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MONTEREY, CALIFORNIA

SYSTEMS ENGINEERING CAPSTONE REPORT

CONCEPTUAL DESIGN OF THE USMC FUTURE VERTICAL LIFT (FVL) LIVING LAB

by

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December 2021

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LIVING LAB**

Irene Cho, Craig L. Earls, Mary Mesa,
Josue L. Ramos-Calvario, Lauren Reichert, and Savannah E. Wood

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ABSTRACT

The United States Marine Corps (USMC) is developing the Future Vertical Lift (FVL) system that will rely heavily on Marine-machine teaming, a complex process that requires further development. The development of a living lab (LL)—a multi-function network of simulators that will serve as the platform for testing, experimenting, and training new technologies and ideas for how the FVL will operate—will help mitigate Marine-machine collaboration and trust issues. This capstone studies the options and requirements for developing a LL through interviews, research that focuses on existing technologies and operational concepts, and Model-Based Systems Engineering tools using a systems engineering approach. The report includes a detailed needs and requirements analysis, stakeholder analysis, and functional design. The team presents a conceptual design, that includes the system architecture, comprising of system, function and physical views, system life cycle, and the evaluation criteria for a LL. The final product is a set of use cases and concepts of operation. The USMC needs a new approach that supports rapid and relevant upgrades that optimizes the system life cycle and keeps the Marine in mind. This team recommends the USMC consider these findings and continue researching and developing a LL.

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LIST OF ACRONYMS AND ABBREVIATIONS

AATD	advanced aviation training devices
AI/ML	Artificial Intelligence/Machine Learning
ALS	Aviation Logistics Support
APM	Autonomous Pilot Module
ATD	aviation training devices
BATD	basic aviation training devices
BDD	block definition diagram
BIT	built in test
C2	command and control
CCS	Combat Convoy Simulators
CONOPS	concept of operations
COTS	commercial-off-the-shelf
CV	combat evaluation
COR	Contracting Officer Representative
DIS	Distributed Interactive Simulations
DISA	Defense Information Systems Agency
DOD	Department of Defense
DODAF	Department of Defense Architectural Framework
DODIN	Department of Defense Information Network
DON	Department of the Navy
DREN	Defense Research Enterprise Network
EMD	Engineering, Manufacturing, and Development
EPCA	Enterprise Piers Connectivity Architecture
FAA	Federal Aviation Administration
FARA	future attack and reconnaissance aircraft
FFS	full flight simulators
FGT	Functional Ground Test
FLRAA	future long-range assault aircraft
FMS	Flight Management System
FSCC	Fire Support Coordination Center

FSTD	flight simulation training devices
FTD	flight training devices
FVL	Future Vertical Lift
GOTS	government-off-the-shelf
HMT	Human Machine Teaming
IEEE	Institute of Electrical and Electronics Engineers
IHD	Indian Head Division
INCOSE	International Council on Systems Engineering
ISSO	Information Systems Security Officer
JCIDS	Joint Capabilities Integration and Development System
JTAC	Joint Terminal Attack Controller
LL	living lab
LVC	Live Virtual Constructive
LVC-TE	Live Virtual Constructive Training Environment
MAGTF	Marine Air Ground Task Force
MBSE	Model-Based Systems Engineering
MCAS	Marine Corps Air Station
MCEN	Marine Corps Enterprise Network
MILCON	Military Construction
MIT	Massachusetts Institute of Technology
MOVES	Modeling Virtual Environments and Simulations
MTA	Middle-Tier Acquisition
MVP	Minimum Viable Product
NAS	Naval Air Station
NIWC	Naval Information Warfare Center
NMCI	Navy Marine Corps Intranet
NOE	Nap of the Earth
NPS	Naval Postgraduate School
NSWC	Naval Surface Warfare Center
OODA	observe orient decide act
OTA	over-the-air
PTN	Pilot Training Next

RC	Recommendation Consul
RFP	request for proposal
SAR	search and rescue
SISO	Simulation Interoperability Standards Organization
SME	subject matter expert
SOCOM	Special Operations Command
SOVT	System Operation and Verification Test
SSDS	Ship Self-Defense System
SysML	Systems Modeling Language
TD	technology development
TEMPMOD	temporary modification
T&E	test and evaluation
TTP	Tactics, Techniques, and Procedures
USAF	United States Air Force
USCG	United States Coast Guard
USMC	United States Marine Corps
USN	United States Navy
VR	virtual reality
VRAM	Vulnerability Remediation Asset Manager
WCS	Weapon Control System

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EXECUTIVE SUMMARY

The United States Marine Corps (USMC) is developing Future Vertical Lift (FVL) aircraft platforms to replace their aging aircraft. The FVL program's aircraft platforms are expected to be in service well into the 2060s (Lamb 2020). Although the FVL program was initiated by the U.S. Army, the USMC joined the program searching for replacements for their aging H-1 platforms. Leadership is concerned that current acquisition processes will not support the rapid acquisition and fielding timelines required to promote the integration and incorporation of the latest technologies into the FVL aircraft platforms (Jasper 2020).

To mitigate this, the USMC proposed the development of a living lab (LL) that will function as a network of remote simulators and prototyping sites to support testing, evaluation, simulation, and training for existing and emerging technologies and capabilities. The USMC already uses a LL at Marine Corps Air Station (MCAS) Miramar called the 5G Living Lab. Using the 5G LL, the USMC has been able to test new capabilities for services within the base and gather large amounts of data using the latest 5G technology provided by Verizon (Kanowitz 2020). The FVL LL is envisioned as a system of systems with a larger outreach, that incorporates simulators which support USMC aviation squadron users and other simulator capabilities that assist other USMC missions, such as maneuver, surveillance, and fires.

The purpose of the LL is to serve as a distributed but well-connected network to collect, organize and analyze experimental data extracted from remote USMC simulators. The concept promotes rapid prototyping and learning by enabling program offices, warfare centers, engineering activities, and vendors to propose new capabilities for the FVL, and added requirements for other mission systems, and gain access to a large operator test pool. By pushing the new capability simulation to remote simulators, the LL will be able to gather feedback and data to present to decision makers when deciding whether to proceed with the acquisition of new technologies. Figure 1 depicts a high-level operational view of the LL concept with possible USMC concentration areas where remote simulators will be located.

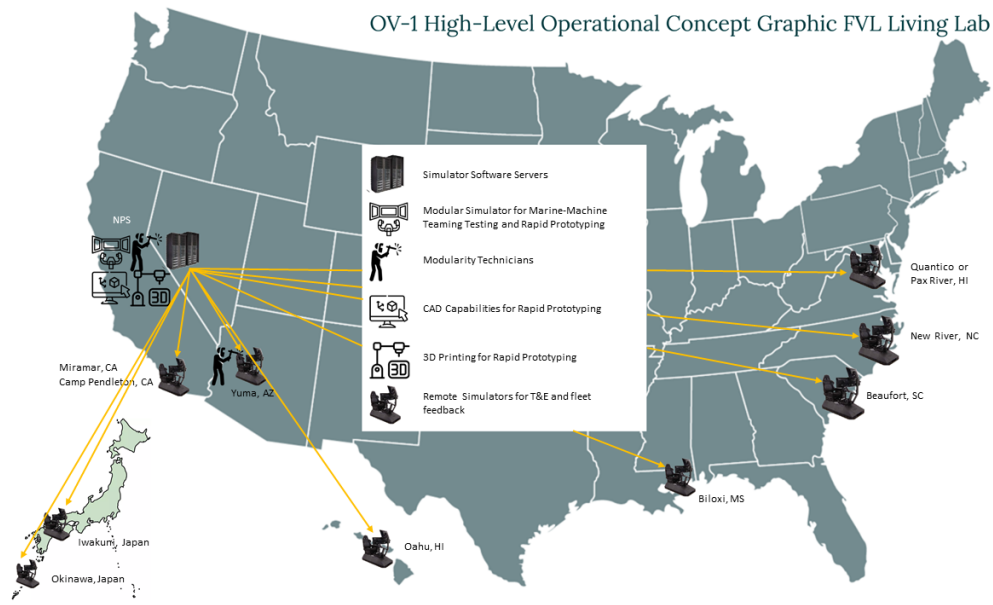


Figure 1. Living Lab OV-1

This capstone project examined the needs and applications for a LL within the USMC FVL program. The capstone explored possible integration options involving new and existing simulation systems and centers. The team developed a system architecture for FVL LL based on a needs analysis that incorporated stakeholder input. The capstone team established a set of objectives for the project:

- To understand the needs for a FVL LL.
- To identify stakeholders and understand and analyze their concerns and requirements.
- To evaluate the acquisition benefits of implementing the FVL LL.
- To establish an engineering framework for the FVL LL by conducting a systems analysis and developing a conceptual design.
- To assess the FVL LL conceptual design by identifying a set of operational concepts and using them as use cases to explore the design utility.

The capstone team used a systems engineering analysis approach to evaluate the needs and requirements of stakeholders, create a conceptual design and CONOPS, and create a high-level SysML architecture to establish an engineering framework for the future FVL LL. The team gathered data and information through literature review and discussion with stakeholders. The team used this information as the basis for an analysis of stakeholder needs. The team used the stakeholder needs to identify system requirements. The team analyzed the system requirements and categorized the requirements based on their type: functional, suitability, organizational, performance, and interoperability requirements.

The capstone team used the results of the research, stakeholder analysis, and requirements analysis to develop a high-level conceptual design consisting of architectural drawings of the system and its components. This included a block definition diagram, internal resource flow (SV-2), functional flow (SV-4), functionality flow description (SV-4), and system interface (SV-1). The team developed system life cycle and supportability considerations and developed a system evaluation criteria. The team developed a set of concepts of operation (CONOPS) and used them as use cases to assess the utility of the conceptual design.

This capstone's findings and systems engineering products establish an engineering framework for the USMC to use as it continues to pursue the development of a FVL LL. The FVL LL is envisioned as multi-function network of geographically distributed simulators and experimental centers to support the USMC and DOD make informed decisions for the acquisition of new technologies. The FVL LL is also envisioned as a critical part of experimentation and training to support future FVL pilots and crew members as they embark on operating and maintaining the highly technologically advanced and evolving aircraft of the future.

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I. INTRODUCTION

The United States Marine Corps (USMC) has embarked on a program called Future Vertical Lift (FVL) to develop a future family of aircraft that incorporates technology innovation for a diverse set of missions including transport, logistics, strike, and reconnaissance (Lamb 2020). The intention is to connect the FVL aircraft by a digital backbone to incorporate next generation avionics that are planned to be operational well into the 2060s according to James Conroy of Northrop Grumman (Lamb 2020). The Department of Defense (DOD) initiated the Joint FVL program in 2012 with a plan to “recapitalize its entire rotorcraft fleet over the coming 30–40 years” (Hirschbert 2019). The program is making great strides with planned upgrades and replacements to piloted aircraft as well as development of a diverse set of unmanned aircraft.

A. FUTURE VERTICAL LIFT AND LIVING LAB CONCEPT

The FVL program, led by the U. S. Army, was initially proposed in 2009 with the intention of developing a replacement for the U.S. Army UH-60 Black Hawk and Marine Corps H-1 “Huey” aircraft in support of the Army Assault missions and Marine Corps Attack and Assault/Utility missions (Gertler 2021). The goal is to have these aircraft operational between the 2030–2032 timeframe (Department of Defense 2016). More recently, the U.S. Navy announced in early 2021 that “it’s looking to join the Army’s Future Vertical Lift program” to find a replacement for the MH-60 Seahawk and MQ-8 Fire Scout (Seck 2021). Each branch of the armed services has different requirements for capabilities and instruments that the aircraft will use depending on the mission.

The challenge is that the USMC and Joint Services need to revitalize acquisition processes and timelines to be able to support the highly complex analysis, evaluation, testing, and training needs of the advanced technologies that will be present in the FVL systems. Alan Shaffer, deputy defense undersecretary for acquisition and sustainment, recently explained that “development timelines for major capabilities are still far too long” and that help is needed to “accelerate acquisition and fielding timelines and to provide greater depth in our analytic understanding necessary for design decisions” (Jasper 2020).

Lt Col Alan Clarke, USMC, recognizes the challenges involved in engineering complex automation and introducing an innovation paradigm into operations, to include planning multi-mission operations involving piloted and autonomous aircraft, incorporating automated decision aids into the observe-orient-decide-act (OODA) loop, and overcoming Marine-machine teaming trust and explainability challenges (Clarke 2021).

The USMC is envisioning an FVL “living lab” (LL) as a set of connected experimental simulators and physical prototyping tools that promote the visualization of future highly advanced aircraft and supporting systems in operational situations. This distributed lab will enhance the systems engineering design and evaluation of advanced FVL capabilities and will improve the overall acquisition and training needs of this new paradigm in the aircraft fleet. The desire is for the LL to become an advanced, agile, and distributed simulation test environment to “reach” many Marines, engineers, and scientists to test and train on a highly diverse set of USMC operational scenarios across different flight regimes and missions with new and emerging technologies and different combinations of flight systems—including piloted, remote-controlled, and autonomous. The LL is envisioned to enable simulators and models to interact with other existing simulators and virtual or augmented realities to support experimentation and evaluation of emerging capabilities.

The LL will be designed with the purpose of rapid prototyping and experimentation, maximized exposure development, design thinking development, and as a central node for program offices, warfare centers, engineering activities, and vendors to interact. The LL will serve as a facility for projects interested in running problems and simulations for their products within a one day to a six-week cycle. The LL is envisioned as an evolving lab, which will provide the capability of spreading to other platforms as well as supporting new weapons and systems. The LL will be located near high user density locations with the ability to leverage web-enabled systems for remote access. Figure 1 depicts a high-level operational view of what is envisioned for the LL. The LL in this figure is depicted in Camp Pendleton, a high concentration area with remote simulators dispersed throughout other high concentration areas to allow for as many operators as possible be able to test and operate equipment.

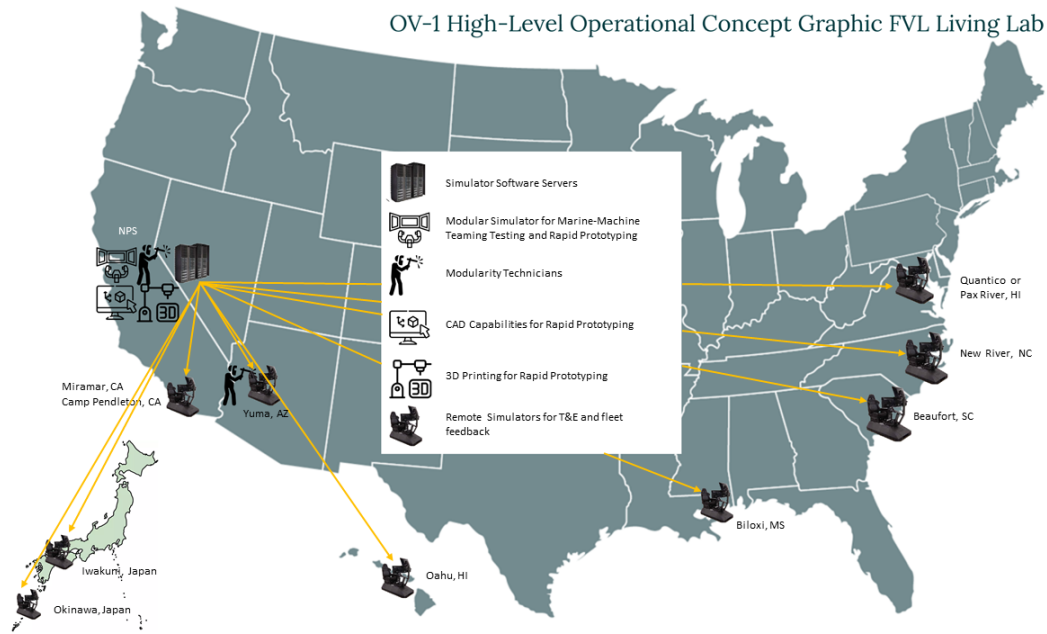


Figure 1. Living Lab OV-1

B. PROBLEM STATEMENT

Current acquisition processes do not effectively support testing and implementation of technological advances to existing systems without committing the DOD to these proposed technologies. This sometimes causes problems during the implementation cycle as testing and evaluation adds to the time needed to field the proposed technologies. There exists an opportunity to develop a process to address this within the current development of competing Future Vertical Lift platforms. These new platforms are being developed with the objective of supporting multiple missions which requires a combination of complex systems integration. The USMC envisions a LL that allows engineers, scientists, and Marines the ability to test and experiment with new and emerging technologies. The LL would allow simulators and models to interact with other existing simulators and virtual or augmented realities with the end goal of developing capable Marine-Machine teaming options.

Living labs are not new concepts, but they have only recently been implemented within the DOD in the last year. The 5G LL in MCAS Miramar was implemented in 2020 and its successes are still being measured; however, its application is different for that

system when compared to the LL supporting warfare missions. Using lessons learned from current living labs, research and analysis will be conducted to determine the need and requirements for how to apply the LL concept into the FVL.

C. PURPOSE STATEMENT AND PROJECT OBJECTIVES

This project studied how a LL can support the USMC's need to experiment with, and evaluate, new technologies for the FVL program. The capstone team established the following project objectives:

- To understand the needs for a FVL LL.
- To identify stakeholders and understand and analyze their concerns and requirements.
- To evaluate the acquisition benefits of implementing the FVL LL.
- To establish an engineering framework for the FVL LL by conducting a systems analysis and developing a conceptual design.
- To assess the FVL LL conceptual design by identifying a set of operational concepts and using them as use cases to explore the design utility.

D. PROJECT TEAM AND ORGANIZATION

The capstone team consisted of six NPS systems engineering students with various academic and professional backgrounds. The team consists of:

- Irene Cho is an interoperability software engineer for Naval Surface Warfare Center (NSWC) Corona, California. She started working at NSWC Corona in 2016 after graduating from California State Polytechnic University, Pomona with a bachelor's degree in computer engineering. Her technical competencies include software development, software management, and interoperability analysis.

- Craig Earls is a project manager and electrical engineer for the United States Coast Guard (USCG) Machinery Propulsion Control and Monitoring System at NSWC Dahlgren Division Dam Neck Activity in Virginia. He started working at Dam Neck in 2018 as an intern while finishing his bachelor's degree in electrical engineering at Old Dominion University. Prior to obtaining his degree in 2019, he spent nine years as a Machinist Mate in the Navy, eight years as a commercial electrician and five years as a marine electrician. He versed in cryogenic distillation, system automation, and currently using machine learning to develop a model to predict equipment failure.
- Mary Mesa is an Enterprise Software Solutions Manager for Navy Marine Corps Intranet (NMCI) with Naval Information Warfare Center Pacific (NIWC PAC) in San Diego, California. Prior to working with NMCI, she worked as the Production and Modernization Lead with Enterprise Piers Connectivity Architecture (EPCA). She also worked as Project Lead in Yokosuka, Japan and Guam supporting Military Construction (MILCON) and Shore Network Installations. She graduated in 2009 with a bachelor's degree in computer information systems from the University of Guam.
- Josue Ramos-Calvario is a branch contracting officer representative (COR), Division Information Systems Security Officer (ISSO) and computer engineer for the Vulnerability Remediation Asset Manager (VRAM) system at NIWC PAC in San Diego, California. He started at NIWC PAC after serving seven years in the U.S. Navy as a Surface Warfare Officer. He graduated in 2013 with a bachelor's degree in systems engineering from the United States Naval Academy. His technical competencies include configuration management, technical writing, and cyber security.
- Lauren Reichert is a project manager and systems engineer for the Evolved SeaSparrow Missile at NSWC Indian Head Division (IHD) in

Indian Head, Maryland. She started at IHD in 2016 after graduating from the University of Virginia with a B.S. in Chemical Engineering. Her technical background includes aircrew escape systems focusing on rotary aircraft for the USN and USMC, logistical support for special operations, and human subject surveying.

- Savannah Wood is a Lead Test Engineer for NSWC Dahlgren, VA working on the Ground/Air Task Oriented Radar Special Training System for the Marines. She started at NSWC after graduating from Randolph-Macon College with an Engineering-Physics degree with minors in computer science and mathematics.

Figure 2 illustrates the FVL Team organization with Dr. Bonnie Johnson of the Systems Engineering Department as the lead advisor, CAPT Scot Miller, USN (Ret) serving as a technical advisor and Lt. Col. Alan “Ira” Clarke, USMC, serving as a USMC fleet advisor.

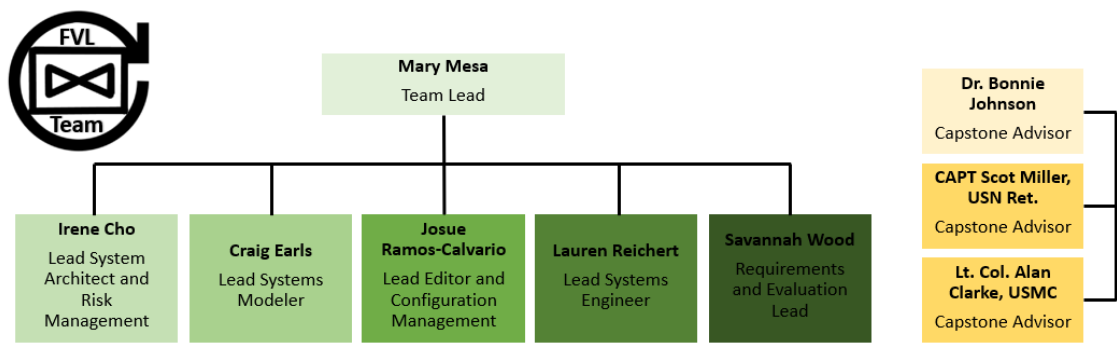


Figure 2. FVL Team Organization

E. SCOPE

The scope of this project was limited to creating the foundation for the systems engineering design of the LL. The project encompassed the first three phases of the International Council on Systems Engineering (INCOSE) Vee-diagram, shown in Figure 3

with the objective of developing and evaluating a conceptual design as well as an initial system architecture and requirements. These systems engineering artifacts will provide a foundation for the USMC to develop a detailed design in future work.

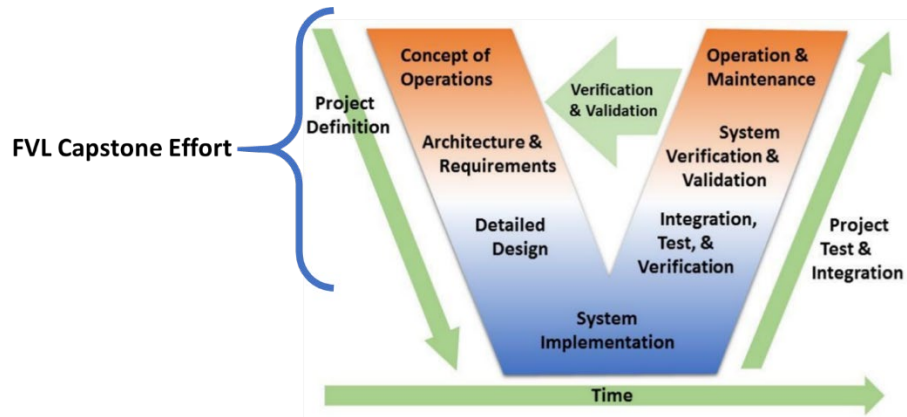


Figure 3. INCOSE Vee-diagram Project Approach. Adapted from The International Council on Systems Engineering LA Chapter and The Creativita Institute (2015).

The team limited the FVL LL scope to focus on the integration of existing research and Living Labs. The team documented any deficiencies left unresolved, missing tools, dead ends, or challenges outside this scope that they discovered during the study and discuss these items in the section on future work.

F. METHODOLOGY

The project applied a systems engineering approach as shown in Figure 4. The process began with a needs analysis which included the study of stakeholder needs, support needs, and the development of an operational view of the USMC FVL LL. Next the team conducted a requirements analysis based on the stakeholder needs. This led to the development of a conceptual design in the form of a block definition diagram (BDD) and a design analysis. Finally, the team developed a concept of operations (CONOPS) which includes a study of the systems involved and their functionality.

