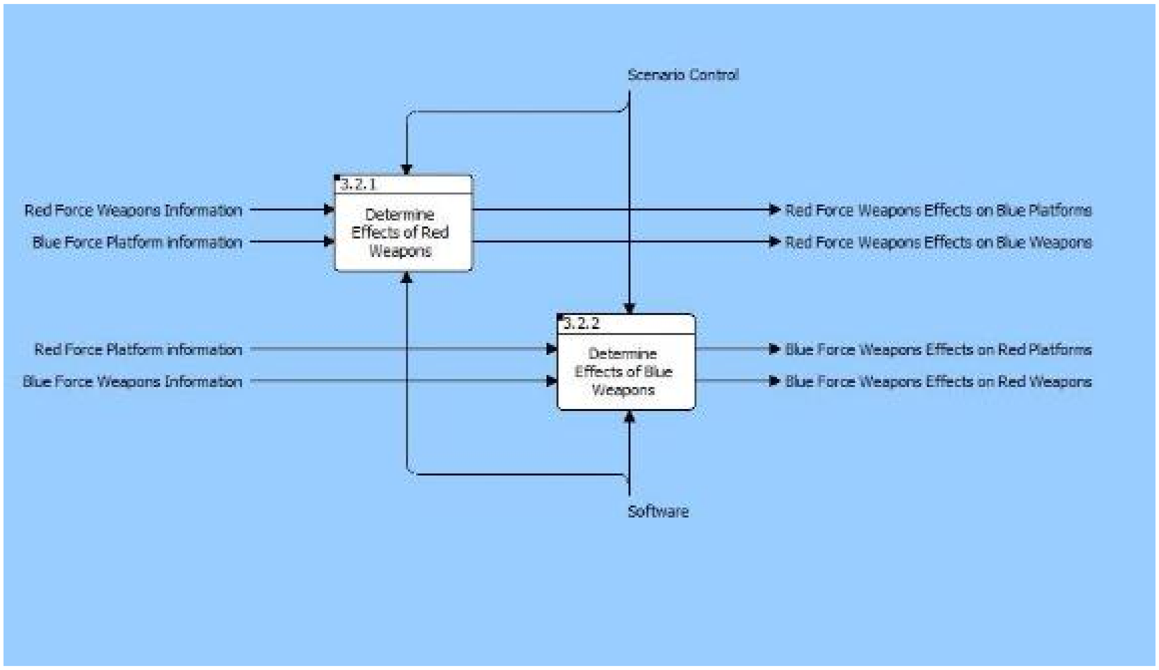

Figure 61. 3.2-Determine Effects of Blue Weapons on Red Forces IDEF0

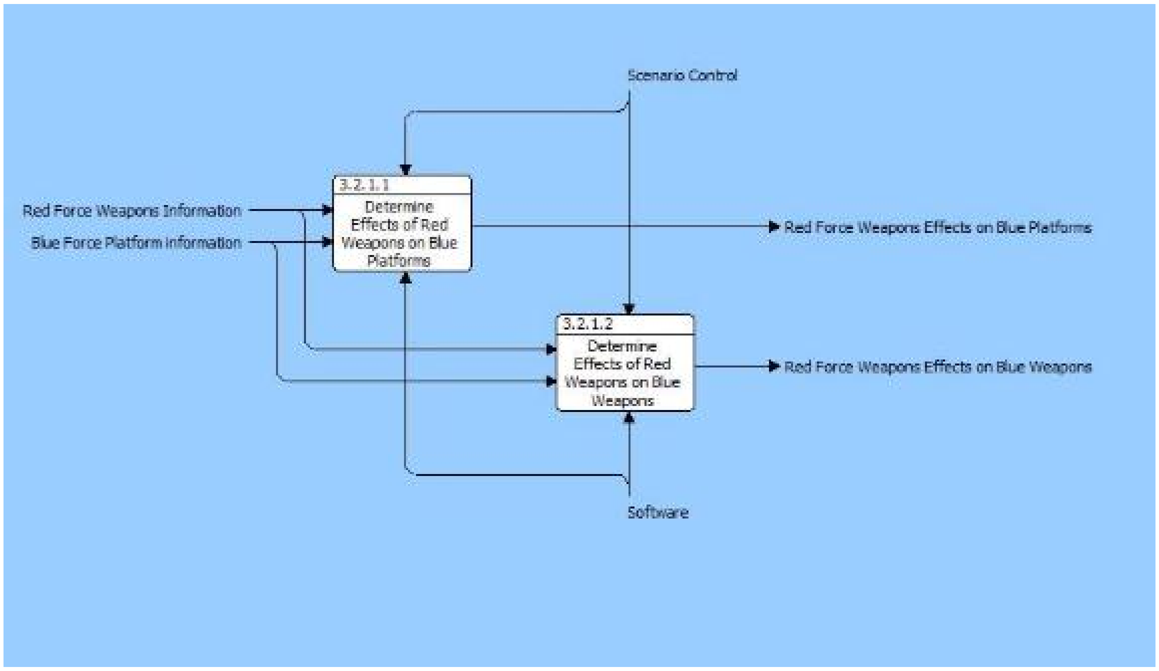

Figure 62. 3.2.1-Determine Effects of Red Weapons on Blue Forces IDEF0

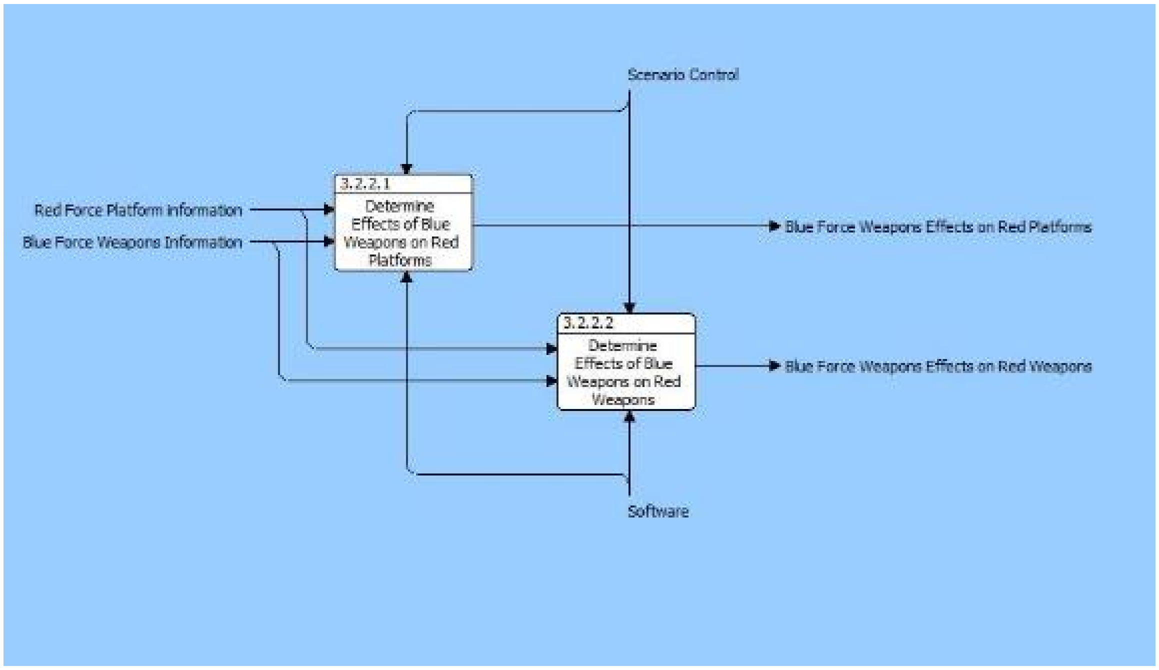

Figure 63. 3.2.2-Determine Effects of Blur Weapons on Red Forces IDEF0

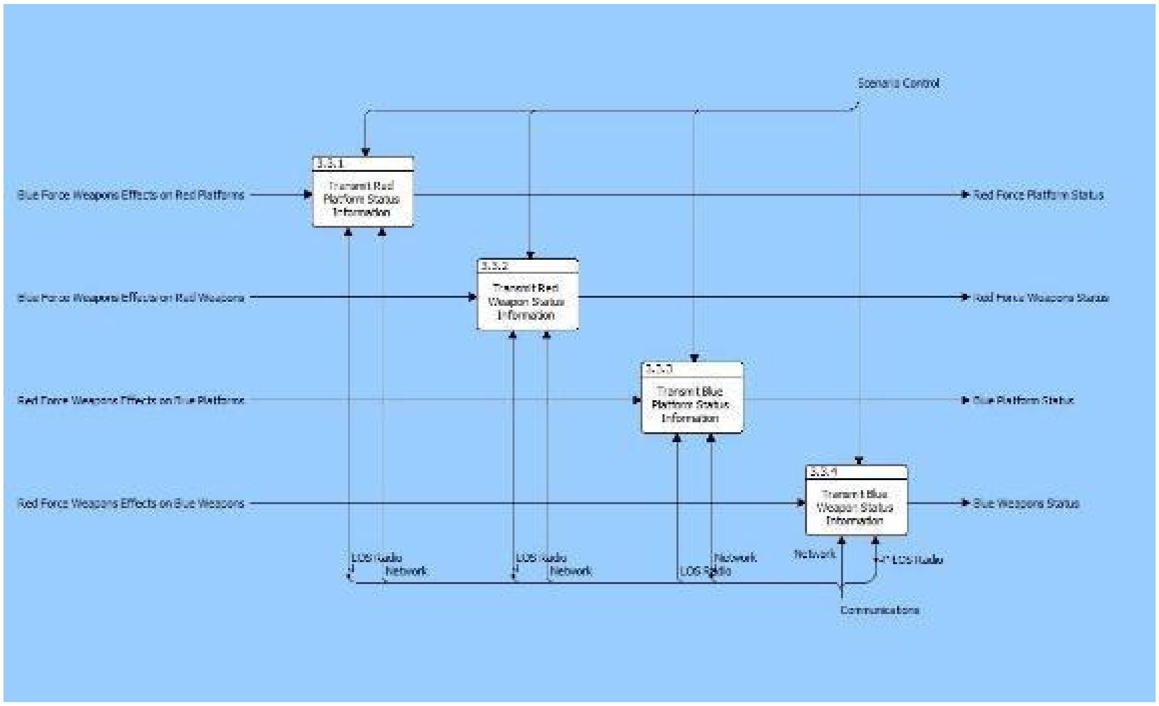

Figure 64. 3.3-Transmit Data IDEF0

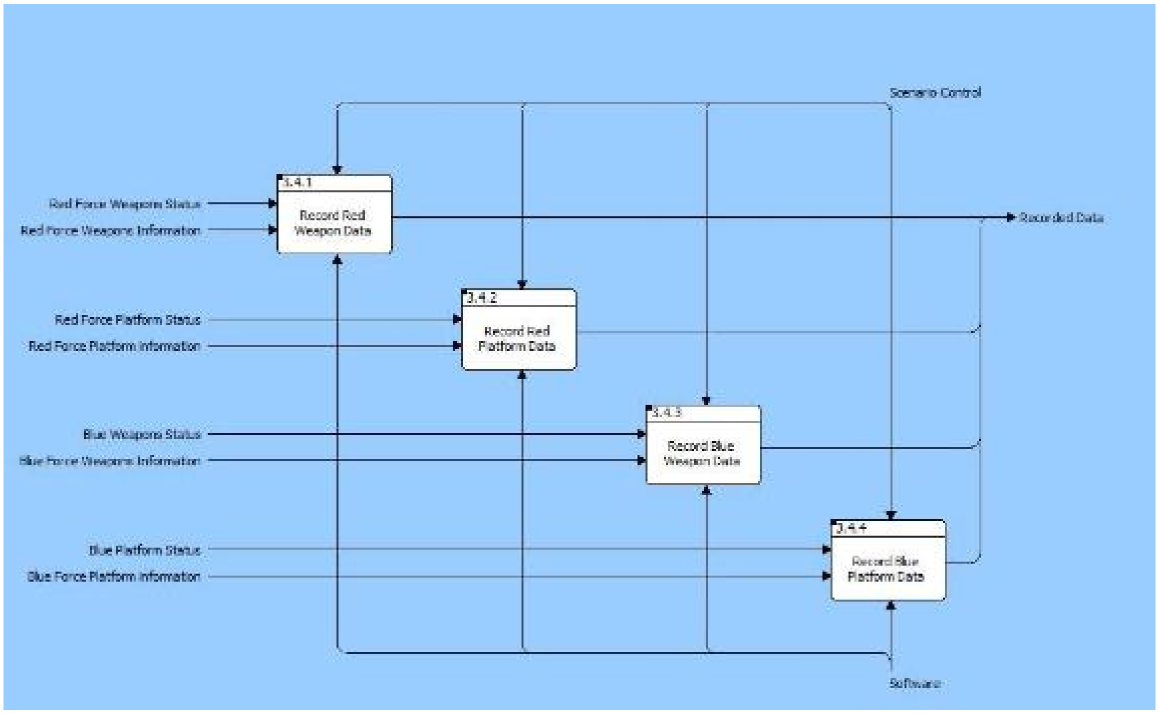

Figure 65. 3.4-Record Data IDEF0

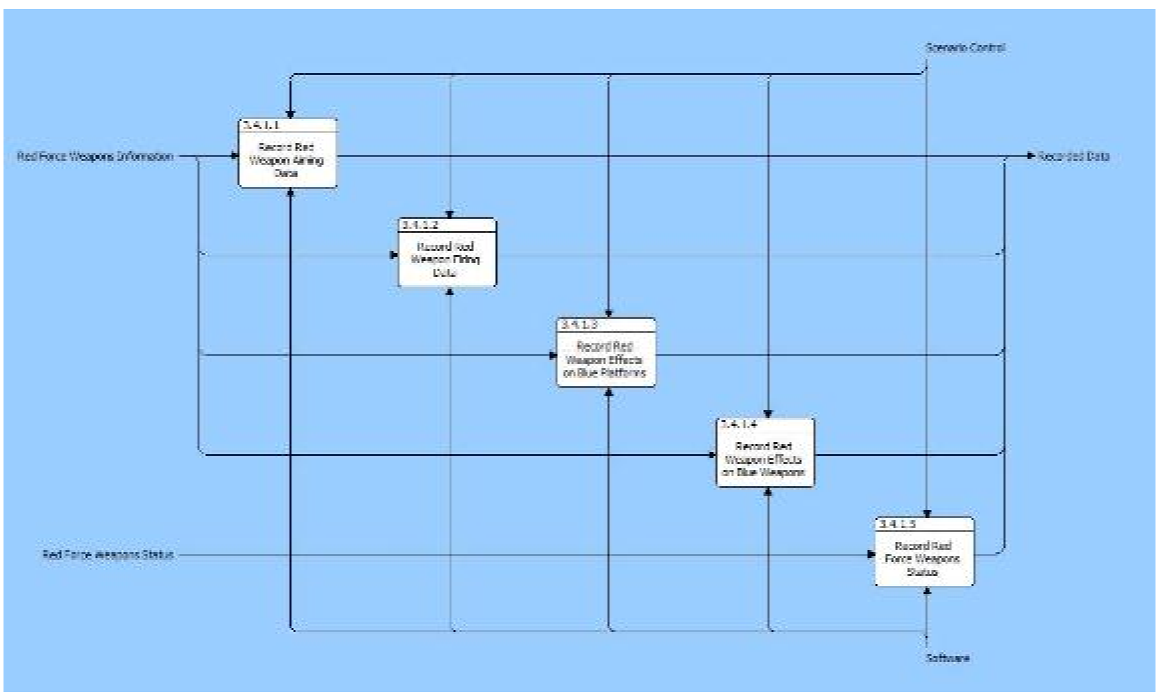

Figure 66. 3.4.1-Record Red Forces Weapons data IDEF0

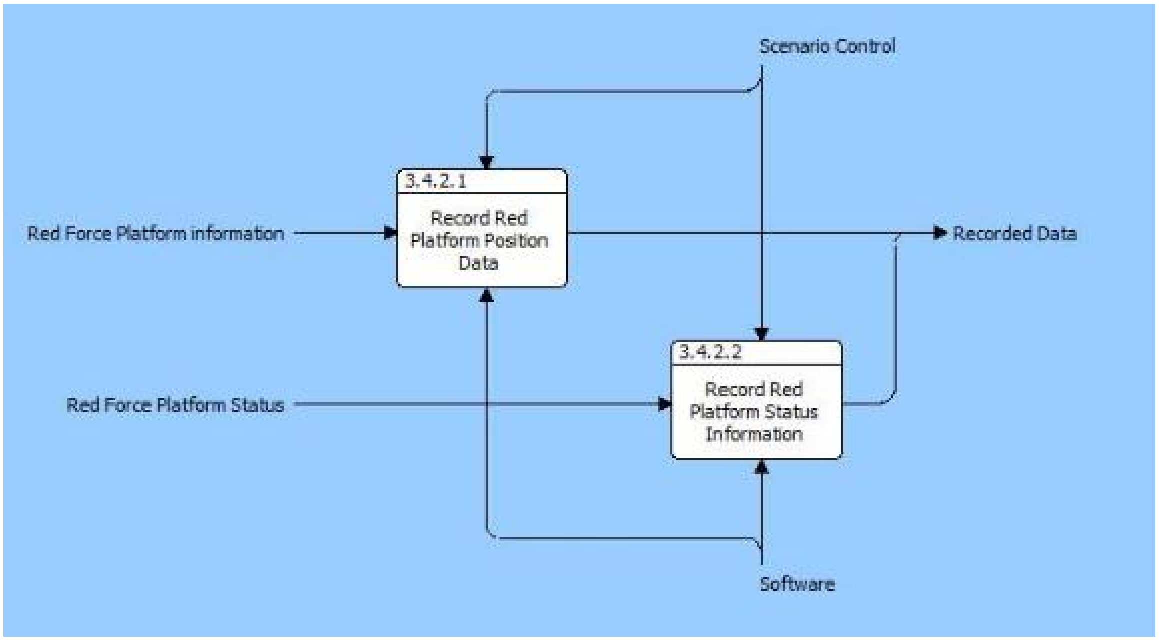