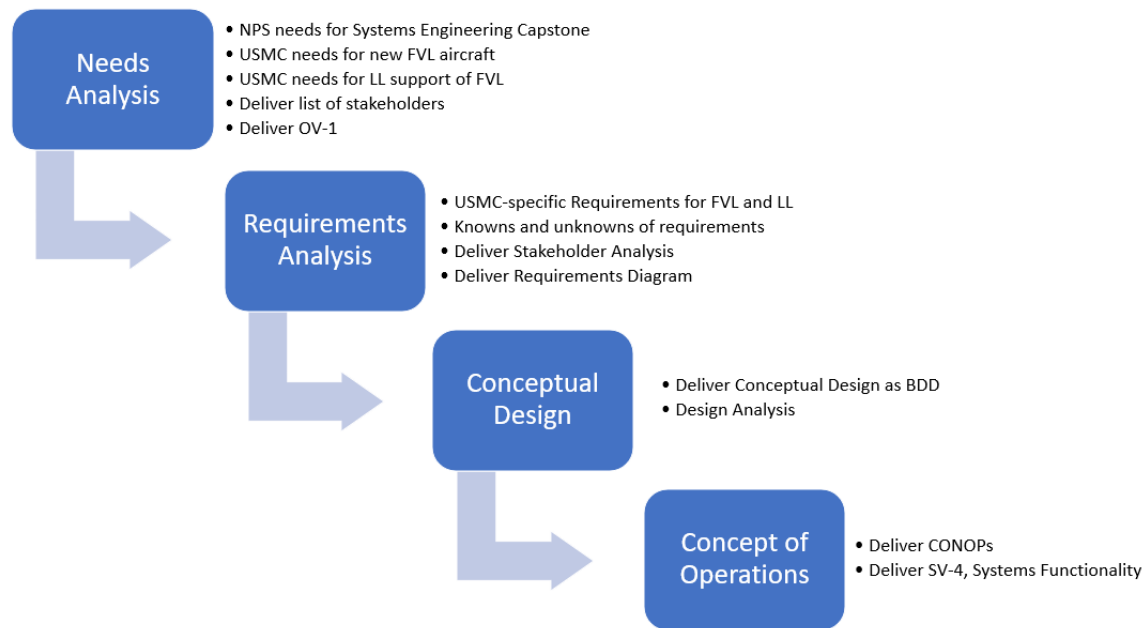


Figure 4. Systems Engineering Methodology

To begin, the team researched topics related to the FVL program, living labs, and potential components and functions for the LL. The team interviewed subject matter experts in simulations, human machine teaming, the FVL program, and the only existing USMC LL. This data was compiled in the literature review to understand the needs and requirements for the LL.

After conducting the research, the team conducted a stakeholder analysis and developed a breakdown of all stakeholders. Next, the team performed a requirements analysis to identify functional, performance, organization, interoperability, and suitability requirements.

The team applied a Model-Based Systems Engineering (MBSE) method to develop system and operational views, a functional architecture, activity diagrams, and other system artifacts based on the DOD Architectural Framework (DODAF) and Systems Modeling Language (SysML). These items were used to describe the conceptual design of the FVL LL. The team also developed evaluation criteria to assess innovative solution capabilities for the FVL LL. Conceptual designs cannot be fully analyzed and validated without knowing about the systems behavior (Couturier and OImoussaten 2015).

Therefore, the team documented decisions made throughout the design process, analyzing options based on available information. As the FVL is developed, information and requirements may change, so future efforts should revisit these decisions to determine if they still apply.

During the final phase, the team developed CONOPS as use cases to illustrate ways the LL will work in supporting the FVL and USMC.

G. BENEFIT OF STUDY

The results and products of this capstone project establish an engineering framework for the USMC FVL LL. The USMC stakeholders can use the capstone deliverables, including the system requirements, conceptual design, system architecture views, and CONOPS as a basis for their detailed design and development of the network of FVL LLs. The capstone's use case analysis shows how the conceptual FVL LL can be used in a series of CONOPS. This capstone's engineering framework is an initial step towards ensuring that the USMC can experiment with advanced technologies to support effective Marine-machine teaming in future advanced FVL aircraft. The capstone's engineering framework also supports the training needs of future FVL pilots and crew as they learn to operate and maintain the advanced technology in future FVL aircraft.

Since the FVL is not expected to be fielded until 2030, the rising concern for future technological advancement will need to be addressed when forming any requirements and design specifications. This will likely be a reoccurring issue during the development of the LL. The LL will help identify issues before the systems being tested are integrated with the FVL.

H. THESIS OVERVIEW

Chapter I of this thesis presents an introduction to the capstone project and provides a background discussion, the purpose and objectives of the project, the project team organization, the project scope, the project methodology, and a discussion of the benefits of the study. Chapter II presents the capstone's literature review, covering topics relevant to the study including the FVL, LL, simulators, interoperability, data collection, and digital

twin technology. Chapter III contains the capstone's needs analysis that captured stakeholder needs and developed system requirements. Chapter IV contains the capstone's conceptual design including system, functional, and physical architecture views. Chapter V presents the capstone's CONOPS analysis that describes several use cases and how the FVL LL will support each. Finally, Chapter VI is the capstone's conclusion which summarizes the project and discusses the team's recommendations and areas for future work.

II. LITERATURE REVIEW

A. CHAPTER OVERVIEW

The team reviewed a variety of sources including previous capstone project reports, theses, peer-reviewed reports, articles, and industry literature. The team gathered information on the FVL aircraft and its development, living lab technology, simulators, interoperability, data collection, digital twin technology, rapid prototyping, human machine teaming, and concepts of operation. The team identified these topics as being relevant to the capstone project topic and methodology.

B. FUTURE VERTICAL LIFT

The LL will support the FVL aircraft currently being developed. As described in the Army FVL Congressional Research Service report (Gertler 2021), shortened to Army FVL, and Marine Corps Aviation Plan (USMC 2019), two styles of aircraft are being developed. One style is the Future Attack and Reconnaissance Aircraft (FARA) to replace the AH-64 Apache, CH-47 Chinook, and OH-58 Kiowa for the Army (Seck 2021). This aircraft will be smaller and support shorter missions. The second platform, the Future Long-Range Assault Aircraft (FLRAA), will replace the UH-60 Black Hawk for the U.S. Army and the AH-1Z and UH-1Y “Huey” for the USMC. For the USMC, the new aircraft will support the F-35 and MV-22B by enhancing the Marine Air Ground Task Force (MAGTF) as an escort with manned and unmanned teaming options (USMC 2019). Replacing the “Huey” with the FVL aircraft will allow the USMC to modernize and upgrade its fleet while providing the capability to conduct a wider range of missions. The focus of this research will be on the FLRAA as it relates to the USMC Huey replacement.

Developmental efforts of both FVL platforms began in 2009 with the strategic plan outlined in 2011 (Gertler 2021). Contractors have started their development and have produced prototypes for both the FLRAA and FARA, shown in Figures 5 and 6. Requests for proposals (RFPs) were due from Bell and Sikorsky-Boeing in July 2021 (Gertler 2021). As of this report, no information has been released to the public.



Figure 5. FARA Designs Bell 360 Invictus Concept and Sikorsky S-97 Raider. Source: Army FVL (2021).



Figure 6. FLRAA Demonstrators Bell V-280 Valor and Sikorsky-Boeing SB-1 Defiant. Source: Army FVL (2021).

Each military organization, the U.S. Army, U.S. Navy (USN), USMC, and Special Operations Command (SOCOM), has their own needs and set of requirements for the new aircraft based on their respective missions. The USN hopes to utilize the new aircraft in surveillance, reconnaissance, search, and rescue (SAR), and make it deployable on any USN ship, but Bell and Sikorsky-Boeing may not adapt their current design paths to accommodate the USN requirements (Seck 2021). The mission goals for the USN match those of the Army and USMC but similar mission types can differ greatly across services due to their operating environment, whether on land, sea, or both. Currently the MH-60 Seahawk, the USN variation of the Army Blackhawk, can deploy off any ship, but the FLRAA demonstrators may involve too many adaptations to meet this requirement. The USN is working with Bell to procure its new CMV-22 Osprey adaptation (Seck 2021). This

would not be deployable on all ships like the Seahawk but would be an addition to the carrier and delivery aircraft currently fielded.

Both the Army and USMC are further along than the USN in developing requirements for the FLRAA. The Army has previously set forth a few price caps on one aircraft with one report by Graham (2019) stating \$30M and another, Freedberg (2019), stating \$43M. As of early 2019, the USMC, USN, and SOCOM had not yet set budgets for their aircraft, but the USMC has more rigorous requirements than the Army (Freedberg 2019). The USMC threshold requirements are near or higher than the Army objectives for both speed and range as shown in Figure 7. The USMC also specifies a dash speed instead of just cruise speed which is even higher at 310 knots (Graham 2019). While the Army requires a modular open system architecture, the USMC specifies the ability for manned-unmanned teaming. SOCOM mostly follows the Army's lower requirements, but it does require that the aircraft fit in an Air Force C-17 for transport, and the USMC, on top of their higher performance requirements, wants the aircraft to fit on USN amphibious ships (Freedberg 2019). The USMC also requires an in-flight refueling option for long range requirements, which SOCOM wants the option to add this to some of their aircraft. The one area where the USMC has a lower requirement is on personnel transport. Per Freedberg (2019), both the Army and SOCOM want the aircraft to transport the two pilots and twelve additional personnel while the USMC only requires the two pilots plus ten personnel. The Army will be the largest market for the FLRAA with the lowest requirements. Further tracking should be done to see if the USMC or USN reduce any of their requirements to get a slightly modified Army aircraft or if they will have to back out of the effort and conduct their own acquisition.

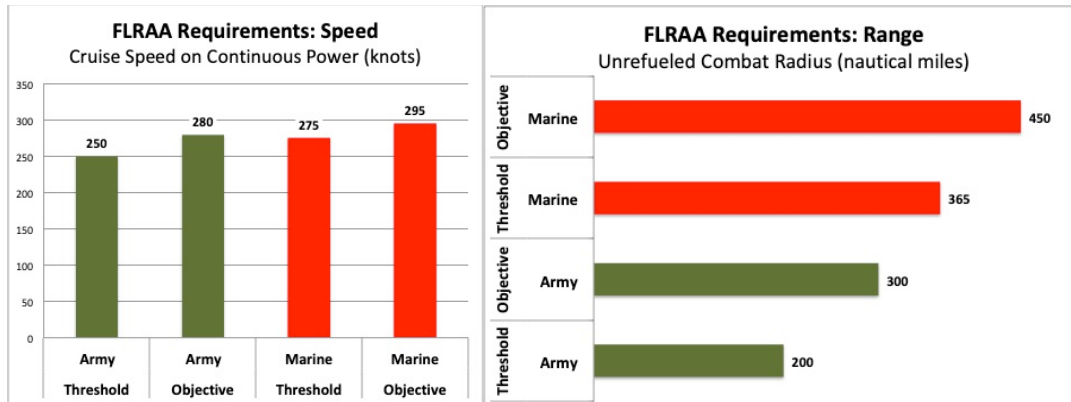


Figure 7. Speed and Range Requirements Army and USMC. Source: Freedberg (2019).

Further research should be conducted as development efforts, including designs, acquisition plans, and requirements progress and the program matures.

C. LIVING LAB

Many examples of current LLs are focused on user living spaces or open software operations. The original LL was the PlaceLab at Massachusetts Institute of Technology (MIT) which started in July 2004 (Intille 2004). There, they had over 425 sensors, 80 switches, 18 cameras, and 18 microphones connected in a 1000 square foot apartment to monitor the “user,” or the person living in the apartment, researching the user’s activities. The study showed that traditional laboratory studies and surveys do not accurately portray a user’s activities, so a LL gives more realistic data. This is due to the user being more relaxed in their environment and acting without thinking about it. It is monitoring someone in their everyday life instead of putting them in a new environment like a lab or asking them to recall their behaviors in a survey. The European Union developed the Living Lab Research Infrastructure to research residents of eco-friendly or sustainable homes (Liedtke 2011). Research involved analyzing user interaction with integrated home technology designed to promote an eco-friendlier home. The remote lab control allowed researchers to make changes to the home system such as temperature and lighting then recorded the impact on residents and the changes they made. While these

LLs were not focused on making technological improvements remotely, they show the benefits of real-time research in the user's regular environment.

The U.S. military is developing LLs for multiple uses and platforms. One example is the USMC 5G LL at Marine Corps Air Station (MCAS) Miramar. This program consists of four pilot programs: energy communications, connected vehicles, drones, and "digital fortress" which is a counter-intrusion protection system (Kanowitz 2020). The goal is to remotely operate and update the systems in the programs using the Verizon 5G network. This remote control would demonstrate the success of the four pilots and, therefore, the idea of military LLs, which could lead to development for their use at other installations. These and future LLs will integrate into current activities and systems giving real time data and allowing for real time changes by remote and/or on-site operators.

The 5G pilots that may provide valuable information for the LL application are the network connected vehicles and drone efforts. MCAS Miramar has an unmanned logistics program with air and ground vehicles in place, but the LL has connected these vehicles using 5G for better remote control and communication across platforms. For example, during the COVID-19 pandemic, the autonomous shuttles were used to deliver parts across the installation, but for future work, the goal is for them to deliver Marines to the flight line, requiring communications with air traffic control, road traffic, and flight plans.

In an interview with Maj. Steven Harvey, USMC, (Director of NavalX SoCal Tech Bridge) the team was able to gain some insight into MCAS Miramar's adaptation of a LL. The 5G LL is currently being employed differently than how the FVL LL is envisioned in that the base is the LL. To begin, there is not a centralized location where the information is processed. Each of the previously mentioned projects conducts their own testing through the infrastructure that the 5G ecosystem has built. This has allowed for individual efforts to be conducted simultaneously without disrupting or requiring Marine resources. At the same time, these efforts allow for open lines of communications between the vendor and the USMC as they execute the "buy-try-decide" model (Bailey 2020). The LL at Miramar currently serves as the platform for the USMC to execute Combat Evaluation (CV) actions for small projects that have the potential to grow into a full-scale program. Figure 8 depicts a MAGTF combat evaluation scenario derived from the USSOCOM Directive 70-1,

Acquisition Management System Policy Combat Evaluation appendix, and created by Col. Robert Bailey, USMC.

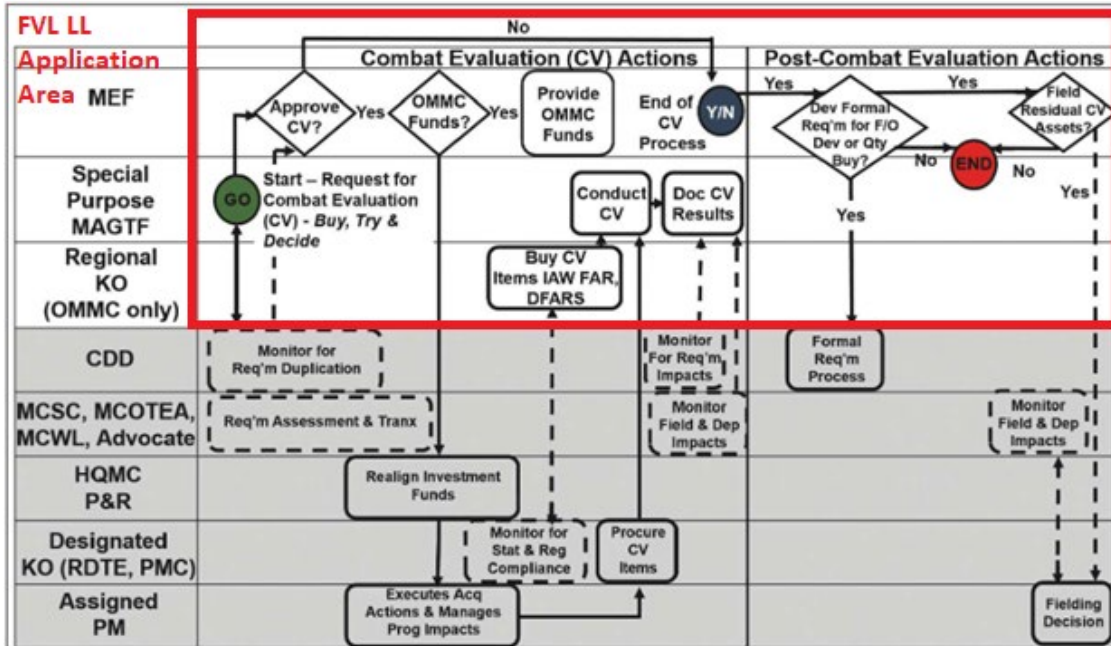


Figure 8. Notional Special Purpose MAGTF combat evaluation process flow. Adapted from Bailey (2020).

The FVL LL would be a method for applying this “buy-try-decide” model that encompasses the CV Actions and Post-Combat Evaluation Actions. In this case, the LL would serve the purpose of streamlining this process by acting as an inexpensive platform for performing the testing and simulations on integration. This means that for systems such as missile weapon systems, missile performance would still need to be tested concurrently in a live-fire exercise, however the integration of the weapon system could be tested on the FVL LL with minimal impact to USMC resources. The area includes post-combat evaluation because of the LL’s ability to generate performance data to analyze and use when deciding on acquiring the equipment or not.

D. SIMULATORS

Aircraft and flight simulators are used for initial and recurring training for pilots, engineers, students, and maintainers throughout private industry and the DOD. Some levels of private industry simulators are regulated by the Federal Aviation Administration (FAA) if they are used for certification purposes. The main levels of industry simulators are Full Flight Simulators (FFSs), Flight Training Devices (FTDs), Aviation Training Devices (ATDs), and personal simulators or simulator games (Bernard 2012). Bernard defines FFSs and FTDs together as Flight Simulation Training Devices (FSTDs) with both simulating actual aircraft cockpits or flight decks, the former has movements while the latter does not always. They are valuable but expensive resources for training pilots, aerospace engineers, students, maintainers, and others who work in and around the cockpit, giving them low-risk practice to hone their skills before moving to actual aircraft. FSTDs are under the FAA National Simulator Program with FFSs used for ratings and FTDs for upgrades such as First Officer to Captain (Bernard 2012).

The general category of ATDs covers both Basic ATDs (BATDs) and Advanced ATDs (AATDs). Bernard states that the former is used for certain training and proficiency credits on instrumentation as they contain the instrumentation and software of a generic aircraft (2012). AATDs meet all BATD criteria according to Bernard but serve as ergonomic representatives of generic aircraft and contain GPS and auto-pilot features such that it can be used for some training hours towards commercial and airline transport pilot certificates (2012). One of the most well-known personal simulators is Microsoft Flight Simulator which was released in 1982 and is available across a variety of platforms (Gulick 1987). People can use the game to prepare for flight school, practice maneuvers or events on their own time, or just have fun. It is not FAA regulated but is available to anyone who purchases the game.

Most training hours are conducted in actual aircraft, but some hours can be conducted in simulators, saving on fuel costs, and lowering risk of potential damage to aircraft and personnel. Per 14 CFR § 61.159 (2021), for a Part 61 certificate, up to 100 hours of the 1,500 necessary for an Airline Transport Pilot may be done in simulators. Any hours may be done in an FFS and instrument flight time may be done in an FTD as they

represent the specific aircraft for which the training is earning their certificate. Trainees and those looking for higher levels of certification or upgrades can practice as much as time and funding allows on the simulators to focus on certain skills, dangerous scenarios, or challenging maneuvers all at the lower risk and cost provided by the simulators.

Simulators are also used for engineering studies. The Boeing 727 simulator, released in 1985, in Oklahoma City was designed for safety inspector training and as a lab test tool for studying wind shear and other common weather hazards (Johnson 1985). Private industry has used simulators for decades, recognizing the main benefits of lowered cost and risk while pilots, engineers, maintainers, inspectors, and others develop and refresh their skills.

The DOD recognizes many of the same benefits and both groups are currently struggling with pilot shortages so any way to save money and time in training is something to pursue. Naval Air Station (NAS) Whiting Field has been using TH-57 simulators since 1981 and started receiving updated versions in 2019 including some level 6 units, stationary units with full visual screens, and some level 7 units that add full-motion and a larger field of view (Garrett-Glaser 2019). Another upcoming deliverable is a central control station to connect the simulators for formation and communication practice (2019). The USMC recently received their F-35 simulators at MCAS Miramar where pilots can hone their skills and practice operations across different services, platforms, and locations (Allen 2021). This helps prepare the pilots for deployment, sharing airspace with other branches and operating off of USN ships.

To combat the pilot shortage, the DOD is pushing for small, portable simulators that can be used on laptops that trainees can take home for practice (Vergun 2020). A big driver is that there is a shortage of pilot instructors on top of the shortage of pilots. Vergun notes that the goal is that trainees can practice flights and skills by themselves, with an instructor present in the room, or even with an instructor watching virtually through the simulation (2020). This allows for more training centers across the country without having to staff instructors at each site. Another way to combat the shortage is through heavy recruitment. The USMC has sent out an RFI for small virtual reality (VR) simulators that can be moved by one person to recruiting events to immerse potential pilots, maintainers,

and crew chiefs in a virtual environment (Harkin 2020). In the past, pilots would take prospective recruits up in leased aircraft to show them what flying is like, but according to Harkins, that has become cost prohibitive and the hope is that these simulators will foster the same excitement and interest at a much lower cost and no need for a nearby airstrip (2020).

Once in the service, the U.S. Air Force (USAF) and USN are working more and more simulator time into training to speed up the process, lower risk, and lower costs. In 2018, the USAF rolled out the Pilot Training Next (PTN) program that has trainees jump right in with VR training then learn instrumentation before going out on the T-6 trainer instead of starting in the classroom on instrumentation (Pawlyk 2021). Starting with simulator training gives the future pilots realistic scenarios and an opportunity to see what does and does not work in the aircraft without risk and for many, it helps them learn faster. The program covers the F-22, F-35, F-15, and F-16 and has shown a positive impact on training, particularly for the F-22 and F-35 students (Pawlyk 2021).

The USN has a variety of simulators but one of the big successes is the training for Joint Terminal Attack Controllers (JTACs) as NAS Fallon (Eckstein, New Simulators Give Naval Aviators an Edge in High-End Fight 2018). As JTAC students prepare, they go through a five-week course that starts with two weeks in the classroom, one week with the simulator, then two weeks with live practice as noted by Eckstein (2018). She states that adding in the simulator training has output more prepared JTACs who immediately jump in and help their pilots conduct air strikes instead of still navigating a learning curve when they join the fleet (2018). This is a great example of connecting aircraft simulators with those whose mission is ground based, as in the JTAC's case, and is a preview of what the Marines' hope the LL will become. The simulator is advanced enough that it can bring in live data from aircraft flying for realistic training. NAS Fallon is also getting simulators for "pretty much anything in the carrier strike group" per Steinbaugh and has surface to air missile simulators to train pilots on flight paths and avoiding ground threats (2018).

As the USN and USAF take advantage of aviation and aviation-related simulators, the USMC's main simulator system is the Combat Convoy Simulators (CCSs) There are two CCS facilities at Marine Corps Base Camp Pendleton which help to train convoy

operation, basic Tactics, Techniques, and Procedures (TTPs), weapons engagements, target extraction, and a variety of customized operations (Scanlan 2013). Per Scanlan, the facilities can mimic the clime and place of the selected training environment and fit two seven-ton trucks plus four Humvees in each location. The goal is to fully simulate what Marines could see when they enter a combat zone with IEDs on the “road” they are driving such that they need to stop and bring in EOD, or insurgents will be shown on simulated equipment as they are practicing a patrol. Scanlan believes that one of the biggest advantages of the CCS is the immediate training reviews as everything is recorded in the simulator and teams can review how they handled the scenarios to improve for the next one or for deployment (2013). The benefits of implementing training simulators such as at NAS Fallon or the CCS have motivated the services to invest in different kinds of simulators to reap the benefits cost savings, improved risk management, portability, shorten training times and improve personnel management.

There are simulators used outside of training though. For example, the USN runs simulated tests for the Tomahawk Cruise Missile using its Tomahawk Functional Ground Test (FGT) facility at NSWC IHD. Instead of conducting a full flight test on a Tomahawk, the FGT uses a missile with an inert payload as well as a six degree of freedom setup with sensors and simulated mapping to conduct a test that can replace a full flight test at a fraction of the risk and cost (DeLong, Spriggs and LeGoullon 1998). DeLong, Spriggs and LeGoullon note that NSWC Dahlgren Division is home to the Tomahawk Weapon Control System (WCS) and is the group to “launch” the missile and control its flight as it is held in place at NSWC IHD. Once “launched,” the missile goes through its booster, drops that off to enter cruise mode, then “hits” its target and terminates the simulation (1998). This simulation is localized to the Tomahawk and its specific software but has been in operation for over two decades with a test at least as recently as 2017. In 1999, DeLong, Spriggs, and LeGoullon predicted a cost avoidance of over \$260 million and with the program still in effect, it has likely exceeded that amount.

E. INTEROPERABILITY

The ability to connect and operate different simulators together, especially across different locations, drastically expands the potential uses of those simulators. This interoperability is already in use by the DOD with published examples in the USN. Upon delivery of the ten TH-57 simulators under contract for NAS Whiting Field, all will be connected through a central control station (Garrett-Glaser 2019). The connection is only at that air station but allows up to ten pilots or crews to practice flying in formation or carrying out missions. Details on how these simulators will be connected were not provided, but the USMC and LL engineers can use the proven simulator example for the LL.