Figure 67. 3.4.2-Record Red Forces platform data IDEF0

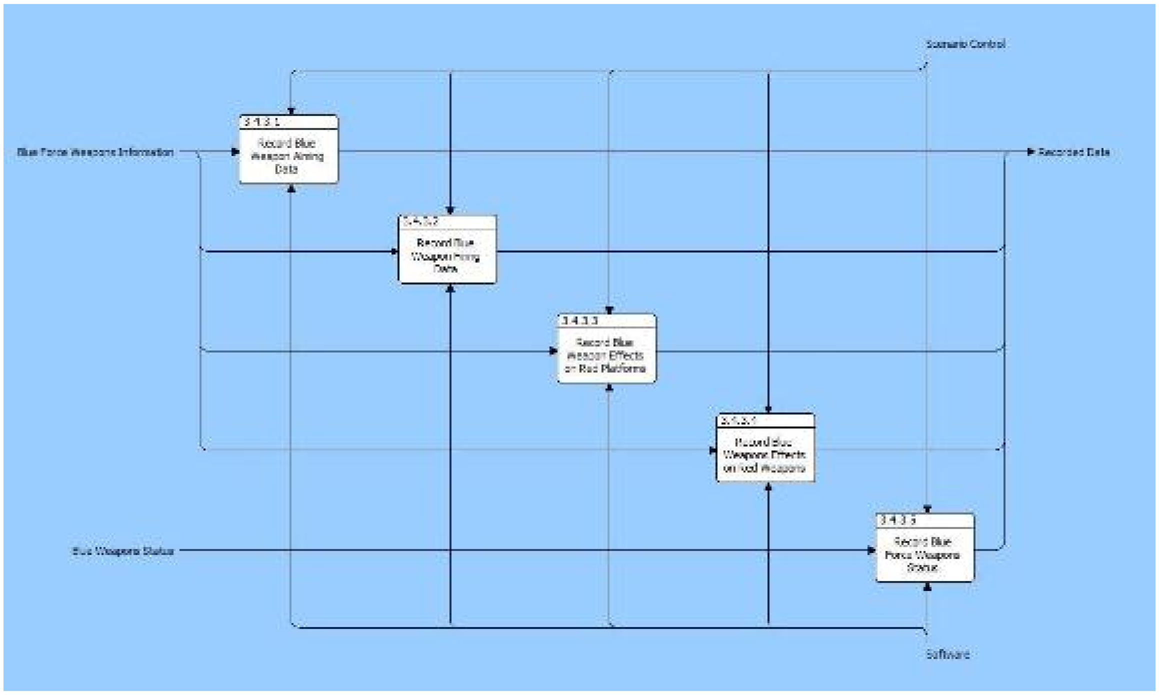

Figure 68. 3.4.3-Record Blue Forces Weapons data IDEF0

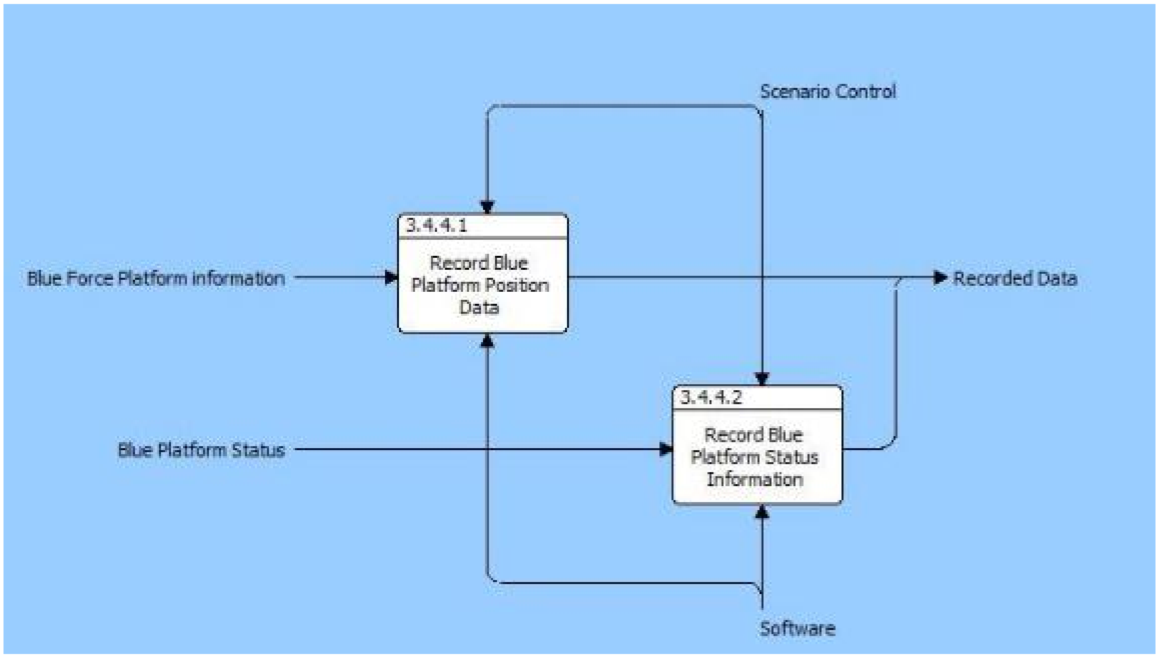

Figure 69. 3.4.4-Record Blue Forces platform data IDEF0

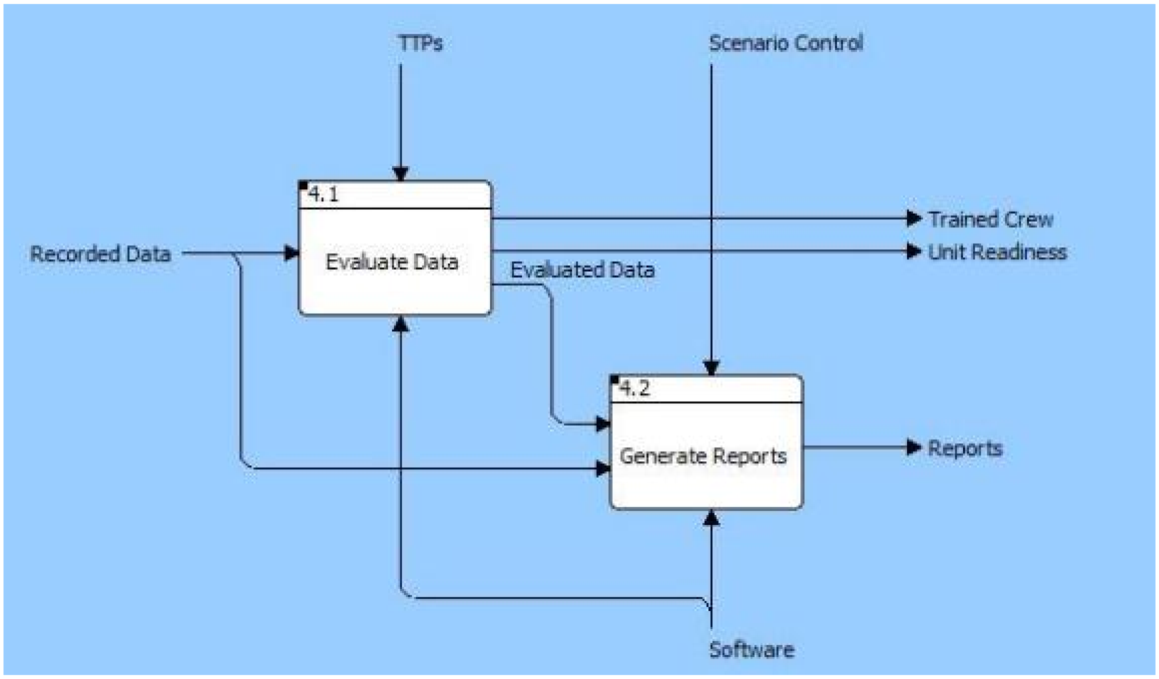

Figure 70. 4-Evaluate Performance IDEF0

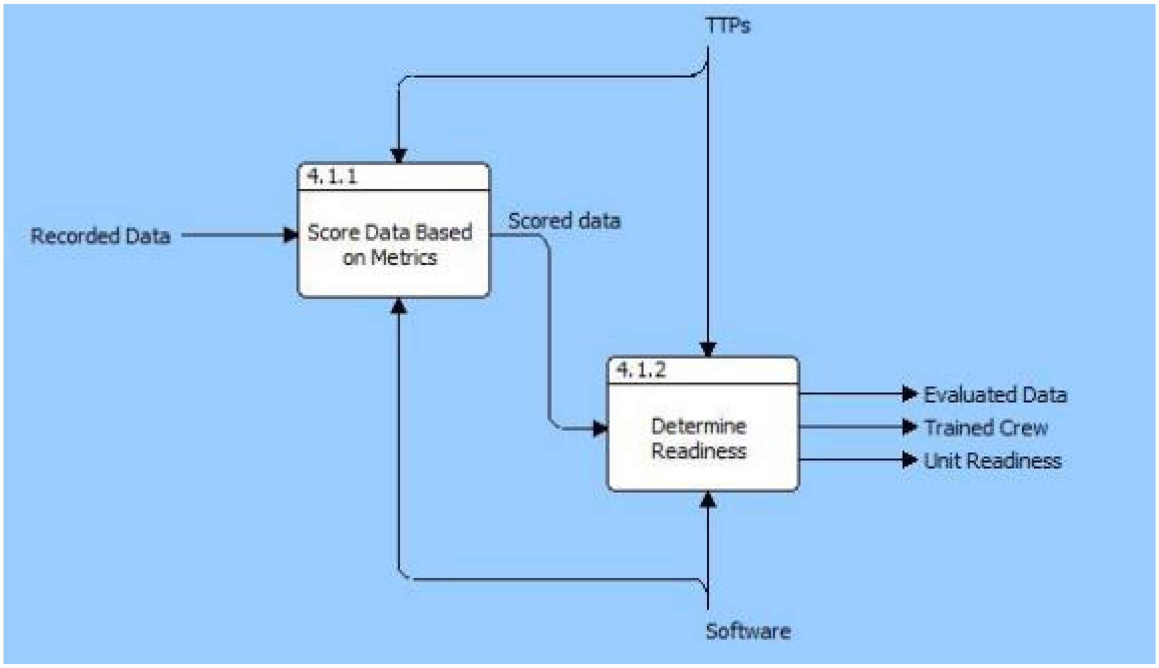

Figure 71. 4.1-Evaluate data IDEF0

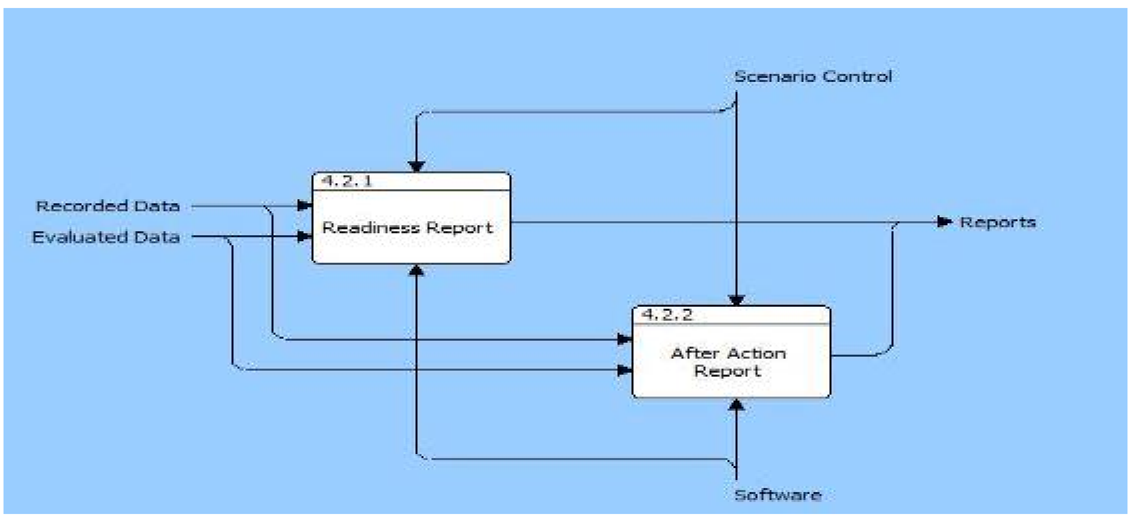

Figure 72. 4.2 Generate Reports IDEF0

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APPENDIX F. MOTION CAPTURE

Motion capturing, also known as MOCAP, has expanded from its main application in the entertainment industry. Industries implementing the use of MOCAP include medical, sports, biomechanics, and the military for the use of head mounted displays. “Motion capture involves measuring an object’s position and orientation in physical space, then recording that information in a computer-usable form” (Martin, Zulauf and Dyer 1995, 1). Hence, this technology would be able to provide precise data on the motion of the user interacting with the training system. It has been demonstrated in movies where animation actors’ play out scenes that are then captured real time with a high degree of motion and facial capture that is then processed in post-production.

There are three methods that MOCAP can be used including mechanical, optical and magnetic summarized below (Furniss 2004; Srikanth 2013)

1. Mechanical

Mechanical motion capture is done through the use of exoskeleton suit with rods connected by potentiometers. Potentiometers record the analog voltage changes and converts to digital values.