One area in which the USMC is already working is their Live Virtual Constructive (LVC) systems, particularly the LVC Training Environment (LVC-TE). The idea is still in development with an RFI sent out in November 2019 (Marine Corps (DOD - Navy) 2019). The solicitation covers a desire for a Contemporary Operational Environment (COE) which would allow units to “interact across LVC domains as though they are physically located in the same operational environment” (Marine Corps (DOD - Navy) 2019). It is expected that LVC-TE will have system compatibility standards for use across different training platforms to create a training continuum that can operate within the Department of Defense Information Network (DODIN) (Marine Corps (DOD - Navy) 2019). Because the LVC-TE is still in development, a specific network or connection was not specified in the solicitation, it will be up to the awarded design agent to select that interoperability path.

One option to directly connect LLs is via Distributed Interactive Simulations (DIS) which are an Institute of Electrical and Electronics Engineers (IEEE) and Simulation Interoperability Standards Organization (SISO) form of connection and communication within simulators specifically. A bigger challenge of interoperability is the actual network connection across simulators and platforms. DODIN is a broad category including NMCI, Marine Corps Enterprise Network (MCEN), and Link 16, among others. The challenge will be to find a network that works across the different operating systems and communications structures. Determining the network is beyond the scope of this capstone.

F. DATA COLLECTION

The FVL LL is a keystone for experimentation to press the boundaries of technological advancement that will benefit all FVL operators. The FVL Team interviewed Dr. Molly McGuire (assistant professor of information sciences, Naval Postgraduate School) on August 16, 2021, and discussed methods of data collection currently used within experiments to better understand Human Machine Teaming (HMT) and other factors that can affect cognitive load. This capstone team tagged Dr. McGuire because her current work directly benefits and reflects how the FVL LL's experimentation capabilities can identify where automation, Artificial Intelligence/Machine Learning (AI/ML), or a hybrid of both could be beneficial in future upgrades of FVL.

When determining how and what data should be collected, experiment designers, or SMEs, must begin with the end in mind. Then, the SMEs determine what needs to be observed and how it is going to be measured. Examples of data that can be measured are reaction times, eye motion, heart rate variability, body temperature, and pupil dilation. Technology that's available in the commercial industry includes multi-screen eye trackers, body temperature sensors, galvanic skin response sensors, and various other biosensors. These data points can determine how intuitive the technology is, assist in what training methodology is best for an operator, and evaluate how much trust an average participant is willing to give to an AI's recommendation (McGuire 2021). Effectively, data collections via the right experimentations in the FVL LL identifies what processes can be automated or assisted with AI/ML to reduce the cognitive load of FVL operators and allow them to keep focus on decisions that have greater affect towards mission success and/or the preservation of lives.

G. DIGITAL TWIN

The digital twin concept is an emerging technology that has slowly been growing in industries like health, manufacturing, and energy, among others. Kvamsdal, Rasheed, and San define a digital twin "as a virtual representation of a physical asset enabled through data and simulators for real-time prediction, optimization, monitoring, controlling, and improved decision making" (2020, 21980) They go on to break it down to three pillars.

The Virtual Twin, “a virtual representation of a physical asset or a device in the cloud.” A Predictive Twin, a “physics based, data driven or hybrid models operating on the virtual twin to predict the [behavior] of the physical asset.” Lastly, a Twin Projection, an “integration of insights generated by the predictive twin into the business operation and processes.” The LL provides an opportunity for a digital twin to be used as part of the FVL life cycle to aide decision makers on the acquisitions side, when predicting maintenance parts and labor, and assessing risk while on the military operator side, the decision maker can have the ability to monitor and control in real time.

The USN has implemented a Virtual Twin to reform the speed and method for providing software updates to the Aegis system (Eckstein 2021b). The Aegis system is the missile defense system used on cruisers and destroyers, where the current software takes up several server rack space within each ship. The virtual twin already in use on USS Monterey uses half of a rack of computer server, where the software runs in the background while the ship conducts normal operations (Eckstein 2017). This allows for the ship’s crew to perform a mission, exercise, or test on the current operating version of Aegis, while the new version of the Aegis software runs in the background, taking input from the ship’s sensors real time and conducting its own battle problem without interfering with the Sailor’s combat actions. Data retrieved from the performance of the new software is pushed back to a centralized location called The Forge at the University of Maryland College Park, where the development team currently comprising of government personnel from the Naval Surface Warfare Center Dahlgren Division review and correct the code. Eventually, The Forge plans on awarding contracts for small business who have new capabilities and ideas to bring their code in for testing. The process aims to reduce the process for software patch updates to go from years to months or weeks. This reduction in timeline will provide faster solutions to avoid sending Sailors in to combat with known issues that would normally not be fixed for years (Eckstein 2021b). This is an example of what LtCol Clarke calls reducing the acquisition OODA loop.

The USN has also applied the use of a digital twin to a ship’s gas turbine engine. In this situation, the digital twin was utilized to diagnose the issue, determine where the failure originated from, and provide a replacement part. This process reduced time and

resources spent by the ship's force conducting continuous troubleshooting, while they waited for a technician to be flown out to the ship to repeat the troubleshooting and solution development process, which takes weeks (Eckstein 2021a). According to Eckstein, Vice Adm. William J. Galinis "added that there are some good digital shipbuilding tools the Navy and industry are using, but a lot of work remains to integrate these tools together and create a comprehensive digital environment that can support the entire process of Navy concept design, industry detail design and then follow-on sustainment throughout the life of the ship class."

Taking Vice Adm. Galinis' statement into consideration, the development of a LL in conjunction with the FVL design would be crucial to ensure a proper digital twin is developed. This would provide two useful functions. First, integration between the LL and the FVL systems will be seamless as both systems would be built simultaneously with integration in mind. Second, once the FVL is completed, as issues, new systems, or capabilities are added in the early stages of production, the LL can serve as the centralized location where these issues can be corrected using the digital twin.

Another function that The Forge was able to apply, was the incorporation of virtualizing systems that would not normally be compatible with Aegis. Aegis was developed by Lockheed Martin for surface combatant ships, while aircraft carriers and amphibious warships used the Ship Self-Defense System (SSDS) developed by Raytheon. In a perfect world, both combat systems would be able to interact and exchange data to develop a complete battle picture to ensure correct and timely decisions are made using all available information. This has not been the case as both systems currently do not have that capability. Using what has been learned using the virtual twin, The Forge is in the process of virtualizing the SSDS to develop software independent of their respective hardware to create an "integrated combat system that is force-wide" (Eckstein 2021b). If this is successful, it could prove that the LL's digital twin functionality could branch out to other legacy systems that the USMC currently uses. This function could create the ability to integrate combat information from all other sensors on the air, on land, and sea. The LL could build on the findings from the USN's virtual twin and provide a foundation for all other service branches to adopt, providing a world-wide integrated combat system.

H. RAPID PROTOTYPING

One of the key focus areas to delivering relevant technologies to the Marine Corps revolves around the successful implementation of short iterative upgrades. The FVL LL leverages several established methodologies to incorporate into daily operations. A hybrid of SCRUM, Agile, and previous Rapid Development studies formed the basis for the FVL LL rapid prototyping implementation. MITRE corporation evaluated Agile as a well-established method for upgrading software. MITRE also evaluated why and how integrating SCRUM helps establish stakeholder roles and desired timelines (Northern, et al. 2010).

The goal of Scrum is to “deliver a Minimum Viable Product (MVP) at the end of each Sprint, or development period” (Garzaniti, et al. 2019). By first defining requirements and breaking those down to smaller viable release requirements, FVL LL Subject Matter Experts (SMEs) determine the “Hows” of implementing those changes within each sprint. The advantage of iterative cycles lies not only with the swift delivery of products, but also in flexibility should emergent requirements or new technology present itself. Between every sprint is an opportunity to evaluate whether the tasks are still relevant or new ones need be defined. Sprint teams aim for one to four weeks maximum for each sprint or burst. A sample Rapid Prototyping process incorporating the Scrum method to Agile is shown in Figure 9. Combined with Agile’s Principle to Customer collaboration over contract negotiation, FVL LL leads with the concept of delivering products to the war fighter that matter when they matter.

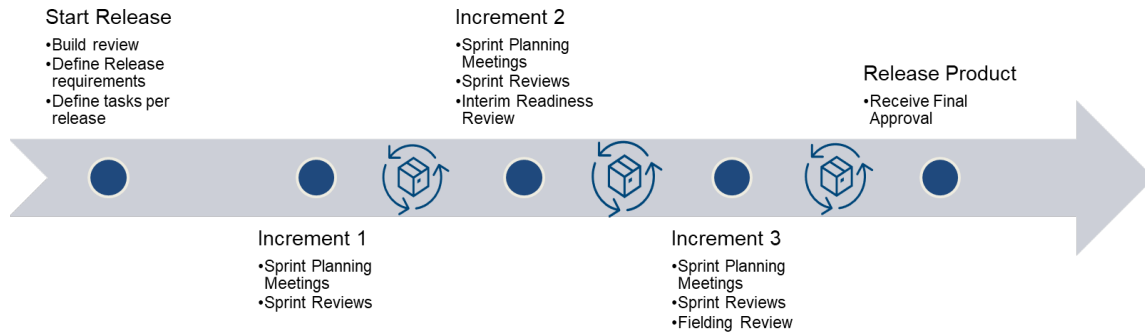


Figure 9. Sample Rapid Prototyping Process

A study of various Unmanned Aerial Vehicle indoor flight tests found successful rapid prototyping measures. For higher rates of successful implementation, several factors must be met. The vehicle must be modularized because it allows for easy addition and removal to support different types of scenarios. Unless priorities point otherwise, modular components with less modification requirements that have good reliability rates and are easily maintained should be serviced first (Liu, et al. 2012). If commercial-off-the-shelf (COTS), components are available and are fully interoperable with existing components, those are evaluated first. If none exist, and minor 3-D printing is required, the USMC also has an existing branch capable of supporting additive manufacturing, the Aviation Logistics Support (ALS) Branch (Rudder 2019). The key is to get to experimentation phases quickly to field quickly.

I. HUMAN MACHINE TEAMING

“Human-machine teaming consists of humans and autonomous machines interacting with each other as team members in a context in which the machine is capable of carrying out similar taskwork and teamwork functions of a human team member” (McNeese, Demir, and Cooke 2021). According to stakeholders, HMT will be a large part of the FVL LL in several different ways. First, the living lab will be used to research HMT and the interactions between Marines and machines. Second, The LL will be used as a training device to try to improve Human-Machine Teaming and how different types of training affect the overall performance of HMT. HMT can be broken down into 10

requirement's themes. Observability, Predictability, Directing Attention, Exploring the Solution Space, Adaptability, Directability, Calibrated Trust, Common Ground, Information Presentation and Design Process (McDermott et al. 2018).

In the article “Architectural Framework for Exploring Adaptive Human-Machine Teaming Options in Simulated Dynamic Environments” Madni and Madni (2018), developed the following framework to help visualize different teaming options (Figure 10).

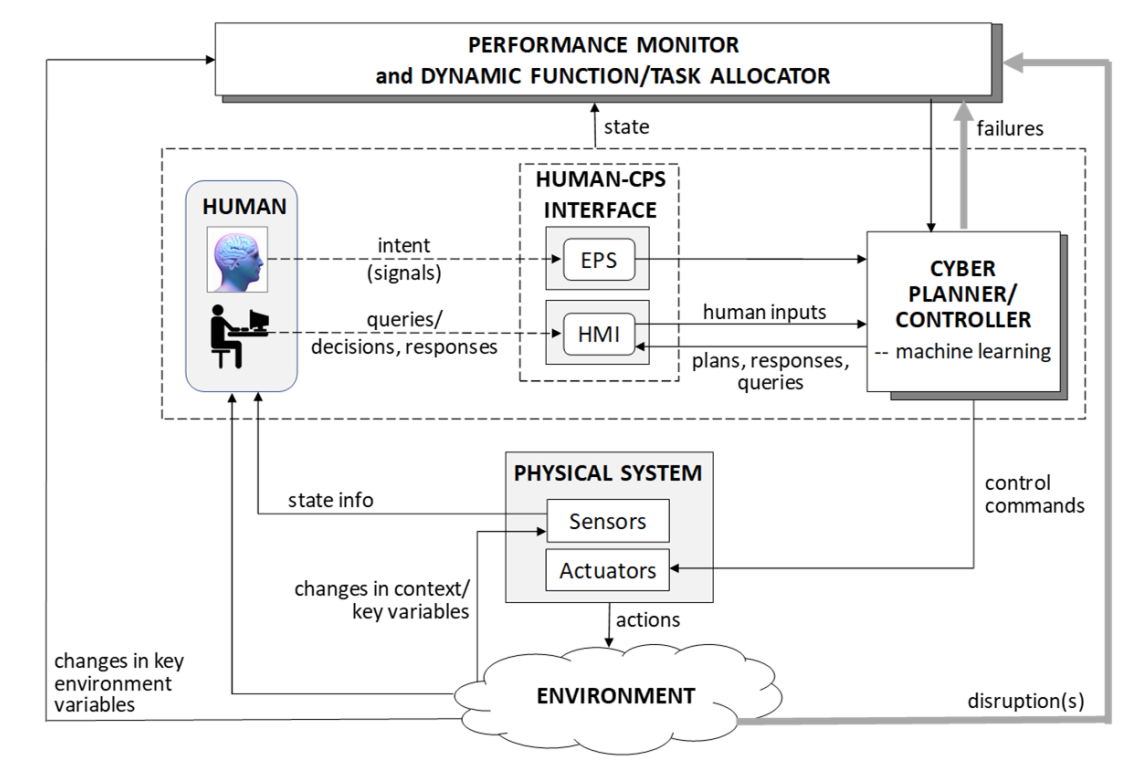


Figure 10. Adaptive HMT Architectural Framework. Source: Madni and Madni (2018).

They further define four basic roles a machine can have as a collaborator including personal assistant, teamwork facilitator, teammate (or associate), and collective moderator and are functionally defined in the following table (Table 1).

Table 1. Machines Collaborator Roles. Adapted from Madni and Madni (2018).

Role		Capability	
Personal Assistant	Do Human's Bidding	Prefetch/Retrieve	Information Respond to Queries
Teamwork Facilitator	Manage Interdependencies	Deliver Right Information	Focus Attention
Teammate (or Associate)	Substitute for Human Teammate	Offload Teammate	Perform Collaborative
Collective Moderator (and "Crowdsourcer")	Grant/Revoke "Control of the Floor"	Perform Real-Time Crowdsourcing	Generate/Create Options

J. CONCEPT OF OPERATIONS

One of the objectives of this report, is to present a CONOPS. There are many definitions for a concept of operations as shown in Figure 11. Edson and Frittmann found that the definition of a CONOPS varies depending on the target audience and that the audience is dependent "on who is writing the CONOPs, what type of CONOPs is being written, and its intended placement within the acquisition timeline" (2010, 6).

Term	Purpose	Reference
User CONOPs	[Defines] basic system requirements. [It] describes what the user wants the system to achieve and the context in which the system will be utilized	Companion & Mortimer, n.d.
System CONOPs	[Defines] how the system will actually be used and provides insight into the total system solution for both short-term and long-term requirements. Similar to ANSI/AIAA ⁷ OCD	Companion & Mortimer, n.d.
ConOps	Provides the user community a vehicle for describing their operational needs that must be satisfied by the system under development	Jost, 2007, p. 14
CONOPs	Provides “a capability description (what an operational unit does) or a prescription of what should be done.”	Nelson, 2007, p. 2
ConOps	“[Transforms] the allocated what to the how and so completes a chain all the way to an instantiation...of the system that enables capabilities.”	Nelson, 2007, p. 2
Concept of Employment	Description of “how a weapon system will be [used] in a combat environment”	Ask a Professor (AAP, 2009
CONOPs	[Provides] the vision and intent for how the system should work within an operational environment in an easy to read format.	Daniels & Bahill, 2004, p. 306, sec 4.1
Use-Case Scenarios	Similar to a CONOPs (see preceding CONOPs definition) but less ambiguous and therefore can be used directly for extracting requirements in an unambiguous way.	Daniels & Bahill, 2004, p. 307, sec 4.1

Figure 11. Perceived Purposes of CONOPs. Source: Edson and Frittman (2010).

The IEEE puts it in its simplest form, “a user-oriented document that describes system characteristics for a proposed system from the users’ viewpoint” (IEEE-SA Standards Board 1998). The IEEE goes on to break down what forms a CONOPS in detail, however the main elements described here and that are recurring themes in the previously discussed definitions are that it describes the existing system, provides justification for the new proposed system, and lastly describes the proposed system. Edson and Frittman present common misuses of the CONOPS within the military acquisition cycle. They describe that throughout the process, several CONOPS are developed throughout the phases, which ultimately causes confusion. They propose the formation of an integrated CONOPS that aligns more specifically with the IEEE definition. According to Edson and Frittman, an integrated CONOPS should provide traceability and continuity (2010). The

concept of the LL is to serve as a platform that promotes full integration of commercial and military equipment. To maintain this “full integration” mentality, it is important that the initial CONOPS conforms to these foundations so that all stakeholders can have a comprehensive understanding of the proposed system. This will establish continuity as the system goes through the acquisition life cycle (2010).

Edson and Frittman propose that a CONOPS should be fluid, being updated throughout the initial, discovery and employment phase of the acquisition cycle. The initial phase CONOPS contains the ideal form of the system and is used to guide the development of the system requirements, the initial capabilities document. The discovery phase includes the technology development (TD) phase, where technological possibilities for the system are assessed. The TD phase returns its findings on technological capabilities available or required to develop the system in the form of a capabilities development document. This starts the process for the engineering, manufacturing, and development (EMD) phase which will produce the capability production document that will list actual system capabilities and limitations. Lastly, the employment phase is when prototypes enter the low-rate initial production that generate the initial feedback for the system. At each step of this timeline, the CONOPS should be updated to reflect findings. Following this process will create a single “integrated system-level CONOPS” that supports traceability and mitigates conflicting system views by continuously referencing the same resource (Edson and Frittman 2010).

III. NEEDS ANALYSIS AND REQUIREMENTS ANALYSIS

This chapter provides the results of the needs analysis and requirements analysis of the USMC FVL LL. The needs analysis was accomplished through discussion with stakeholders and subject matter experts and was informed by the results of the literature review. The intention of the needs analysis was to come to an understanding of the purpose for the FVL LL—how it would be used, who the users would be, and what the users would need from the lab. The requirements analysis was based on the results of the stakeholder needs. The capstone team developed a set of requirements and assessed the requirements based on comprehensiveness, clarity, validity, and verifiability.

A. STAKEHOLDER NEEDS ANALYSIS

Information for the stakeholder needs analysis was obtained through virtual meetings and research conducted by the team. The team interviewed potential stakeholders and their partners to obtain details on their needs and expectations for the FVL LL. The capstone group prepared essential questions for the interviewers to answer to refine the stakeholder needs analysis. The team used their descriptive answers to determine their level of interest and influence on the project. In addition, the team researched existing LL systems to establish the basic needs of the FVL LL system. The team used the extracted data as a foundation for the requirements analysis.

1. FVL LL Stakeholders and Roles

The stakeholder analysis identified the project stakeholders, their level of interest, their level of influence, their needs, and their expectations as depicted in Table 2. This information informed the capstone team's requirements analysis and conceptual design of the FVL LL system. The team defined primary stakeholders as the groups with a high level of project interest and a medium to high level of project influence. The team identified four primary stakeholders for the FVL LL: PMA-205, PMA-276, the Service Level Program Manager, and the Lead System Engineer. The team identified secondary stakeholders as groups with a medium level of project interest and influence. The secondary stakeholders included FVL pilots and operators, LL engineers, FVL technicians, LL human machine

specialists, LL network and communications team, and LL logisticians. One tertiary stakeholder, the third party FVL systems engineers, was identified with a low level of project interest and influence.

Table 2. Stakeholder Description and Roles

Stakeholders	Role	Project Interest	Project Influence
PMA-205 Naval Aviation Training System and Ranges program office	- Schedule aviation test events - Procure access to remote labs - Train DOD pilots - Create training analysis reports - Identify processes to improve operator performance	High	Medium
PMA-276 USMC H-1 Light/Attack Helicopters program office	- Identifies new hardware or software upgrades or needs	High	High
FVL Service Level Program Manager	- Determines FVL Program Portfolio and receives funds	High	High
LL Lead Systems Engineer	- Generates and maintains System of Systems processes through requirements analysis and requirements traceability	High	High
FVL Pilots/Operators	- Execute FVL missions and daily operations	Medium	Medium
LL Engineers	- Receive or anticipate FVL modification requests - Designs, builds, and test hardware and software modifications	Medium	Medium
FVL Technicians	- Perform FVL diagnosis, repairs, and installations	Medium	Medium
LL Human Machine Specialists	- Obtain data and performs analysis on human machine trust	Medium	Medium

Stakeholders	Role	Project Interest	Project Influence
FVL LL Network & Communications Team	- Designs and maintains communication systems within simulators - Installs communication systems to replicate exact FVL communication systems - Maintains global LL training simulation network	Medium	Medium
FVL LL Logisticians	- Coordinate and organize equipment purchasing, transporting, and housing	Medium	Medium
Third Party FVL System Engineers	- Perform missions that require interfacing with FVL	Low	Low

a. Primary Stakeholders

PMA-205 Naval Aviation Training System and Ranges Program Office has high level of project interest and medium level of project influence. They will oversee scheduling aviation test events, training DOD operators, creating training analysis report criteria, and identifying processes to improve operator performance (NAVAIRa n.d.).

PMA-276 USMC H-1 Light/Attack Helicopters program office has high level of project influence and interest. They are responsible for acquiring, developing, and managing the Marine Corps rotary wing aircrafts (NAVAIRb n.d.). They will oversee identifying new hardware and/or software upgrades as needed.

The FVL service level program manager has high level of project interest and project influence. They will oversee the project and directly communicates with the sponsors and lead systems engineer. The program manager determines FVL program portfolio and receives direct funding for the program.

LL lead systems engineer has medium level of project interest and influence. They communicate with the service level program manager and the LL team members. The lead systems engineer generates and maintains System of Systems process through requirements analysis and traceability.

b. Secondary Stakeholders

FVL pilots and operators have medium level of project interest and influence. They will execute FVL missions and daily operations such as flying an aircraft using the simulator.

LL engineers have medium project interest and influence. LL engineers discuss the feasibility of the FVL requests with the lead systems engineer. They will be responsible to design, build, modify, and test hardware/ software elements.

FVL technicians have medium level of project influence and interest. Their role is to perform FVL diagnosis, repairs, and installations.

LL human machine specialists have medium level of project interest and influence. They are responsible of obtaining data and performing analysis on human machine trust.

LL network and communications team have medium level of project interest and influence. Their roles are to design, maintain, and install communication systems within simulators to replicate exact FVL communication systems. They also will maintain global LL training simulation network.

LL logisticians have medium level of project interest and influence. They will coordinate and organize equipment purchasing, transportation, and housing.

c. Tertiary Stakeholders

Third party FVL systems engineers have low level of project interest and influence. They perform missions that require interfacing with the FVL.

2. FVL LL Stakeholder Needs and Expectations

Many FVL LL stakeholders have common needs and expectations as shown in Table 3. The LL lead systems engineer, engineers, and human machine specialists need the system CONOPs and SysML models for reference documentation purposes. They will use the files to update new designs, equipment, methodologies, and integrations. The FVL service level program manager, FVL technicians, and FVL LL network and communication team need CONOPs because they will work closely on the system, but they will not be modifying the system directly. The FVL technicians will focus on repairing the simulators while the FVL service level program manager will be responsible of executing system requirements within a given budget. The FVL LL network and communications team will use CONOPs to manage connectivity between subsystems.

PMA-205 and PMA-276 expect to procure access to remote labs to test scenarios, equipment capabilities, equipment performances, and personnel training. The FVL service level program manager and the LL lead systems engineer are responsible for assigning resources appropriately and guaranteeing system requirements are met. These expectations will verify the system's capabilities and that the product is delivered on time.

PMA-205 will need the FVL LL to have training simulators that reduce pilot cognitive load while maintaining a technological competitive edge over adversaries. Some of their expectations are to identify, design, and implement realistic interference parameters for training and testing purposes.

PMA-276 will need the FVL LL to provide system validation, efficacy reports, and training analysis reports. Their expectations include, but are not limited to, providing funds for the LL, and expanding the number of remote labs.

FVL service level program manager will need the FVL LL to develop a proof of concept, CONOPS, execution timelines, and cost. Some of their expectations include delivering FVL on time and within budget, managing the execution of the LL alterations, assigning resources, and ensuring system requirements are met.

LL lead systems engineer will need a conceptual design of the FVL LL, SysML models, and systems requirements. Their expectations include achieving a fully functioning FVL LL, achieving system modularity, determining modification methods, and prioritizing tasks.

FVL pilots and operators will need the FVL LL to maximize simultaneous usage of various on-board FVL systems, identify system improvements, and familiarization with operating the aircraft. Their expectations include being able to quickly and easily access remote simulators to test new capabilities and gain realistic operational experience.

LL engineers will need a CONOPS, exact FVL hardware and software components, funds, materials, and SysML models for the FVL LL. Some of their expectations are to correct system implementation, provide new functionalities, achieve system of systems (SOS) interoperability, and achieve element compatibility with the system.

FVL technicians will need training simulators to perform new repair techniques, training/repair manuals, and CONOPS for the FVL LL. Their expectations are to identify and provide solutions to enhance aircraft hardware, physical connections, and repair procedures.

LL human machine specialists will need exact FVL system mock-up, accurate data sensors, SysML models, a CONOPS, and list of operator functions. Some of their expectations for the FVL LL are to develop test parameters, develop data gathering methods, identify data types, and analyze operator feedback.

LL network and communications team will need access to third party networks, DISA, various simulator networks or commercial providers, and SysML models. Their expectations include achieving FVL communication systems with high fidelity to real-work operations, achieving network nodes interconnectivity, and securing simulation data.

LL logisticians will need access to direct funds, list of equipment needs along with final destinations, and third party or in-house warehouse and transportation services. Their FVL LL expectations are to enhance the acquisition process, deliver components on time and within budget, guarantee system usability after transportation, and negotiate with sellers for best price.

Third party FVL systems engineers will need to be able to communicate directly with FVL team members, receive FVL LL experiment schedule, and test/scenario configuration. They will expect to provide interface requirements, interoperability requirements, system data, and SMEs for the FVL LL.

Table 3. Stakeholder Needs and Expectations

Stakeholder Number	Stakeholders	Needs	Expectations
1	PMA-205 Naval Aviation Training System and Ranges program office	- Training Simulators with extensive reach - Reduce pilot cognitive load - Maintain technological competitive edge with adversaries	- Identify and provide realistic mission scenarios - Identify, design, and implement realistic interference parameters - Schedule aviation test events - Procure access to remote labs
2	PMA-276 USMC H-1 Light/Attack Helicopters program office	- System validation - Efficacy reports - Training analysis reports	- Procure access to remote labs, - Receive analysis reports - Expand the number of remote labs - Responsible for system modification and acquisition decision-making - Establish and provide funding for LL
3	FVL Service Level Program Manager	- LL proof of concept - CONOPs - Execution timelines and costs	- Deliver on time and within budget - Manage the execution of the LL alterations - Assign resources - Ensure system performance and functionality requirements are met
4	LL Lead Systems Engineer	- Conceptual design - SysML models - System requirements	- Achieve fully functioning FVL LL - Achieve system modularity - Determine modification method and priorities - Assign resources - Ensure system performance and functionality requirements are met

Stakeholder Number	Stakeholders	Needs	Expectations
5	FVL Pilots/Operators	- Maximize simultaneous usage of various on-board FVL Systems - Identify FVL Improvements - Familiarize operating an aircraft	- Quick remote simulator access to test new capabilities - Gain realistic operational experience and training
6	LL Engineers	- CONOPs - Access to exact FVL Hardware and Software replicas - Access to funds and materials - SysML models	- Correct system implementation - Correct system performance - Test and validate new functionalities - Provide new functionalities - Achieve System of Systems interoperability - Ensure component compatibility with the system
7	FVL Technicians	- Training Simulators to perform new repair techniques - Training or Repair Manuals - CONOPs	- Identify and provide solutions to improve aircraft hardware or repair procedures
8	LL Human Machine Specialists	- Exact FVL system mock-up - Accurate data sensors - SysML models - CONOPs - List of operator functions and actions	- Develop test parameters - Develop data gathering methods - Identify data types - Analyze operator feedback - Identify pilot processes to automate or replace with Artificial Intelligence
9	FVL LL Network & Communications Team	- Access to third party networks (Marine Corps Base Network) - Defense Information Systems Agency (DISA) - Various simulator networks and/or commercial providers - SysML models	- Achieve and maintain FVL communication and network systems with high fidelity to real-work operations - Achieve and maintain network nodes interconnectivity - Secure and maintain simulation and experimentation data

Stakeholder Number	Stakeholders	Needs	Expectations
10	FVL LL Logisticians	- Access to direct funds - List of equipment needed and final destinations - 3rd party or in-house warehouse and transportation services	- Enhance acquisition process - Deliver components on time and within budget - Guarantee system usability after transportation - Negotiate with sellers for the best price
11	Third Party FVL System Engineers	- Fully functional communication with FVL team members	- Provide interface and interoperability requirements - Provide system data - Provide Subject Matter Experts

B. REQUIREMENTS ANALYSIS

The requirements analysis was conducted in three phases: requirements elicitation, requirements specification and requirements validation. The requirements elicitation phase consisted of creating a list of wants and needs. Each team member made a list from prior knowledge and from recommendations from the advisors and stakeholders. Table 3 lists stakeholders and their needs and expectations derived from the stakeholder analysis. The list of wants and needs were converted to shall statements during the requirements specification stage. At this point, the requirements were not final and still included some technical information. The requirements were put into a final state during the requirements validation phase. This process can be found in Figure 12. During the requirements validation phase, the requirements were broken into groups and subgroups, as shown in the Figure 13. The requirements are separated by type in the following sections.

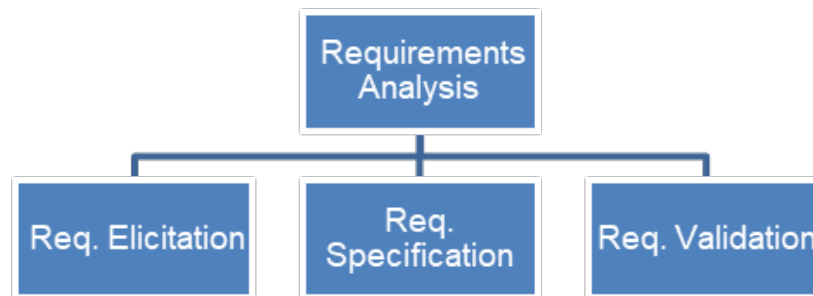


Figure 12. Requirements Analysis Process

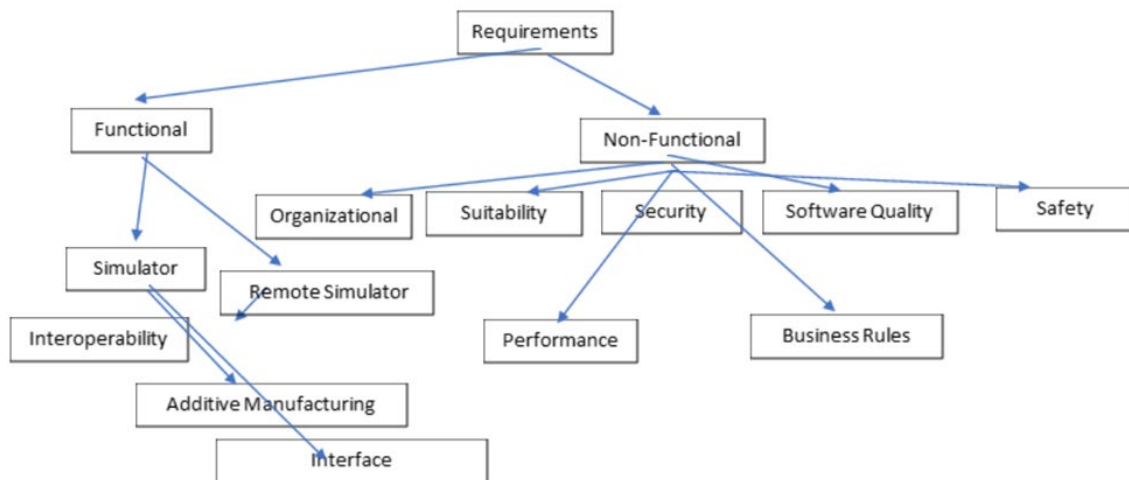


Figure 13. Requirements Analysis

1. FVL LL Functional Requirements

Table 4 lists the functional requirements for the FVL LL. The functional requirements define the basic system behavior that is expected in the early stages of the project. This set of requirements is considered comprehensive because the team was able to define them by brainstorming the tasks, expectations and stakeholder needs for the FVL LL. The initial list includes ideas from each team member, the advisors, and the stakeholders themselves, giving the requirements depth based on their inputs. These tasks, expectations and stakeholder needs were broken out into “shall” statement requirements. They are clear and concise, as they were written to allow third parties to understand them without much context. The validity of the functional requirements comes from the feedback provided to create the requirements. By having multiple people, each with different roles in the project, provide opinions on the wants and needs expected of the FVL LL, better quality requirements were created. The functional requirements are verifiable and testable because they are specific and provide enough detail to allow the systems engineer to easily pass or fail the requirement without difficulty. Test cases for each requirement could be created to provide the pass or fail feedback.

Table 4. FVL Living Lab Functional Requirements

Rqt ID	Requirement Type	Requirement	Verification Method	Stakeholder Traceability #
F1	Functional	FVL LL shall record pilot inputs into the system.	Test	1, 2
F2	Functional	FVL LL shall provide rapid prototyping services.	Demonstration	1, 2, 3, 5, 7
F3	Functional	FVL LL shall provide rapid experimentation with new and existing systems.	Demonstration	1, 2, 3, 5, 7
F4	Functional	FVL LL shall provide testing and scenario outputs into human readable format for analysis purposes.	Test	1
F5	Functional	FVL LL shall fabricate physical component changes within 48 hours so long as the physical interfaces with other system(s) is two (2) or less.	Demonstration	7, 10
F6	Functional	FVL LL shall provide no more than 3 hours of initial training for users.	Demonstration	2, 7
F7	Functional	FVL LL shall detect all inputs made by the operator with no more than a 2 second delay.	Test	6, 8
F8	Functional	FVL LL shall allow two pilots to simulate at the same time.	Demonstration	5,8
F9	Functional	FVL LL shall provide an observance feature for others to observe the pilots/users during the simulation.	Demonstration	1, 5
F10	Functional	The main FVL LL remote simulator shall use exact parts or equivalent components as used within the FVL cockpit.	Demonstration	6, 7, 8
F11	Functional	If an FVL component is found End of Life and End of Sale, the FVL LL shall design, test suitable replacement.	Test	7
F12	Functional	FVL LL shall act as a digital twin for Agile capabilities evaluation.	Demonstration	9, 10
F13	Functional	FVL LL shall utilize agile methodology to conduct rapid testing.	Demonstration	1, 2, 3, 4
F14	Functional	FVL LL shall allow for white hat hacking and cyber penetration tests.	Test	9, 10
F15	Functional	FVL LL shall be designed to analyze human machine teaming.	Analysis	8
F16	Functional	FVL LL shall be offered as a place to compare the education gained by various education approaches.	Demonstration	1, 2
F17	Functional	FVL LL shall be designed to transfer data to flow to the maintenance levels.	Test	9
F18	Functional	FVL LL shall provide an easy venue for Fleet Marine Force maintainers to try different access approaches to the FVL Family of Systems.	Demonstration	11
F19	Functional	FVL LL shall provide virtual and augmented reality capabilities to improve maintenance, flight, and weapons training.	Demonstration	7
F20	Functional	FVL LL shall have Additive Manufacturing, or 3D printing, capabilities to produce air-worthy parts.	Demonstration	7
F21	Functional	FVL LL shall allow the users/stakeholders to tailor all parts of the FVL system based on the research, development, test, evaluation, and other explorations	Analysis	2, 4

2. FVL LL Performance Requirements

Table 5, lists the performance requirements for the FVL LL. The performance requirements define how well the software system accomplishes certain functions under specific conditions. This set of requirements is considered comprehensive because the team was able to define them by brainstorming the tasks, expectations and stakeholder needs for the FVL LL. The initial list includes ideas from each team member, the advisors, and the stakeholders themselves, giving the requirements depth based on their inputs. These tasks, expectations and stakeholder needs were broken out into “shall” statement requirements. They are clear and concise, as they were written to allow third parties to understand them without much context. The validity of the functional requirements comes from the feedback provided to create the requirements. By having multiple people, each with different roles in the project, provide opinions on the wants and needs expected of the FVL LL, better quality requirements were created. The functional requirements are verifiable and testable because they are specific and provide enough detail to allow the systems engineer to easily pass or fail the requirement without difficulty. Test cases for each requirement could be created to provide the pass or fail feedback.

Table 5. FVL Living Lab Performance Requirements

Rqt ID	Requirement Type	Requirement	Verification Method	Stakeholder Traceability #
P1	Performance	FVL LL shall be a modular design, so all parts may be interchangeable for testing purposes.	Demonstration	7
P2	Performance	FVL LL shall be able to host multiple remote simulators at once.	Test	9
P3	Performance	FVL LL shall be accessible and connected over the network with minimal delay.	Demonstration/ Test	9
P4	Performance	FVL LL shall transfer data via network with no more than a 2-minute delay.	Demonstration	9

3. FVL LL Organizational Requirements

Table 6, lists the organizational requirements for the FVL LL. The organizational requirements define the vision, goals, objectives, and priorities of the FVL LL. This set

of requirements is considered comprehensive because the team was able to define them by brainstorming the tasks, expectations and stakeholder needs for the FVL LL. The initial list includes ideas from each team member, the advisors, and the stakeholders themselves, giving the requirements depth based on their inputs. These tasks, expectations and stakeholder needs were broken out into “shall” statement requirements. They are clear and concise, as they were written to allow third parties to understand them without much context. The validity of the functional requirements comes from the feedback provided to create the requirements. By having multiple people, each with different roles in the project, provide opinions on the wants and needs expected of the FVL LL, better quality requirements were created. The functional requirements are verifiable and testable because they are specific and provide enough detail to allow the systems engineer to easily pass or fail the requirement without difficulty. Test cases for each requirement could be created to provide the pass or fail feedback.

Table 6. FVL Living Lab Organizational Requirements

Rqt ID	Requirement Type	Requirement	Verification Method	Stakeholder Traceability #
O1	Organizational	Remote simulators shall be located in dense Marine populations.	Inspection	1, 5
O2	Organizational	FVL LL shall be a location to host test events for FVL simulation.	Demonstration	1, 5
O3	Organizational	FVL LL shall be a location for accurate and real-life training of FVL pilots.	Demonstration	1, 5
O4	Organizational	FVL LL analysts shall provide an analysis report within 30 days of testing.	Analysis	6
O5	Organizational	FVL LL shall have storage facility for raw materials, Commercial off the Shelf (COTS), or Government off the shelf (GOTS) system components.	Demonstration	10
O6	Organizational	FVL LL network communications shall not be intercepted, interpreted, or altered in any way (must be secure communications).	Demonstration	9
O7	Organizational	FVL LL shall interact with/will work with the NavalX Tech Bridges to share technology and best practices throughout the Navy.	Test/ Demonstration	1
O8	Organizational	FVL LL physical access shall be limited to individuals with the appropriate clearances.	Inspection	1

4. FVL LL Interoperability Requirements

Table 7, lists the interoperability requirements for the FVL LL. The interoperability requirements define the ability to share information and services. This set of requirements is considered comprehensive because the team was able to define them by brainstorming the tasks, expectations and stakeholder needs for the FVL LL. The initial list includes ideas from each team member, the advisors, and the stakeholders themselves, giving the requirements depth based on their inputs. These tasks, expectations and stakeholder needs were broken out into “shall” statement requirements. They are clear and concise, as they were written to allow third parties to understand them without much context. The validity of the functional requirements comes from the feedback provided to create the requirements. By having multiple people, each with different roles in the project, provide opinions on the wants and needs expected of the FVL LL, better quality requirements were created. The functional requirements are verifiable and testable because they are specific and provide enough detail to allow the systems engineer to easily pass or fail the requirement without difficulty. Test cases for each requirement could be created to provide the pass or fail feedback.

Table 7. FVL Living Lab Interoperability Requirements

Rqt ID	Requirement Type	Requirement	Verification Method	Stakeholder Traceability #
I1	Interoperability	FVL LL shall provide 24/7 physical and remote VPN access to the various remote simulators.	Demonstration	9
I2	Interoperability	FVL LL shall start up and be ready for use within 10 minutes of booting.	Test	8
I3	Interoperability	FVL LL shall be a modular design, so all parts may be interchangeable for testing purposes.	Test/ Demonstration	5, 6
I4	Interoperability	FVL LL shall be compatible with scenarios designed around real-world scenarios to aid in providing an accurate simulation.	Test	5
I5	Interoperability	FVL LL shall contain and maintain formal MBSE models of many FVL Family of Systems capabilities, which support development tradeoff analyses.	Analysis	4
I6	Interoperability	FVL LL shall be able to host multiple remote simulators at once.	Demonstration	9

Rqt ID	Requirement Type	Requirement	Verification Method	Stakeholder Traceability #
I7	Interoperability	FVL LL shall allow technicians to make modifications that take no longer than 3 full business days.	Test/ Demonstration	7
I8	Interoperability	FVL LL shall be accessible and connected over the network with minimal delay.	Demonstration	9
I9	Interoperability	FVL LL shall transfer data via network with no more than a 2-minute delay.	Test/ Demonstration	9
I10	Interoperability	FVL LL shall receive confirmation of sent/receive messages from connected remote labs.	Test/ Demonstration	9
I11	Interoperability	FVL LL shall operate through cellular network or wireless network to avoid having to hardwire equipment together.	Demonstration	9
I12	Interoperability	FVL LL wireless network shall work overseas.	Test/ Demonstration	9
I13	Interoperability	FVL LL modular components shall be evaluated to ensure minimal physical interfaces to ensure quick and simple installation.	Demonstration	7, 9
I14	Interoperability	FVL LL shall have compatible CONOPS and Requirements.	Analysis	4
I15	Interoperability	FVL LL shall use Cameo Systems Modeler to create formal models.	Analysis	4
I16	Interoperability	FVL FoS shall support the generation of sensor and movement data.	Demonstration / Inspection	8
I17	Interoperability	FVL LL software shall incorporate static code analysis tools into the continuous integration development environment to ensure secure and effective coding practices are adhered to.	Demonstration / Analysis	9
I18	Interoperability	FVL LL software shall be compatible with new and existing systems.	Test/ Demonstration	1, 8
I19	Interoperability	FVL LL shall provide instantaneous usable raw data to competent local points for processing.	Test	2
I20	Interoperability	FVL LL shall leverage web-enabled systems for remote access	Demonstration	9
I21	Interoperability	FVL LL shall check for a weekly software upgrade availability.	Inspection	9
I22	Interoperability	FVL LL software shall operate across time-zones with no impact.	Test/ Demonstration	9
I23	Interoperability	FVL LL shall track software changes (good CM/DM practices).	Inspection	9
I24	Interoperability	FVL LL shall meet all applicable U.S., DOD, IEEE, etc., standards and specifications: DOD Instruction 8510.01, "Risk Management Framework for DOD Information Technology"	Analysis/ Inspection	1, 4

Rqt ID	Requirement Type	Requirement	Verification Method	Stakeholder Traceability #
		DOD Instruction 5010.40, "Managers' Internal Control Program Procedures."		
I25	Interoperability	FVL LL new components shall go through a specific testing process (specified by the Test Engineer and Lead Systems Engineer) before it is set for use.	Test/ Demonstration	7
I26	Interoperability	FVL LL shall retain all data rights pertaining to any software altered, created in support of the lab.	Test	9
I27	Interoperability	FVL LL minor software updates shall be ready for fielding within 48 hours or less, to include any testing and acceptance procedures.	Test/ Demonstration	9

5. FVL LL Suitability Requirements

Table 8, lists the suitability requirements for the FVL LL. The suitability requirements define the ability of the system to meet the needs of the stakeholder or user. This set of requirements is considered comprehensive because the team was able to define them by brainstorming the tasks, expectations and stakeholder needs for the FVL LL. The initial list includes ideas from each team member, the advisors, and the stakeholders themselves, giving the requirements depth based on their inputs. These tasks, expectations and stakeholder needs were broken out into "shall" statement requirements. They are clear and concise, as they were written to allow third parties to understand them without much context. The validity of the functional requirements comes from the feedback provided to create the requirements. By having multiple people, each with different roles in the project, provide opinions on the wants and needs expected of the FVL LL, better quality requirements were created. The functional requirements are verifiable and testable because they are specific and provide enough detail to allow the systems engineer to easily pass or fail the requirement without difficulty. Test cases for each requirement could be created to provide the pass or fail feedback.

Table 8. FVL Living Lab Suitability Requirements

Rqt ID	Requirement Type	Requirement	Verification Method	Stakeholder Traceability #
S1	Suitability	FVL LL shall be easy to maintain (Maintainability).	Demonstration	7
S2	Suitability	FVL LL shall be user oriented (Usability).	Demonstration	7
S3	Suitability	FVL LL shall have a quarterly routine maintenance.	Demonstration	7
S4	Suitability	FVL LL shall operate in a year-round condition and environment.	Demonstration	7
S5	Suitability	FVL LL shall have the capability to continue functioning even when a new component is being added (meaning there is no down time in order to add a new component).	Test/ Demonstration	7
S6	Suitability	FVL LL shall be customizable based on changing wants and needs of the FVL.	Demonstration	1-11
S7	Suitability	FVL LL shall request user/stakeholder feedback in all stages of design, to include CONOPS and Requirements creation.	Analysis	4, 8
S8	Suitability	All server racks shall have 45 inches of clearance in front and back of the racks.	Inspection	7, 9
S9	Suitability	The server equipment electrical power supply shall be tied to a smart UPS with isolated grounding.	Inspection	7, 9
S10	Suitability	All server equipment shall be grounded to the rack.	Inspection	7, 9
S11	Suitability	All racks shall be bonded to the building ground and the earth.	Inspection	7, 9
S12	Suitability	Hardware shall be compatible with new and existing systems.	Inspection	7, 9
S13	Suitability	FVL LL shall notify operator of malfunctions within 1 minute of occurrence.	Test/ Demonstration	7, 9
S14	Suitability	The FVL LL shall have an automatic safety mechanism at a circuit shortage.	Inspection	7, 9
S15	Suitability	The FVL LL shall maintain internal heat of primary system and notify operator for abnormalities in temperature change.	Inspection	7, 9
S16	Suitability	FVL LL shall use a power generator to properly shut down the system in case of an electrical outage.	Inspection/ Test	7, 9
S17	Suitability	FVL LL equipment racks shall be bolted down into true floor and rated for earthquake proofing.	Inspection	7, 9
S18	Suitability	FVL LL shall utilize plenum rated cables traversing under raised flooring or in above cable ducts.	Inspection	7, 9
S19	Suitability	FVL LL shall provide a place to try low risk hardware tradeoffs and evaluations.	Test/ Inspection	7, 9

IV. SYSTEMS ANALYSIS AND CONCEPTUAL DESIGN

Findings from the needs and requirements analysis were compiled and developed into the conceptual design of the LL. This chapter details the context diagrams, process flow diagrams, necessary resources, and skills to support the system, an overview of the system's life cycle, and an analysis of the system. All components of the chapter constitute a high-level conceptual design of the FVL LL including a method for analysis.

A. SYSTEM VIEWS

Figure 1 (from Chapter I) illustrates an OV-1 context diagram for the FVL LL SOS. It details strong candidate USMC aviation sites that could house remote simulators that are all part of the overall system, while NPS serves as the headquarters for the LL system. As NPS students knowing there will be future capstone projects on the FVL LL, the team selected NPS as a candidate for the main site following the successes of The Forge being run from the University of Maryland. Ultimately, the main site should be selected based on what best meets the USMC's needs. Each location would contain simulators, either modular or remote, but any can add technicians and/or rapid prototyping to their local system. All simulators will have the ability to connect for demonstrations, training, or for practice joint simulations with other system simulators. This interoperability is critical for the whole system to operate as one entity and prepare Marines, sailors, and pilots for joint missions.

The capstone team developed Block Definition Diagrams (BDDs) for the FVL main site as well as remote sites. Figure 14 details the inputs to the FVL LL main site including stakeholders, remote sites, hardware, and information. Outputs of the main site include information flowing back to the stakeholders and remote sites.