- The performer wears a human-shaped set of straight metal pieces (similar to a basic skeleton) that is hooked onto their back. As the performer moves, this exoskeleton is forced to move as well and sensors in each joint feel the rotations.
- Other types of mechanical motion capture involve gloves, mechanical arms, or articulated models.
- Suit cost can be anywhere from $25,000 to $75,000 (additional cost includes an external absolute positioning system).

The pros and cons for the application of this mechanical MOCAP in a simulated environment are listed below. Figure 73 shows an example of an exoskeleton in use.

Pros:

1. No interference from light or magnetic fields
2. High precision and accuracy
3. Not limited to camera specification and quantity

4. Self-contained

Cons:

1. The technology has no awareness of ground, so there can be no jumping, plus feet data tends to slide
2. Equipment must be calibrated often
3. Unless there is some other type of sensor in place, it does not know which way the performer's body is pointing
4. Absolute positions are not known but are calculated from the rotations
5. Exoskeleton suit weight limits user movements
6. Difficult to track interaction of several exoskeleton

Figure 73. Exoskeleton Suits for Mechanical MOCAP (from Gonzalez 2011)

2. Optical

Optical systems are either Passive (reflective) or Active (light emitting diodes LED). Both systems determine the performers' position with multiple cameras that track the passive or active markers on the body. Passive systems use LED infrared (IR) mounted camera lens that use over the camera lens IR pass filters that measure light reflected from the markers. LED based systems pulse-LED's measuring the infrared light emitted by the LED markers placed on the body. Either passive or active need to have a clear LOS because any occlusion will diminish the light path needed.

- The performer wears reflective dots that are followed by several cameras and the information is triangulated between them.
- This was developed primarily for biomedical applications (sports injuries, analysis of athletic performance, etc.).

The pros and cons of this application in a simulated environment are listed below. Figure 74 shows an example of an optical suit that would be used for this application.

Pros:

1. Performer feels free to move due to no cables connecting body to the equipment
2. Larger volumes possible
3. More performers are possible
4. Very clean, detailed data

Cons:

1. It is prone to light interference
2. Reflective dots can be blocked by performers or other structures, causing loss of data, or occlusion-this can be compensated for with software which estimates the position of a missing dot
3. Rotations of body parts must be solved for and are not absolute
4. Performer must wear a suit with unfamiliar orbs all over
5. Interference from light or reflections can result in so-called ghost markers.

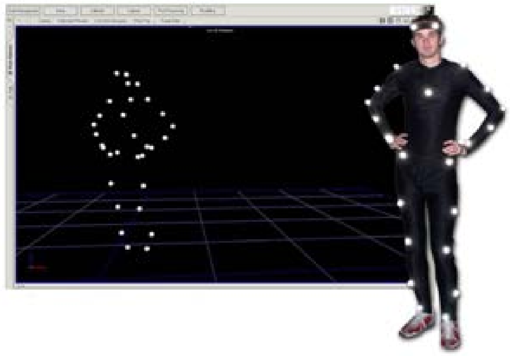

Figure 74. Optical MOCAP Suit from (from Gonzalez 2011)

3. Electromagnetic (Magnetic)

Electromagnetic motion capture is done via data sensors transmitted via network or wirelessly establishing fields in space where sensors can measure position and orientation of performer.

- The performer wears an array of magnetic receivers which track location with respect to a static magnetic transmitter
- One of the first uses was for the military to track head movements of pilots
- This type of motion capture is often layered with animation from other input devices

The pros and cons of this application of MOCAP in a simulated environment are listed below.

Pros:

1. Positions are absolute, rotations are measure absolutely; orientation in space can be determined, which is very useful
2. Can be real time

Cons:

1. Magnetic distortion occurs as distance increases
2. Data can be noisy—it is not as good as optical

3. Prone to interference from magnetic fields - cement floors usually contain metal, so stages must be built

The gap analysis concluded range and LOS limitations translating into data functions of: transmission, receiving and recording. Integration of video capturing technology looked promising to address some these functions. But, similar to MILES technology, range for transmission of data is an obstacle. The transmission of weapon data for both Red and Blue forces would be resolved with the use of optical markers. The active system would not be impeded by the light with the filters attracting only the active frequencies. These sensors would be attached to the weapon and user transmitting motion of both. With sensors being attached to the Red ship, participants would provide precise location on the ship for damage assessment of on board crew. The drawback would be the location of the cameras—three meters is the limitation for the distance from the sensors. Additionally, the integrating of data from either Red or Blue ship to a control tower would need to be capable of transmitting over 2000 meters from both locations. In conclusion, motion capturing has demonstrated its ability for obtaining a high detail of the user or even weapon in a controlled environment. Further research for greater transmission would provide the ability for tracking the weapons and user for AAR in greater detail for scenarios.

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