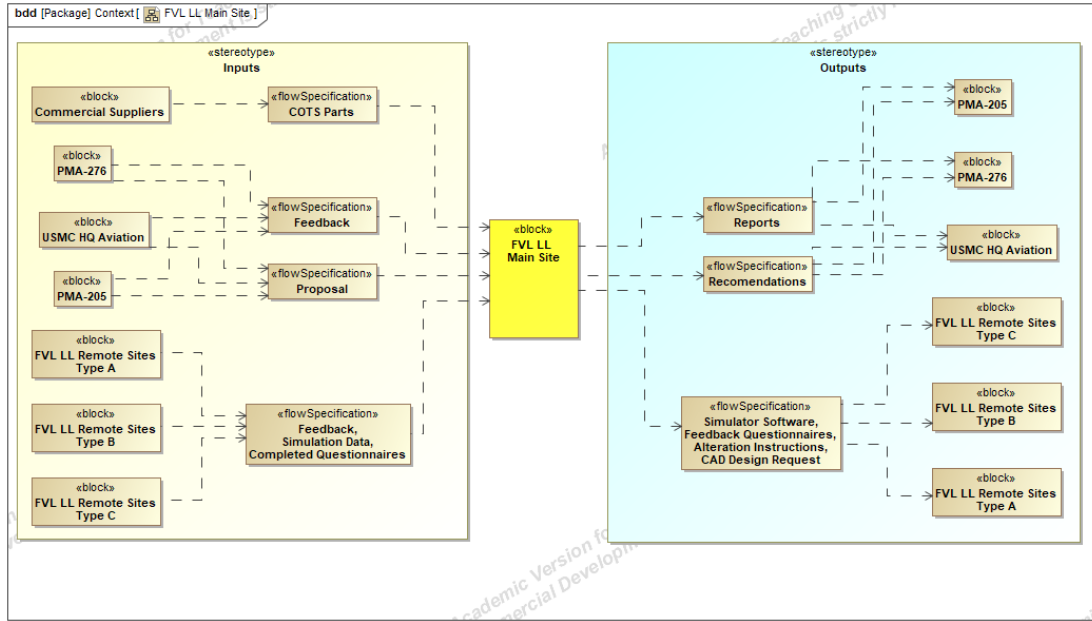


Figure 14. Block Definition Diagram FVL LL Main Site

The three sample sites are potential configurations for the USMC but a benefit of the LL is that sites can pick and choose what capabilities fit their needs. Remote site type A is a sample site containing local squadrons of fleet pilots, test and evaluation pilots, modularity technicians, and simulation technicians. Figure 15 is a BDD for a type A remote site that has the same capabilities as the main site. However, as a remote site, it does not have the input of the stakeholders and does not send outputs directly to them. Instead, outputs flow to fleet pilots and back to the main site for analysis and compilation.

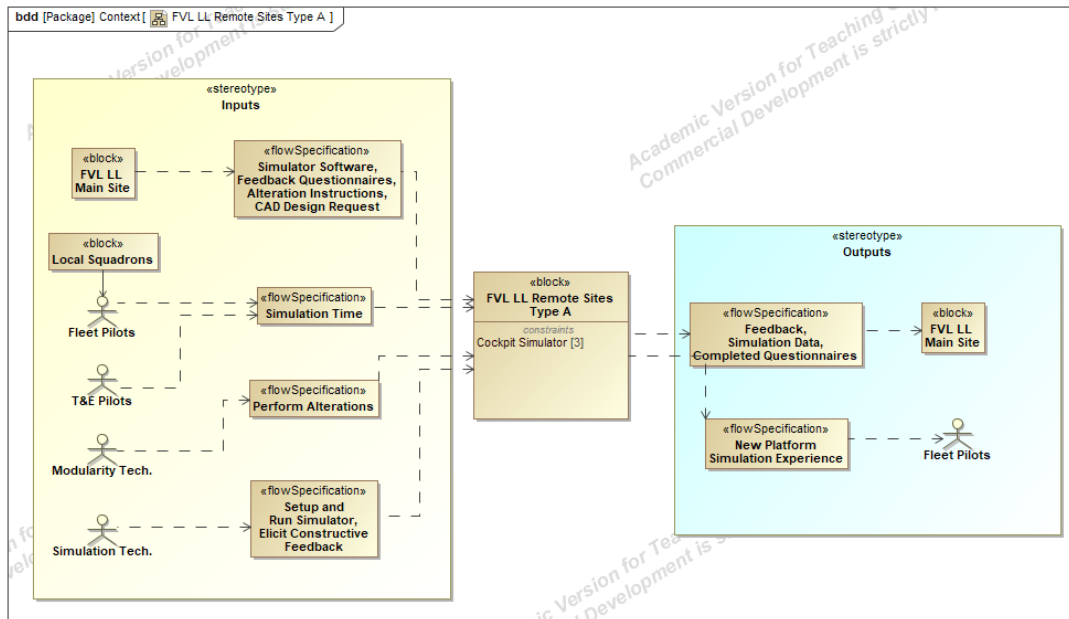


Figure 15. Block Definition Diagram Remote Site Type A

A type B remote site, shown in Figure 16, only has fleet pilots and simulation technicians, differentiating it from a type A site. Therefore, the simulation technician is responsible for alterations to the system as well as all simulator work. Outputs are the same as those from a type A site, information flowing back to the main site and updates to the fleet pilots.

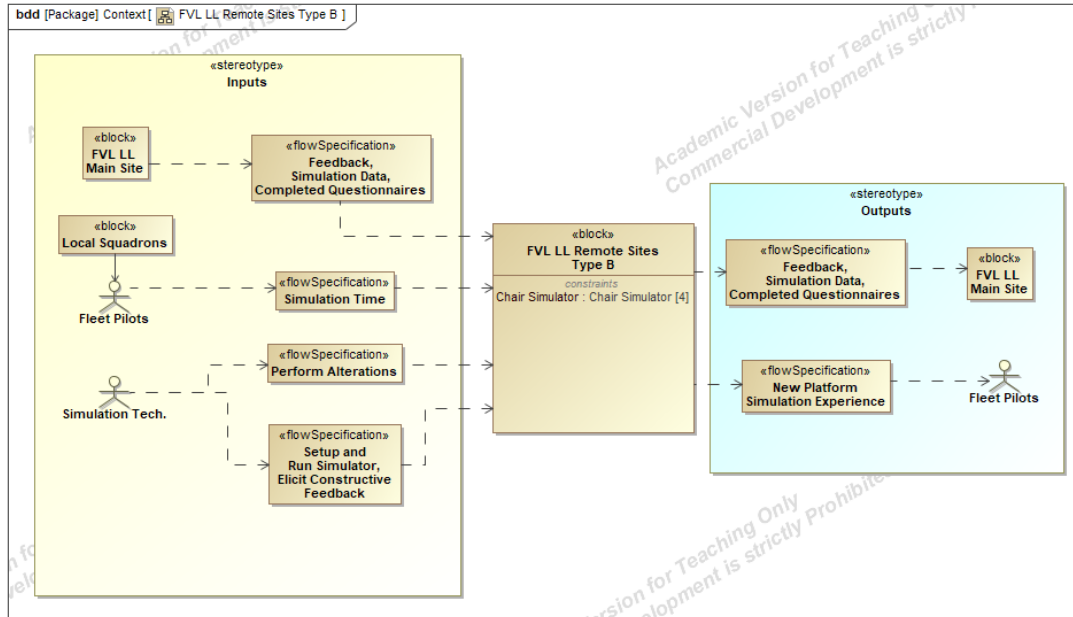


Figure 16. Block Definition Diagram Remote Site Type B

A type C remote site is very different from the others with a Command representative on site along with the fleet pilots, as shown in Figure 17. The representative serves a similar function as the two types of technicians, but may not have the same technical background, so they focus on running the simulator and do not do as much repair or development work. Type C sites could be at smaller and/or more remote locations such as Iwakuni, Japan, New River, NC, and Oahu, HI.

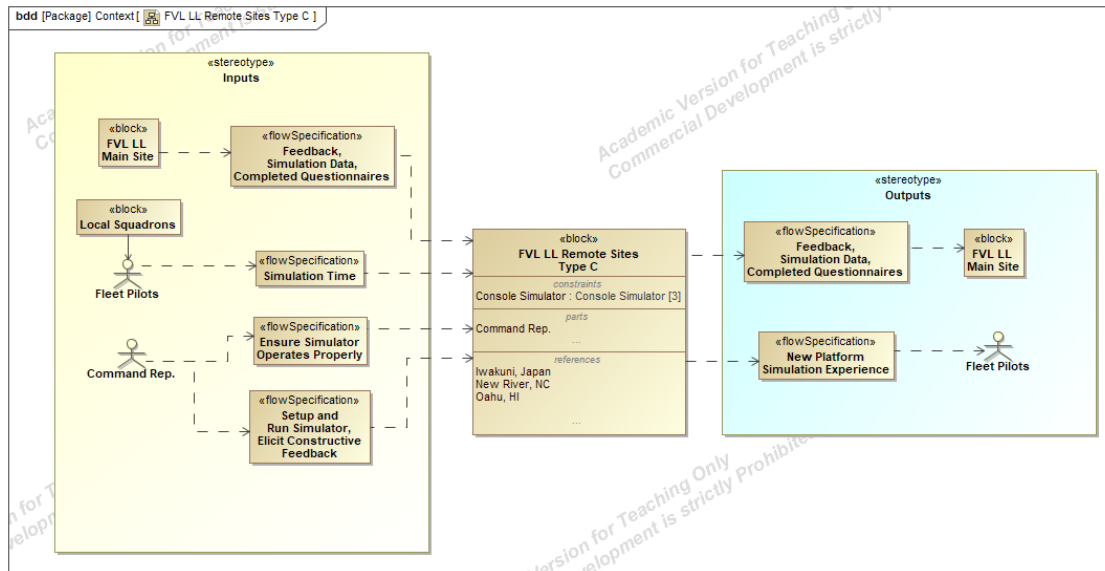


Figure 17. Block Definition Diagram Remote Site Type C

Figure 18 shows how the hierarchy of the LL as a SOS. The constraints are potential simulators at each type. The parts are actors, other equipment, and capabilities at each site. References are ideas for locations for each type.

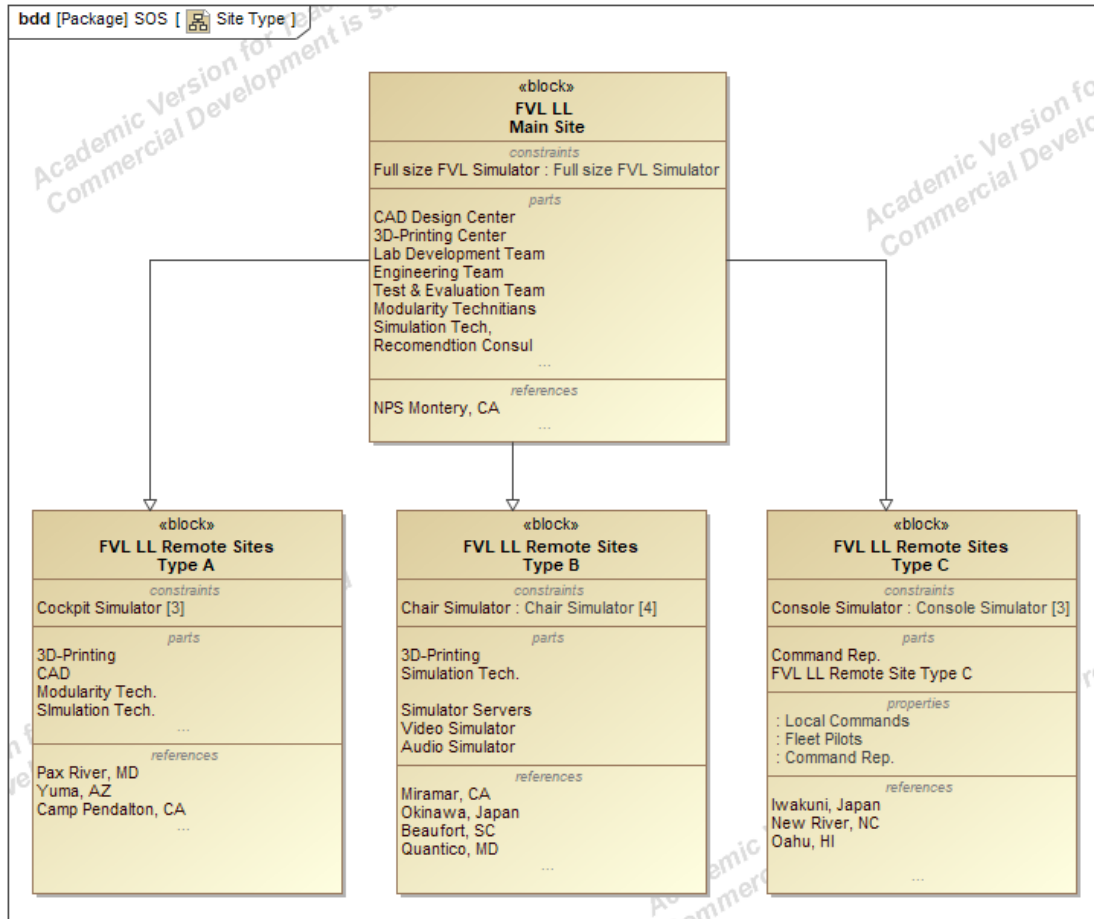


Figure 18. Block Definition Diagram System of Systems Remote Site Architecture

B. FUNCTIONAL VIEWS

This section contains functional views developed in the Cameo Enterprise Architecture modeling platform. These models should be used and updated throughout the life cycle of the LL. To start, Figure 19 is a functionality description of the LL with personnel and equipment that are located across all the sites and the capabilities they can perform. Figure 20 details how the personnel groups in Figure 19 work together to allow ideas, reports, and upgrades flow between them and ultimately into production or onto the shelf. The internal resources needed to accomplish these functions are shown in Figure 21 along with how information flows between them.

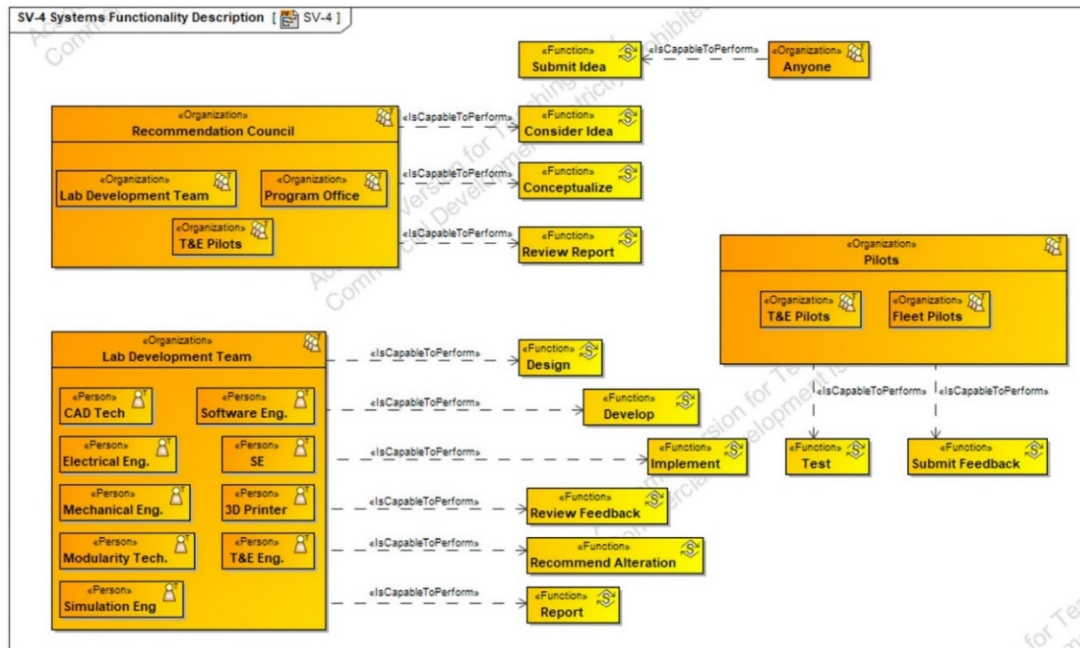


Figure 19. System Functionality Description SV-4

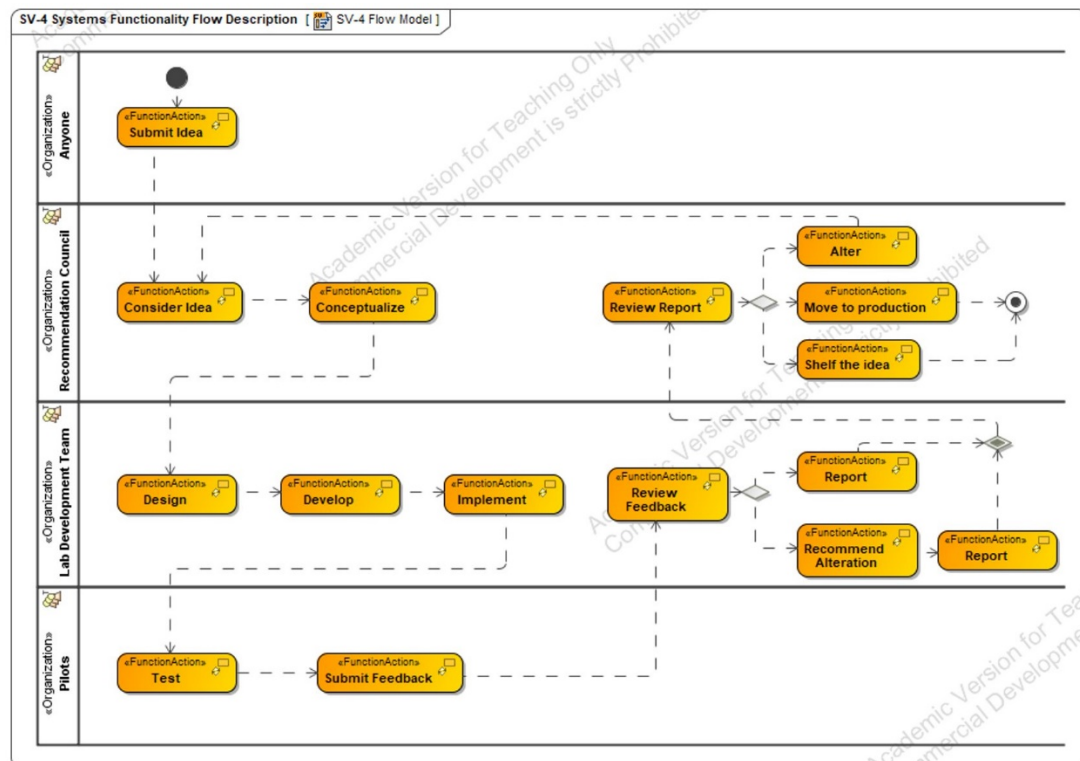


Figure 20. Systems Functionality Flow Description SV-4

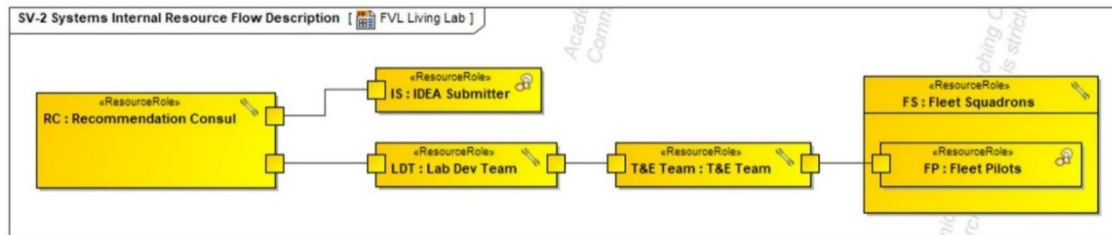


Figure 21. Systems Internal Resource Flow Description SV-2

The LL main site can be broken down with each capability, or function, detailed in Figure 22. Figures 23–25 show the functions of each respective remote type. Many of the sites have common functions with some broken down in their respective figures and others further detailed in Figures 26–31. These functions are a guideline for how actions could flow and work in the LL system. When the system is developed and these steps can be tested, adjustments should be made to optimize the functional flow.

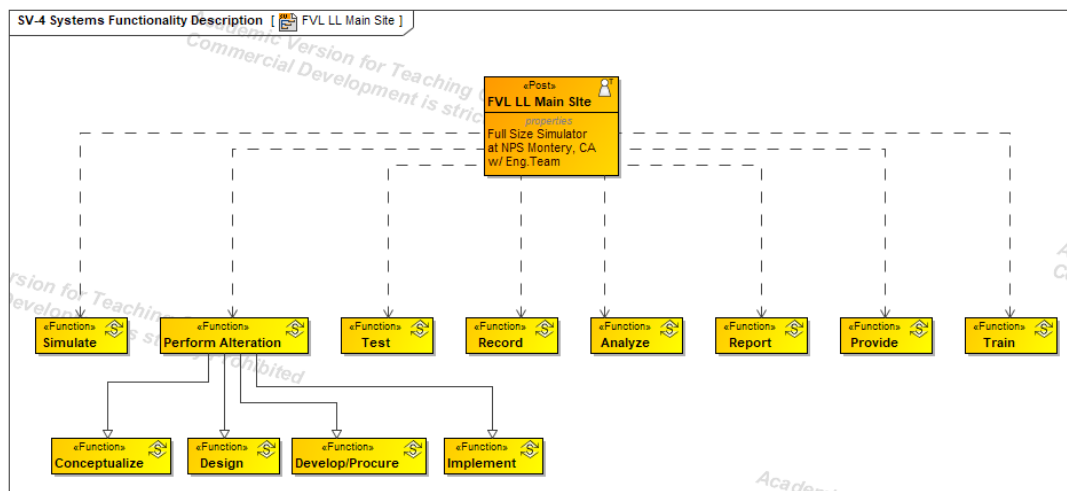


Figure 22. System Functionality Description FVL LL Main Site

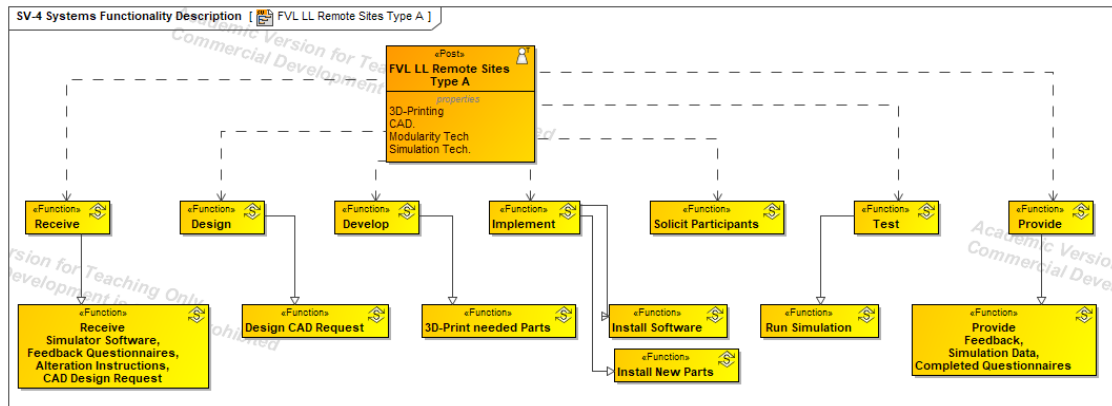


Figure 23. System Functionality Description FVL Remote Site Type A

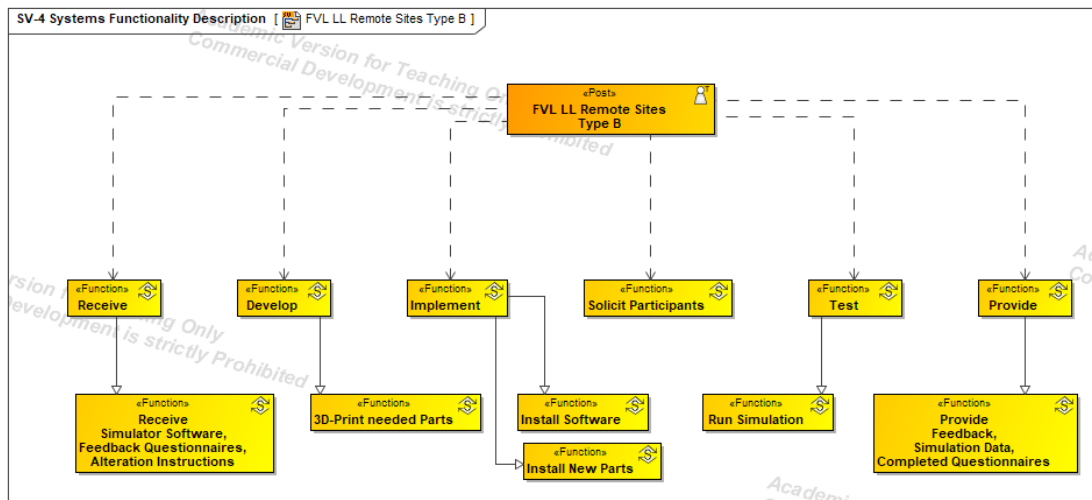


Figure 24. System Functionality Description FVL Remote Site Type B

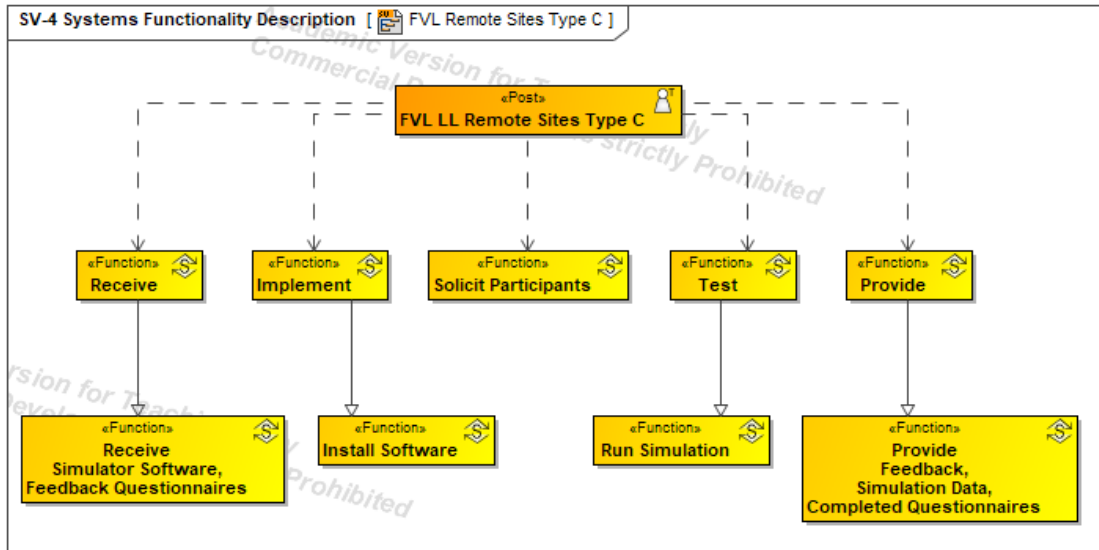


Figure 25. System Functionality Description FVL Type C

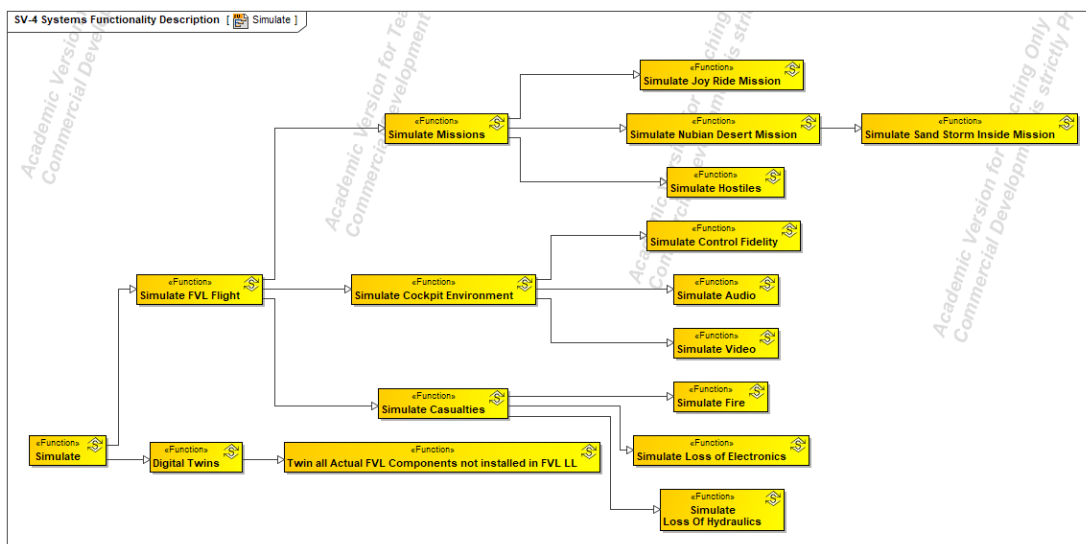


Figure 26. System Functionality Description Simulate Action

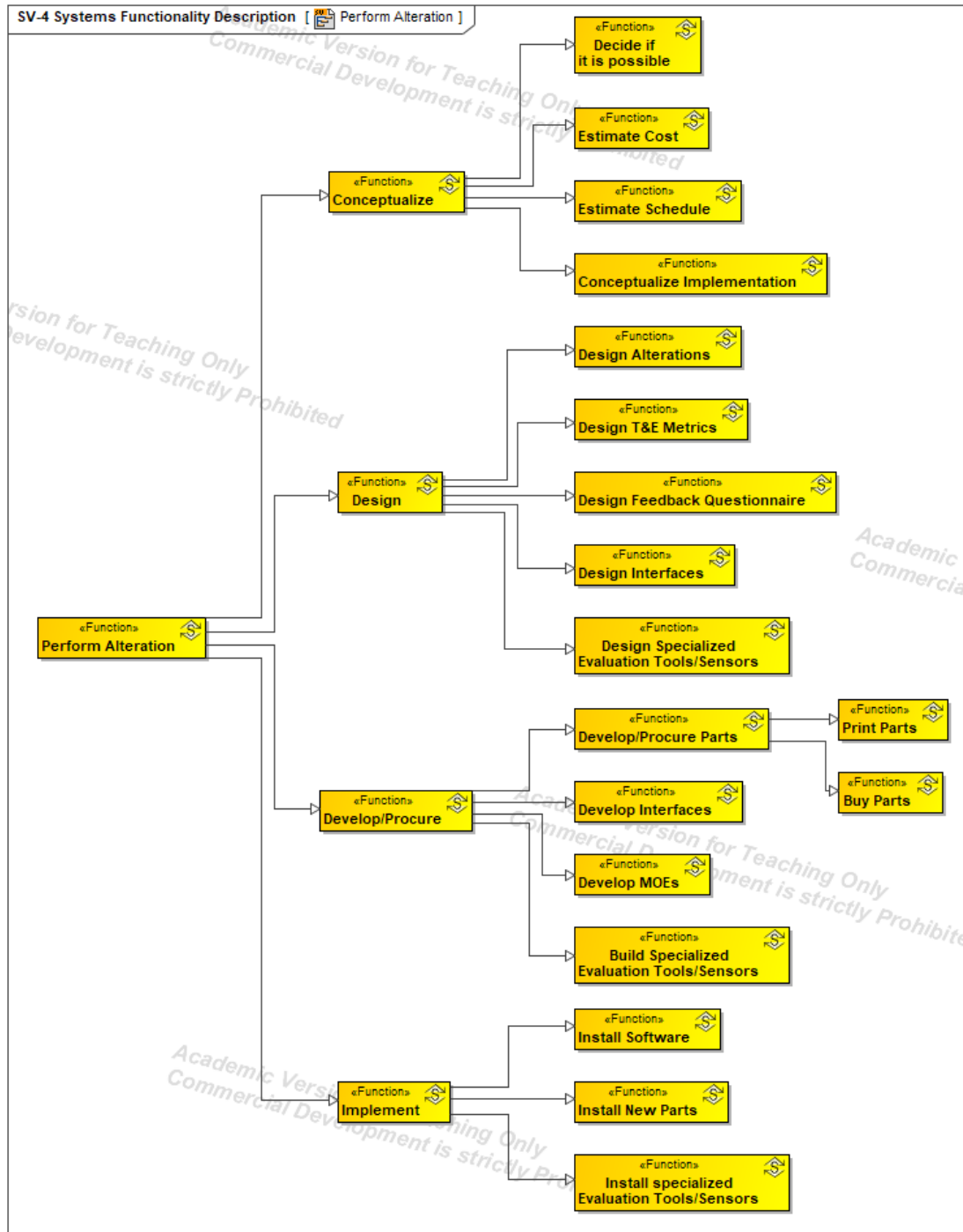


Figure 27. System Functionality Description Perform Alteration Action

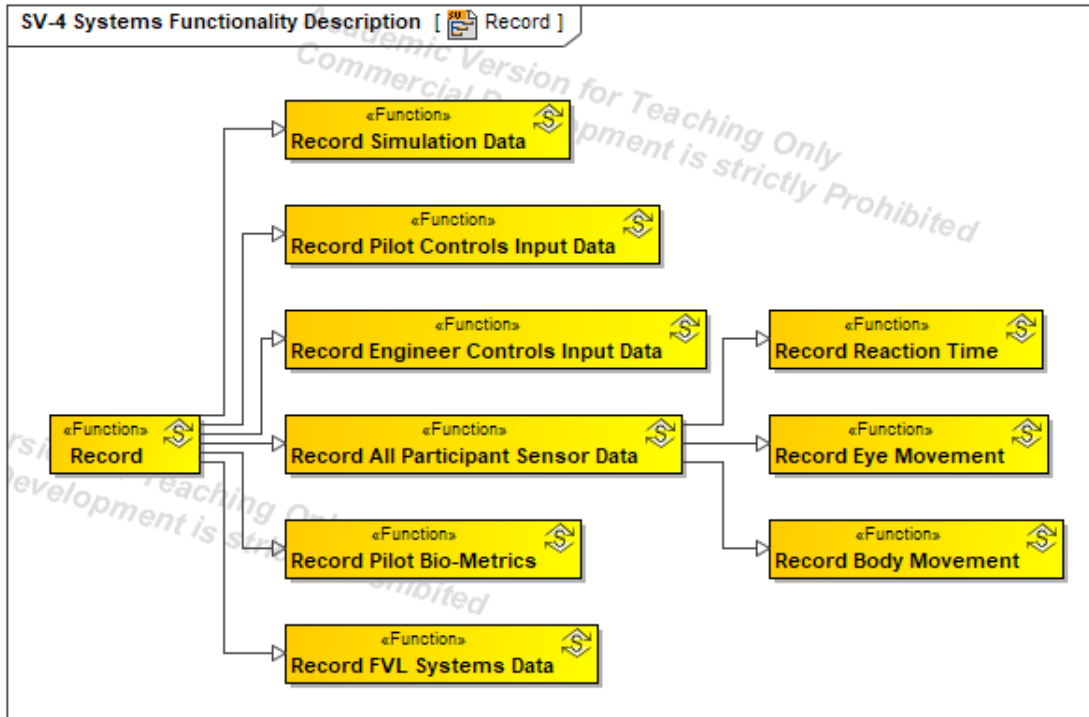


Figure 28. System Functionality Description Record Action

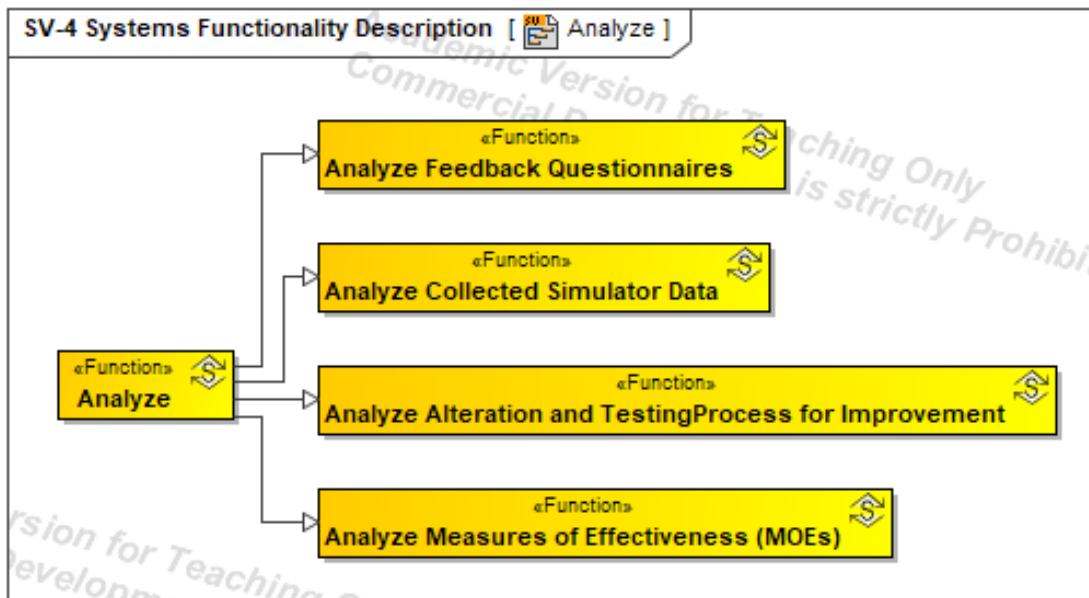


Figure 29. System Functionality Description Analyze Action

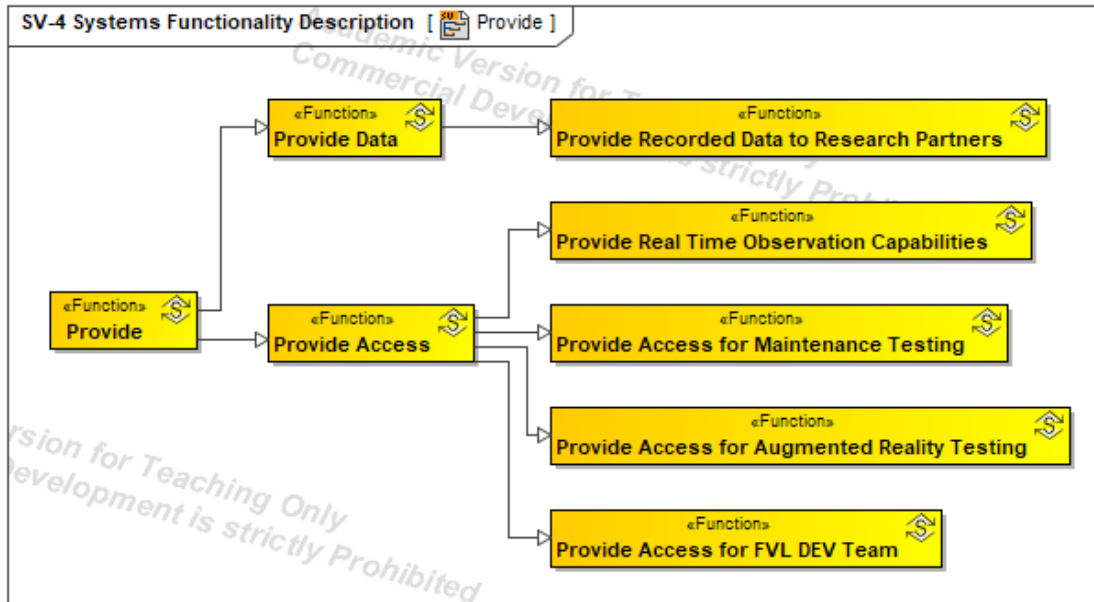


Figure 30. System Functionality Description Provide Action

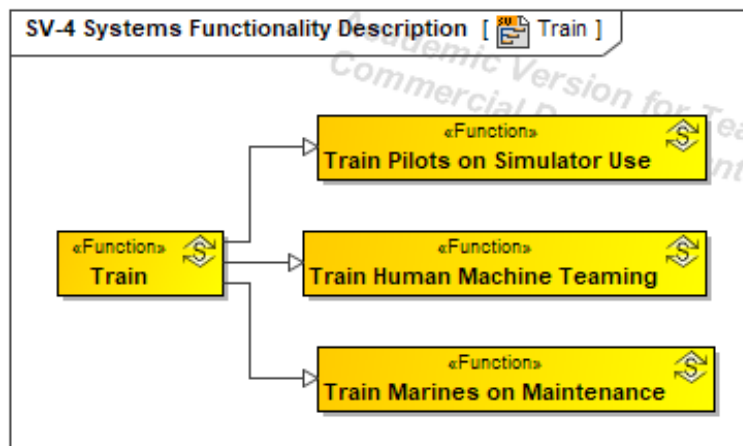


Figure 31. System Functionality Description Train Action

C. PHYSICAL VIEWS

The structural components of the FVL LL are based on the defined system requirements. The system architecture encapsulates external systems including commercial vendors and other DOD entities because FVL LL is a SOS. The physical block diagrams may be modified during planning through developmental stages of the system life cycle as requirements are updated.

The team created a Block Definition Diagram for the FVL LL which consists of the physical elements “to express information about a system’s structure” (Delgatti 2014, 23) as depicted in Figure 32. The master computer connects to and controls the LL devices. The power system supplies electricity to the integrated LL components. The communication system encapsulates network for low latency between data transmission or receive and security to ensure information is not leaked. The remote simulators are used to conduct experiments and training while the data management system is used to collect and distribute data across systems. The rapid manufacturing tools such as 3D printing and welding tools are essential for quick prototyping of parts. There are also internal staff including administrators, technicians, logisticians, and engineers who are directly involved in running the FVL LL. The modular components tie into the FVL LL as crucial and spare parts. The physical environment including safety, security, and building is to facilitate the FVL LL. There are also external factors such as suppliers, operators, and sponsors who deliver materials, control remote simulators, and specify requirements, respectively. Figure 33 shows the interfaces between the different teams to ensure all physical elements in Figure 32 can work together to achieve the mission.

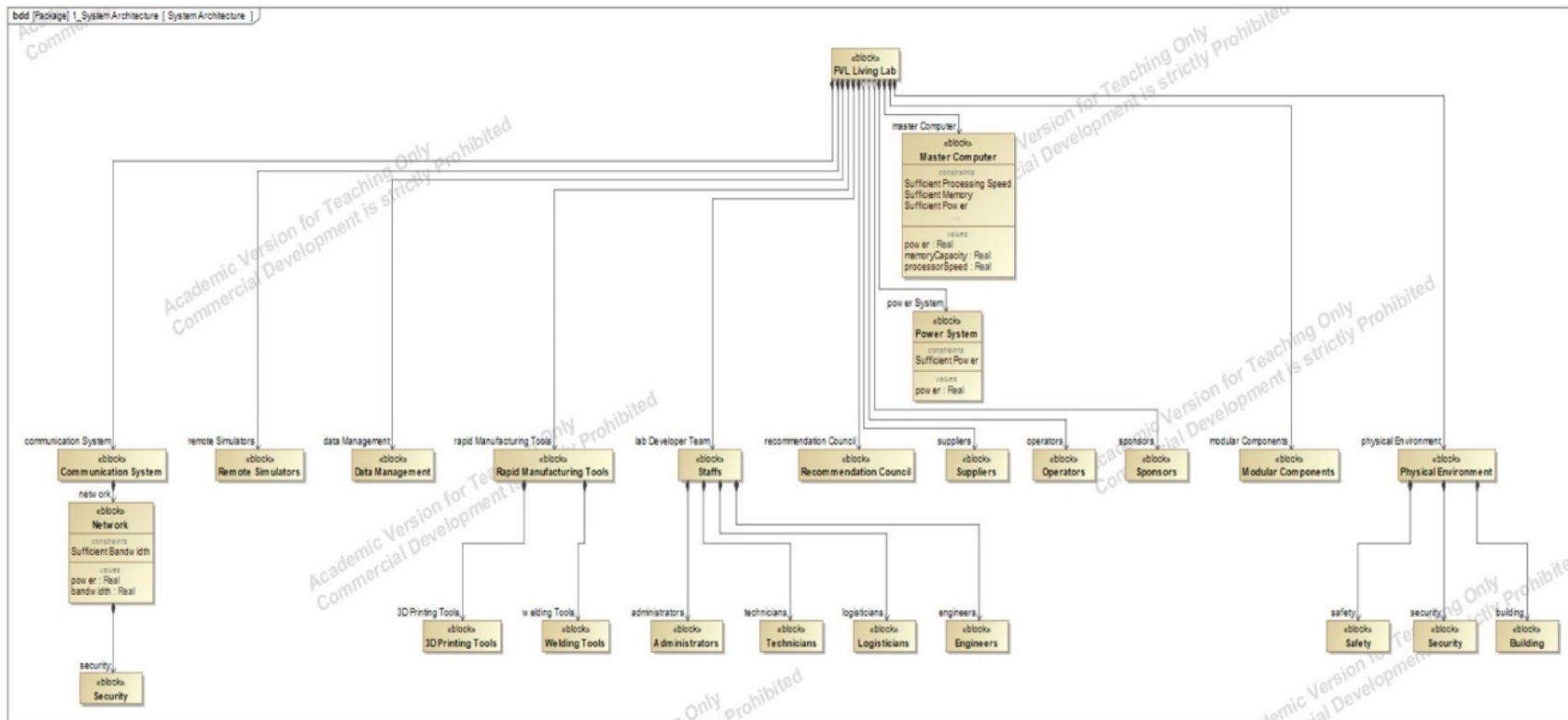


Figure 32. FVL Living Lab Block Definition Diagram

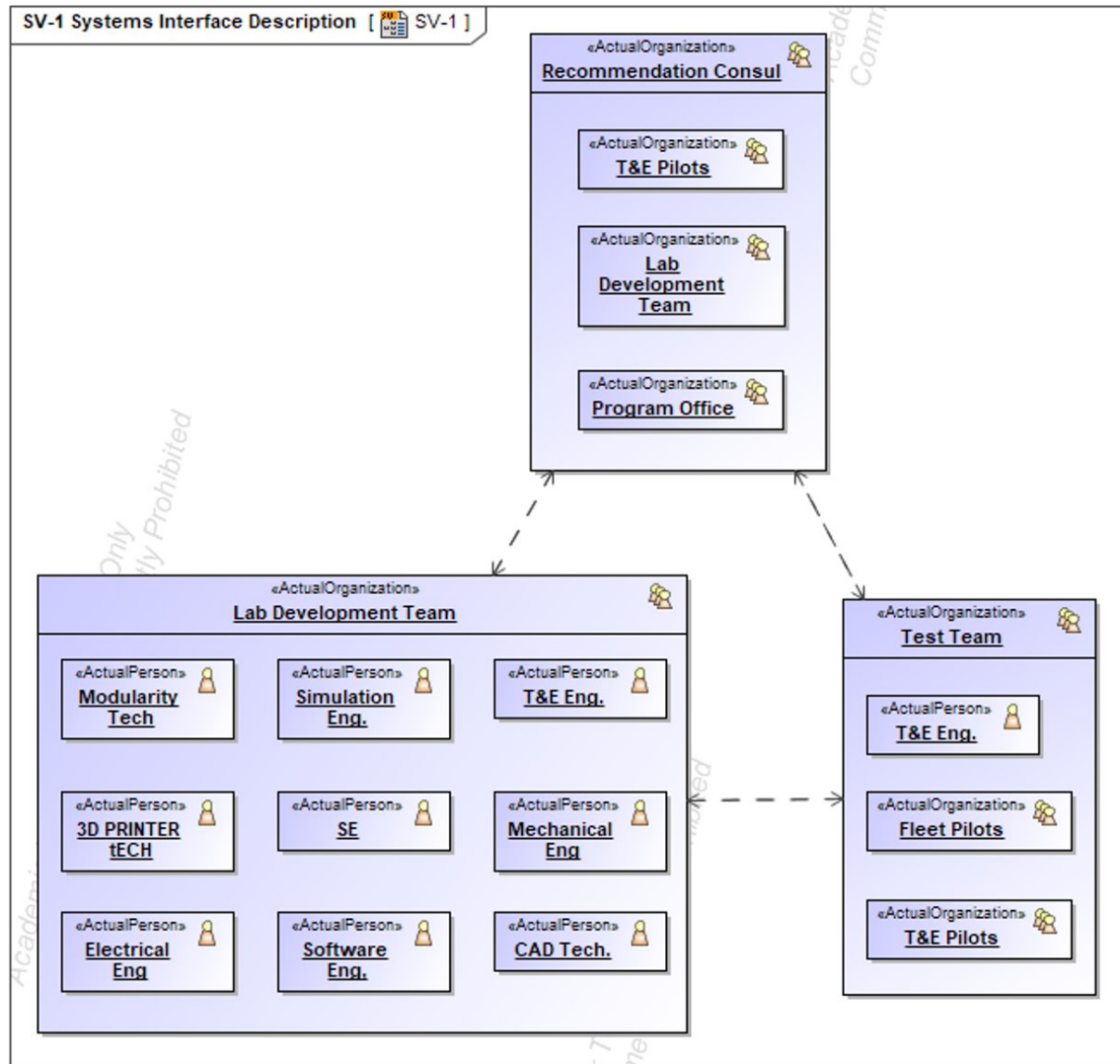


Figure 33. System Interface Description SV-1

The main LL site and different types of remote sites can be broken down and detailed with their Internal Block Diagrams (IBDs). Figures 34–37 show the internal components, all actors, content flowing between, and actions of each site. It is important to note the significance of information flow between the remote sites and the main site. Different actions and functions occur at the different sites but the core functions of information and data flow occur at all sites. As the FVL LL is further developed, these designs should be reviewed and updated.

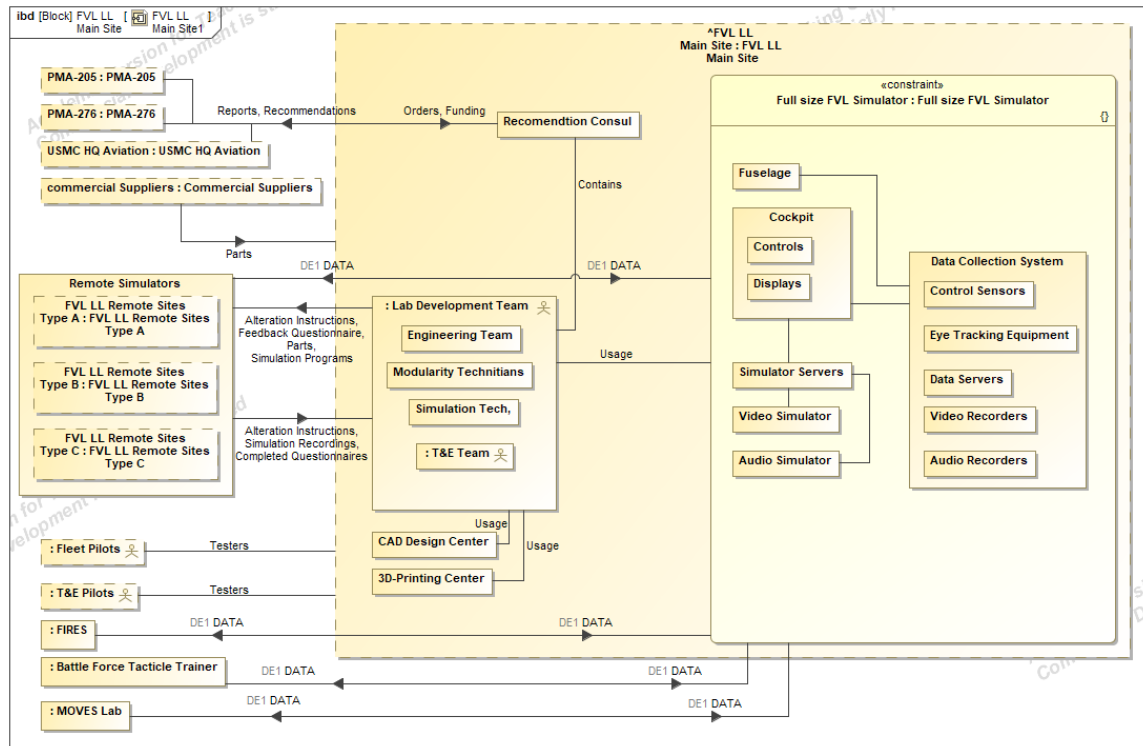


Figure 34. Internal Block Diagram FVL LL Main Site

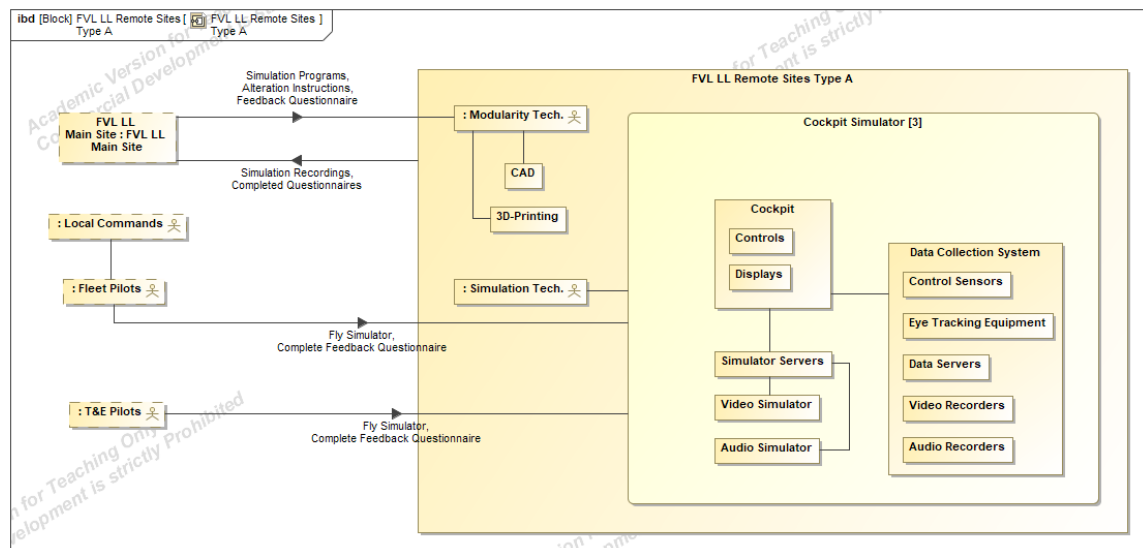


Figure 35. Internal Block Diagram Remote Site Type A

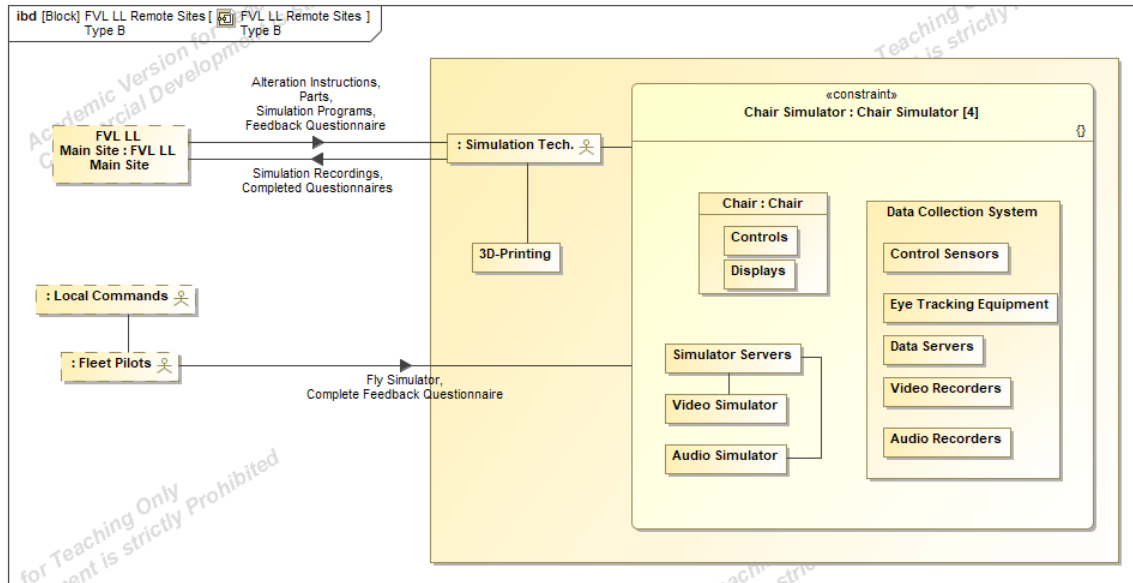


Figure 36. Internal Block Diagram Remote Site Type B

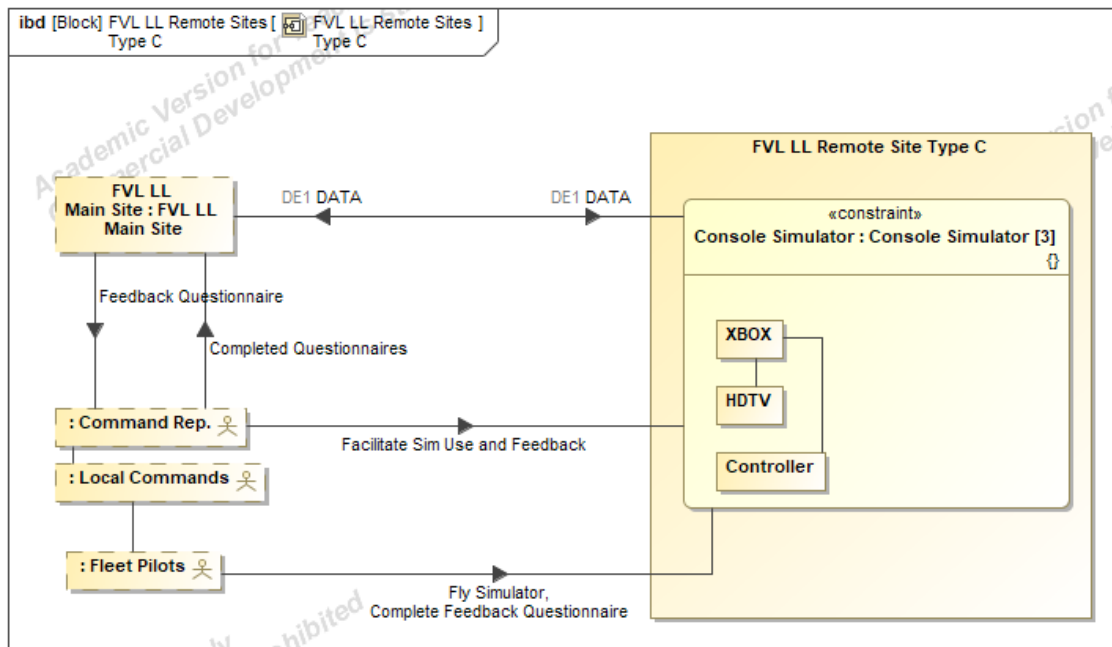


Figure 37. Internal Block Diagram Remote Site Type C

D. SYSTEM LIFE CYCLE

Considering the life cycle of the FVL LL, it follows the general outline of Planning, Develop, Operation, and finally Disposal. This capstone covers a section of the planning

portion including the requirements definition, stakeholder, requirements analysis, needs analysis, and the CONOPS. Future work, either future capstones, or USMC work, will finish the planning portion and go into acquisition. It is recommended that prototype development starts early in the acquisition process, as shown in Figure 38 which details the entire life cycle. This is earlier than usual because the LL relies heavily on testing and user feedback. The prototype development phase starts before test and evaluation (T&E) but they are heavily interconnected with a constant feedback loop of test results determining prototype changes, shown by the circular arrows in the figure. Another important component is the integration of new ideas and technologies. The goal of the LL is to constantly improve and despite the goal of fast acquisition, there will likely be new technologies emerging during development; therefore, the LL needs to have a process for integrating changes.

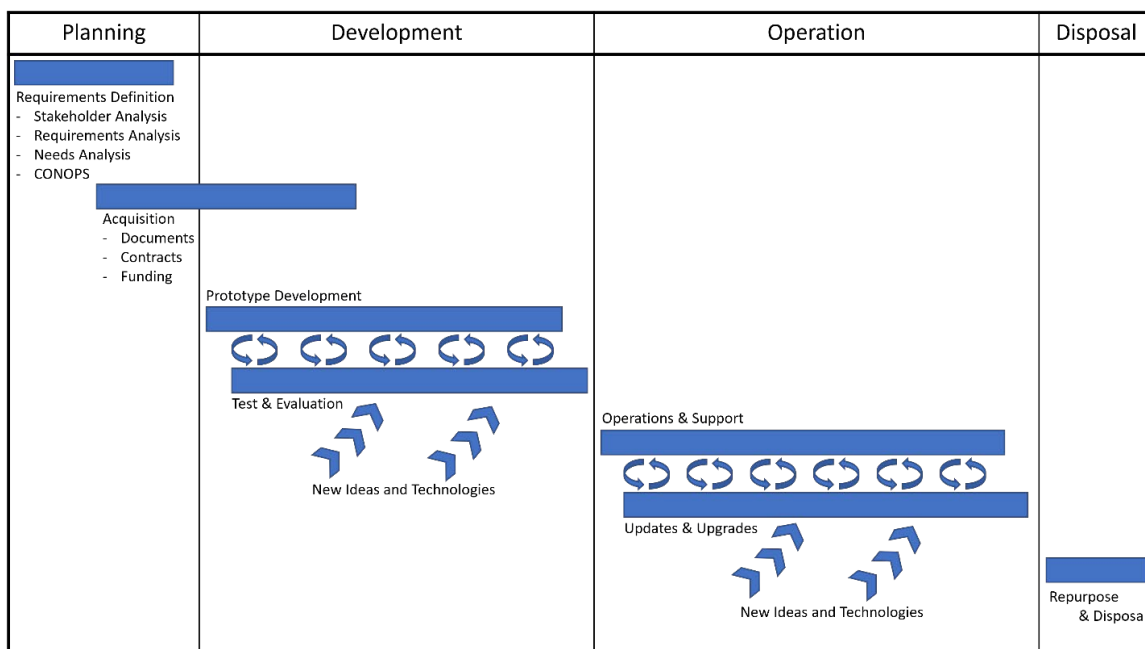


Figure 38. Systems Life cycle Process

Once the prototype is stable enough, it can be converted into a full system and deployed, entering the operations and support phase. This phase is tied closely to the updates and upgrades phase, again with constant feedback loops and admittance of new

ideas and technologies flowing into operations and support. Constant updates and upgrades are more intensive support than most military technologies that are rolled out and only updated as new MODs. Therefore, the FVL LL will be a support-heavy system with some areas of consideration shown in Figure 39. The main areas of support are commercial suppliers, logistics, staffing, network access, and feedback.

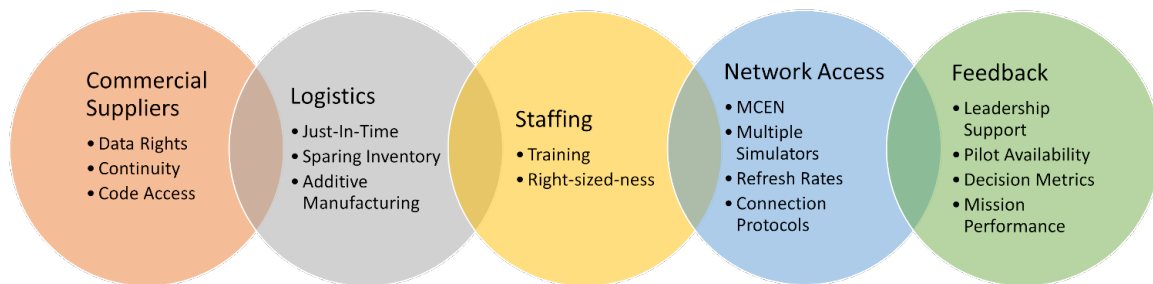


Figure 39. Supportability Considerations

DOD acquisition is a challenge and software contracting has challenges beyond standard acquisition. For example, some major areas of concern are data rights, continuity of programs, and code access. The government needs to make sure they can avoid breaks in continuity due to changing contractors or loss of data at the contractor level if they do not have access or a backup. Working on the logistics side, one of the best ways to minimize costs is to minimize storage and use just-in-time delivery and minimal spares. However, this is a more complex logistic process because there is a risk of downtime if the need for spares or deliveries is underestimated, and the fleet is short on parts. One way to further reduce deliveries and spares inventory is to employ additive manufacturing and make parts on site. That still needs material deliveries, but one type of material can make a variety of parts, reducing the logistics footprint. Staffing is another logistical area to consider but is significant enough to have its own category. Personnel need to be fully

trained and the goal is always right-sized-ness to have just enough knowledgeable staff to run the system.

The next area of consideration is one of the most challenging, equivalent to acquisition, and that is network access. It is imperative that all systems can communicate with each other in real time. That includes multiple simulators with similar refresh rates and proper connection protocols such that all information is encrypted and secure. A viable option is over the MCEN, but it will be up to the USMC and potentially the design agent to determine the best network. With a secure and successful network operating, the final consideration is feedback. There needs to be leadership support for Marines to provide open, honest, and constructive feedback to the system such that it can improve with those updates and upgrades mentioned previously. Pilots and end users need to be available to test the system before they can provide feedback. Also, there needs to be a cohesive decision plan to determine which upgrades to include that can provide metrics on the success of these upgrades and how it impacts mission performance. These are very labor and logistically intensive support considerations, but they will help make the system successful. It is commonly assumed that the operations and support phase of a systems life cycle will require 70%-80% of the total life cycle cost. Due to the heavy support nature of this system, the USMC may want to plan for an even higher percentage once cost estimates are completed.

E. SYSTEM EVALUATION CRITERIA

The best way to analyze a completed product design is through operational testing. With a conceptual design, this is not an option. Therefore, the system was evaluated on how well it is expected to meet the requirements laid out in Chapter III. Initial evaluation will focus on whether the design can meet three overarching requirements:

1. Provide realistic training and exercise planning scenarios
2. Remotely connect simulators at different locations for concurrent operation
3. Accept and implement user feedback for improvements

These generalized requirements cross the needs of multiple stakeholders as well as functional, performance, organizational, interoperability, and suitability requirements. The initial design of the FVL LL system does meet these requirements and should undergo testing throughout prototype development to ensure the more detailed requirements are met. As the USMC moves forward with the FVL LL, requirements will need to be refined to meet their mission and the LL design should be adjusted to meet these updated requirements and reevaluated against the product.

V. USE CASES AND CONCEPT OF OPERATIONS

This chapter describes the FVL Living Lab Concept of Operations and further demonstrates how the concepts would work with five scenarios developed from fictional, yet realistic, user stories. The team used input from stakeholders and primary actors, to develop the use case pilots, to better understand how to design the use cases, and to process the flow of actions or information. Each use case is coupled with a use case model developed in SysML format and a flow chart.

A. FVL LIVING LAB CONCEPT OF OPERATIONS

In chapter two, the concept of operations was described as a fluid document that is be used through the initial, discovery and employment phase of the acquisition cycle. The key elements explained were that it must describe the existing system, provide justification for the new proposed system, and describe the proposed system. To follow Edson and Frittmann's idea of an integrated system-level CONOPS it is imperative that the following section be retained as reference and modified, as needed, to maintain traceability and mitigate conflicting system views throughout the life cycle of the LL.

The FVL LL is envisioned as a multi-purpose modular lab that supports the development of the FVL system. The intended use of the lab will be to perform rapid developmental testing of all FVL systems including the fuselage, cockpit, computer systems, and support systems. Further, the LL will be used to evaluate how FVL systems interact with other USMC mission related systems.

It is further envisioned that the lab can be used for testing and training of other concepts and technologies including but not limited to Marine-machine teaming with other USMC missions, autonomy, maintenance, cyber security, FVL vehicle operation, trust, and field based adaptive manufacturing.

The FVL LL objective is that a new element or concept change can be installed and tested within weeks instead of months. The vision is to have a full-size fuselage and cockpit of the FVL vehicle that includes all the components that will be inside and attached to the vehicle. This vehicle will be built modularly so that it can be changed easily, either to test

changes in the design or to replicate a proposed design change. Modular changes could be as simple as moving a control, display, seat, or mock small weapon or as complex as changing the vehicle size or shape.

A concern of building a new government vehicle is the age of the technology when the system is in production. With a fully operational LL, new technologies could be tested against the existing design rapidly and to ensure the latest technology is used in production. Current legacy platforms suffer from slow update cycles. One FVL LL goal is to reduce the age of system technologies by an estimated five to ten years over the FVL life cycle. After production begins, the lab will continue to be used to rapidly test any new ideas or changes and empower decision makers with performance data when deciding whether to incorporate the new item in production.

To increase the speed at which new items can be tested, the LL will consist of a team of engineers and technicians along with specialized equipment, to design, develop and install the new item as quickly as possible. At a minimum, the LL team should include Systems, Electrical, Mechanical, Modeling/Simulation and Computer Engineers. These engineers will have support from Electrical, Mechanical, Software, and Modularity technicians. A CAD design center, additive manufacturing equipment, ample office space and conference rooms with smartboards will be required to facilitate an increased speed of implementation.

The last aspect of any new element or change is to test. To do this, there will be a need for vast amounts of pilots and crew to test and evaluate. To target the user test group, remote simulators will be placed in fleet concentration areas of vertical lift pilots and crews. These remote simulators will vary in size from game consoles, chair sized simulators, and up to trailer sized simulators. Putting simulators close to personnel may not be enough to gather a large enough test group, thus a marketing team or testing requirement will be useful to increase participation. The focus of testing is to get useful feedback. As part of the design and development stage of the new element or change, feedback questionnaires will be development so that specific questions can be answered by the user testing the alteration. The questionnaire shall be designed to collect measurable feedback.

The next five sections describe five plausible uses cases for the LL and include how the conops would be applied to each. Further, since each use case varies, this analysis demonstrates how the conops flexibly works with each.

B. SCENARIO 1

1. User Story 1

The new Autonomous Pilot Module (APM) has been designed as a “plug-and-play” system that will be inserted into the cockpit of the FVL. It is designed to pilot the aircraft without human assistance in support of various missions. To test the design, the mission planner on the simulator has been programmed to simulate a reconnaissance mission in hostile airspace under less-than-optimal weather conditions. The simulation will test whether the APM is capable of successfully navigating through these adverse conditions.

2. Use Case 1: Design Testing New Capability

Use Case: New system capabilities tested against existing systems

Primary Actors: APM, Existing System/equipment, aircrew, and Marine ISR mission operators

Secondary Actors: Red force generator, weather environment generator, ISR sensors, Supporting common systems (consistently used in most scenarios; components like networks, protocols, security implementation, data collection and storage, message interoperability design, etc.), Lab Technicians

Goal: Evaluate that new system/equipment is compatible with existing systems and equipment and can perform the mission at the same or better levels that the existing system.

Preconditions: Reliable communication between APM, FVL, LL, ISR sensor(s), Marine ISR mission operator, FVL and red force generator, and APM and environment generator.

Scenario:

1. Program office deploys of APM for FVL.

2. APM installed on FVL.
3. LL technicians ensure APM compatibility with the lab environment.
4. Deploy use case simulation data to remote simulators and allow testing for allocated time (varies).
5. Collect data and capture feedback at the LL and submitted to the program office to decide future action on deployment.

Exception: If the installed equipment is not compatible with the lab, testing will not be possible. This should be an indication that the new equipment is not compatible with the system. If this is the case, the FVL LL advisory board should be notified for action. This exception applies to all use cases.

Figure 40 represents a model for the use case described above. This SysML model includes activity diagram (not shown but included in the SysML package) for further instruction on the process for verifying compatibility and testing new configurations.

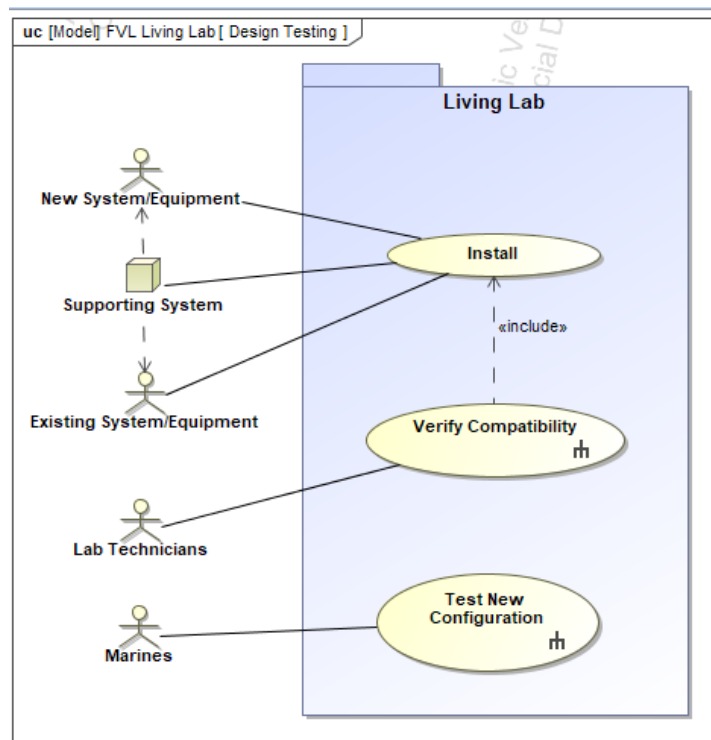


Figure 40. Use Case 1 Model: Design Testing

3. User Story 1 Concept of Operations

a. Existing System Description

FVL with no APM capabilities. FVL is a vertical lift vehicle used for various military missions. Currently only onboard personnel operate and fly the FVL system.

b. New System Justification

The APM will fly the FVL in circumstances where risk of machinery is warranted but risk of pilot and crew life is not. Along with the example above, it could also be used in missions where chemical, biological, or radioactive agents would prevent FVL operation by a live pilot.

c. New System Description

FVL with APM capabilities. The APM would be securely placed in the cockpit of the FVL and attached mechanically and electronically to the FVL sensors and controls. A mission would be programmed into the APM and it would conduct that mission in the same manner of a live onboard pilot.

d. LL Concept for User Story 1

Assume the LL environment is completely operational and programed with a simulation for a reconnaissance mission in hostile air space with a severe thunderstorm in the mission theater. In accordance with Figure 41, the following events would occur:

1. The sponsor of the test event submits a proposal for the APM testing to the LL Recommendation Consul (RC).
2. The RC will use the supplied APM documentation to conceptualize the alterations (sometimes these can be called temporary modifications, or a TEMPMOD) needed and decides if the test is feasible and if funding level is adequate.
3. If approved, The Lab Development Team will perform a baseline System Operation and Verification Test (SOVT) before conducting the alteration.

4. The Lab Development Team will then create a design of the alteration, develop any interfaces or module changes needed, and implement the completely reversible changes to the LL. (usually as part of the TEMPMOD process, return to beginning state is required)
5. Concurrently with step 4, the T&E Team along with the APM sponsor designs and develops the testing plan which includes the evaluation metrics and the addition of any sensors needed to record those metrics.
6. With the alteration in place, perform a second SOVT to ensure the FVL LL simulator is functioning as designed and identical as before the alteration.
7. The T&E Team will test the simulation on several live onboard pilots and record the metrics.
8. The APM sponsor will install the APM
9. The T&E Team will run the simulation several times, record metrics, and collect operator feedback.
10. The data will be given to the APM sponsor and the FVL sponsor for analysis.
11. The Lab Development Team will review any feedback from the T&E Team and report to the RC of further alterations needs for this event.
12. The RC will decide whether to alter the design and continue testing or complete testing.
13. If the recommendation is to further alter the design, the loop would repeat at step 3. If the recommendation is different the sponsors would be notified.

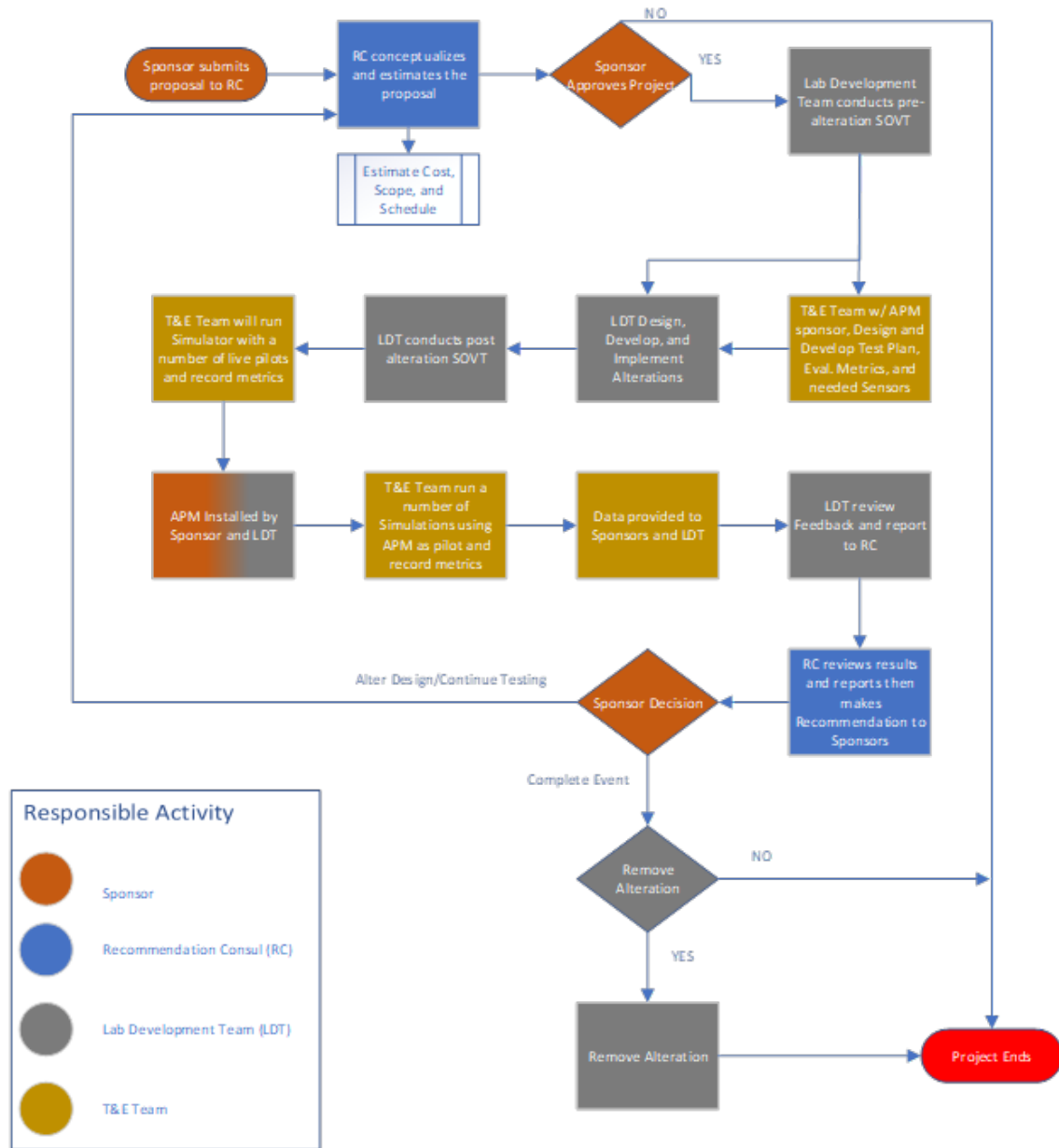


Figure 41. Scenario 1 Flow Chart

C. SCENARIO 2

1. User Story 2

Capt. Clarke, USMC, is a competent and safe pilot. He has been tasked with conducting a short logistics mission, dropping off supplies to an underserved Forward Operating Base in the Nubian desert. Sandstorms have prevented resupply to the outpost

for the last week, and they are panicked. To simulate this mission, he is using the Naval services new Next Gen mission planning system in conjunction with the Marines' new future vertical lift in an unmanned mode. Capt. Clarke believes that if he can program a Nap of the Earth (NOE) flight path, he may be able to avoid the worst of the storms and deliver these supplies.

2. Use Case 2: Mission Simulations

Use Case: Mission planners are considering utilizing innovative solutions to perform specific missions.

Primary Actors: Next Gen mission planning system, FVL, LL, aircrew, remote simulators

Secondary Actors: Weather environment generator, supporting common systems, Lab Technicians

Goal: Analyzing mission performance using innovative solutions.

Preconditions: Reliable communication between the Next Gen mission planning system, FVL, LL, environment generator and remote simulators

Scenario:

1. Program office deploys the Next Gen mission planning system to the FVL.
2. Equipment is installed on FVL.
3. LL technicians ensure compatibility with the lab environment.
4. Deploy simulation data to simulator(s) and allow testing for allocated time (varies).
5. Collect data and capture feedback at the LL and submitted to the program office to decide future action on deployment.

Figure 42 represents a model for the use case described above. This SysML model includes activity diagram (not shown but included in the SysML package) for further instruction on the process for verifying compatibility.

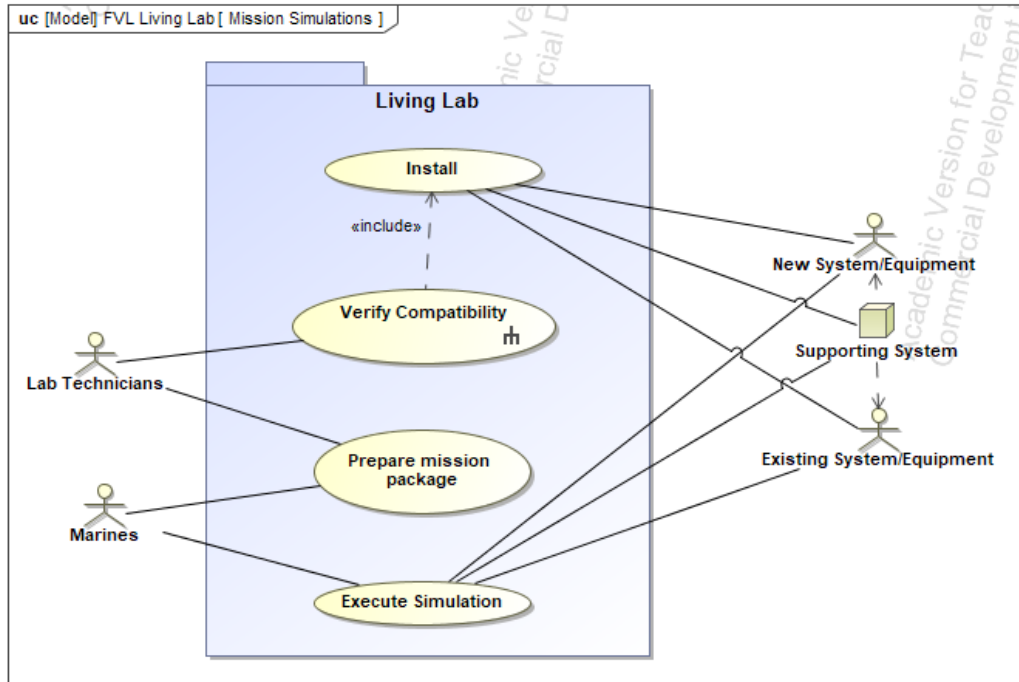


Figure 42. Use Case 2 Model: Mission Simulation

3. User Story 2 Concept of Operations

a. Existing System Description

FVL with standard capabilities. FVL is a vertical lift vehicle used for various military missions. Currently pilots use ForeFlight MFB for mission planning.

b. Test Justification

The test will assess if the NOE flight path created on the Next Gen flight planning system improves pilot performance enough to adopt the new flight planning software.

c. New System Description

FVL with standard capabilities. Pilot uses Next Gen flight planning system to load an NOE flight path into the Flight Management System (FMS).

d. LL Concept for User Story 2

Assume the LL environment and desired remote simulators are operational and programmed with a simulation in the Nubian desert for a resupply mission to a forward deployed unit with severe sandstorms in the area. In accordance with Figure 43, the following events would occur:

1. The sponsor of the test event submits a proposal to the LL RC.
2. The RC will use the documentation in the proposal to conceptualize the test event and decide if funding level is adequate.
3. If approved, The Lab Development Team will perform a SOVT to ensure optimal performance of the LL Simulator.
4. The T&E Team along with the test event sponsor will design and develop the testing plan which includes the evaluation metrics and the addition of any sensors needed to record those metrics.
5. Concurrently with step 4 and since no alterations to the LL system are needed, The Lab Development Team will work with the T&E Team to ensure all the needed performance metric gathering devices are gathering the correct information.
6. The T&E Team will test the simulation with several pilots using existing flight planning techniques, record the metrics, and collect the evaluation questionnaires from the pilots.
7. The T&E Team will test the simulation with several pilots using the Next Gen flight planning system with NOE flight paths, record the metrics, and collect the evaluation questionnaires from the pilots.
8. The data will be given to the test event sponsor and the FVL sponsor for analysis.
9. The Lab Development Team will review any feedback from the T&E Team and report to the RC any changes to the test event that may improve the test results.

10. The RC will decide whether to change the test event and continue testing or conclude the event testing.
11. If the recommendation is to change the event, the loop would repeat at step 3. If the recommendation is different the sponsors would be notified.

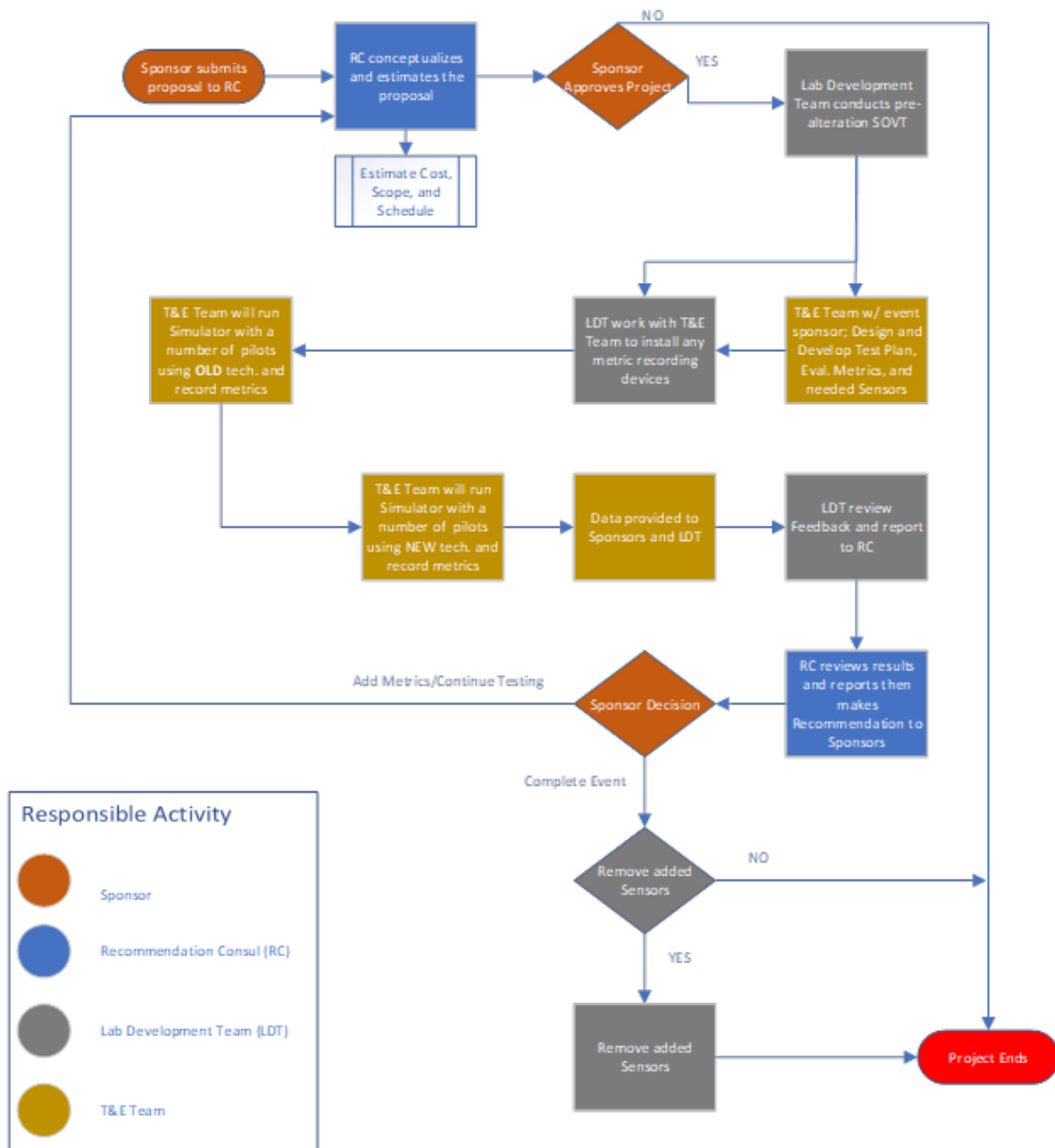


Figure 43. Scenario 2 Flow Chart

D. SCENARIO 3

1. User Story 3

Each pilot uses plasma mission and avionic monitors. These are difficult for pilots to read from their seats. The information displayed is not customizable and sometimes, not pertinent, while other key information is difficult to find. Dr. McGuire will establish a performance baseline on which to compare potential replacement screens by evaluating cognitive load and stress levels using eye tracking tools. Dr. McGuire will conduct her experiments using the LL. Once the new screens are ready to be implemented, integration testing with the FVL will be done using the LL.

2. Use Case 3: User Feedback

Use Case: User submits feedback on FVL cockpit monitors.

Primary Actors: FVL, LL, plasma monitor, aircrew, proposed monitor replacements

Secondary Actors: Lab Technicians, on site manufacturing (as required for mounting alterations)

Goal: Analyze mission performance using new avionics monitors.

Preconditions: Reliable communication between remote simulators, FVL, and LL, and applicable manufacturing capabilities at remote simulator location.

Scenario:

1. User submits feedback to program office on a small change to cockpit design.
2. Feedback is evaluated by SME for feasibility and necessity.
3. LL technicians ensure compatibility of alteration with the lab environment.
4. Deploy simulation data to remote simulators

5. Remote simulator locations are given the order to install or manufacture the new piece of equipment with instructions for install. From example above, remote simulators will install new avionics monitor).
6. Allow testing at remote simulator locations for allocated time (varies).
7. Collect data and capture feedback is received at the LL and submitted to program office to decide future action on deployment.

Exception: If the installed equipment is not compatible with the lab, testing will not be possible. This should be an indication that the new equipment is not compatible with the system. If this is the case, the FVL LL advisory board should be notified for action. The SME may also consider this feedback may cause scope creep or may not bring much value. The SME shall submit his/her considerations for review by program office before the feedback is officially turned away.

Figure 44 represents a model for the use case described above. This SysML model includes activity diagram (not shown but included in the SysML package) for further instruction on the process for validating changes, manufacturing, and proposing changes.

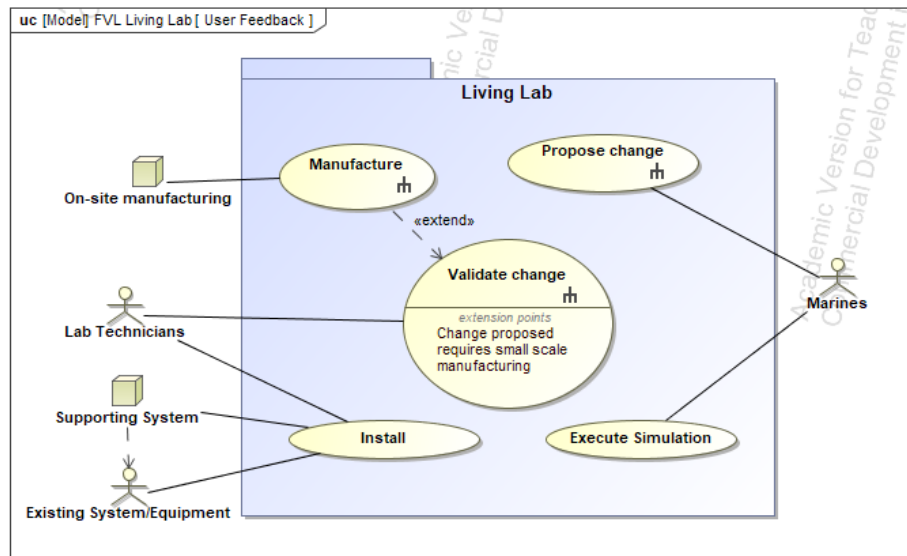


Figure 44. Use Case 3 Model: User Feedback

3. User Story 3 Concept of Operations

a. Existing System Description

FVL with as designed capabilities utilizing plasma monitors.

b. Test Justification

The old-style plasma monitors are hard to see and not customizable. The test will collect data to determine if new types of monitors would be useful improvements and cost effective. The test will also determine if a customizable screen will improve pilot performance.

c. Testing Description

Pilots will take turns being evaluated on their performance in the simulator first with the plasma monitor as a baseline and then each subsequent test would be with a different type of monitor.

d. LL Concept for User Story 3

Assume the LL environment is operational and programmed with a simulation developed for testing pilot performance. In accordance with Figure 45, the following events would occur:

1. FVL sponsor submits a proposal to evaluate FVL pilot performance using several different types of replacement cockpit monitors to the LL RC.
2. The RC will use the supplied documentation to conceptualize the alterations needed and decide if the test is feasible and if funding level is adequate.
3. If approved, The Lab Development Team will perform a baseline SOVT before the TEMPMOD.
4. The Lab Development Team will create a design of the alteration, develop any interfaces or module changes needed, and implement the TEMPMOD to the LL.

5. Concurrently with step 4, the T&E Team along with the FVL sponsor will design and develop the testing plan which includes the evaluation metrics and the addition of any sensors needed to record those metrics.
6. With the old monitors in place, perform a second SOVT to ensure the FVL LL simulator is functioning as designed and identical as before the alteration.
7. The T&E Team will test the simulation on several pilots and record the metrics as a baseline of performance.
8. The Lab Development Team will install one type of replacement monitor.
9. The T&E Team will run the simulation again on the same pilots, record metrics, and collect operator feedback.
10. Steps 8–9 will be performed with each type of monitor.
11. The data will be given to the FVL sponsor for analysis.
12. The Lab Development Team will review any feedback from the T&E Team and report to the RC of further alteration needs for this event.
13. The RC will decide whether to alter the testing event and retest or conclude testing.
14. If the recommendation is to further alter the design the loop would repeat at step 3. If the recommendation is different, the sponsors would be notified.

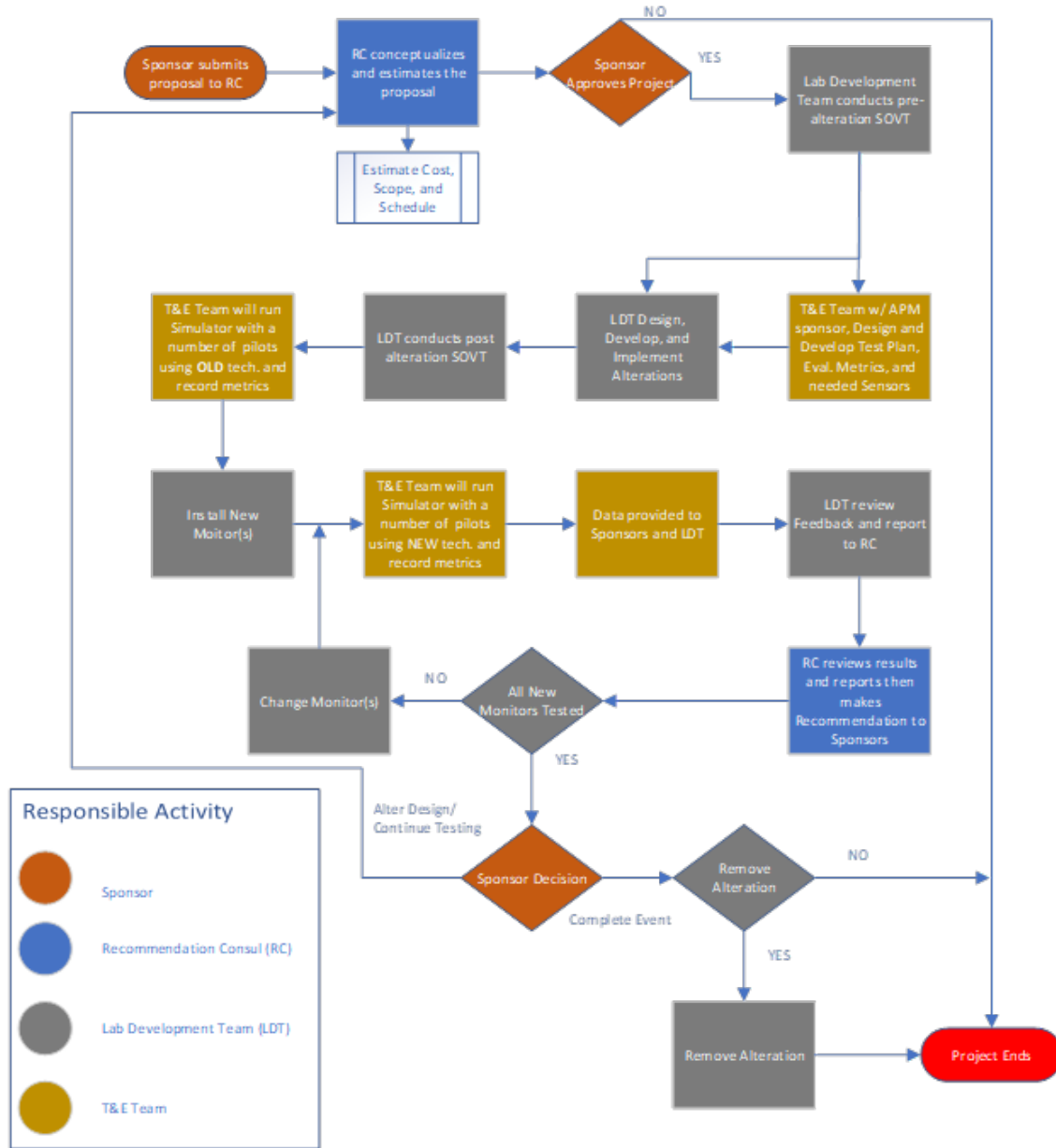


Figure 45. Scenario 3 Flow Chart

E. SCENARIO 4

1. User Story 4

Software developers for the built-in testing (BIT) system that is being used on the FVL have created a new version. The developers want to make sure that the update does not cause any failures and that it operates as designed. To ensure this, the software will be

tested within the LL model and each fault will be ingested to the model to test for detection. The model will save man-hours and possible equipment damage by ensuring all tests happen on an isolated clone FVL system and will not require equipment specialists as all faults can be inserted by a lab technician.

2. Use Case 4: Software Update

Use Case: Test software update on digital twin

Primary Actors: LL, FVL, aircrew, MCEN, Defense Research Engineering Network (DREN)

Secondary Actors: Lab Technicians, software developer

Goal: Test Over-the-air (OTA) software updates

Preconditions: Reliable communication between remote simulators, LL, FVL and supporting simulators

Scenario:

1. Software developer provides generated code
2. Software is uploaded to a digital twin generated by the LL
3. Software testing is conducted on the digital twin using simulations and remote simulators
4. Issues are noted or software is verified approved to deploy.

Figure 46 represents a model for the use case described above. This SysML model includes activity diagram (not shown but included in the SysML package) for further instruction on the process for verifying compatibility.

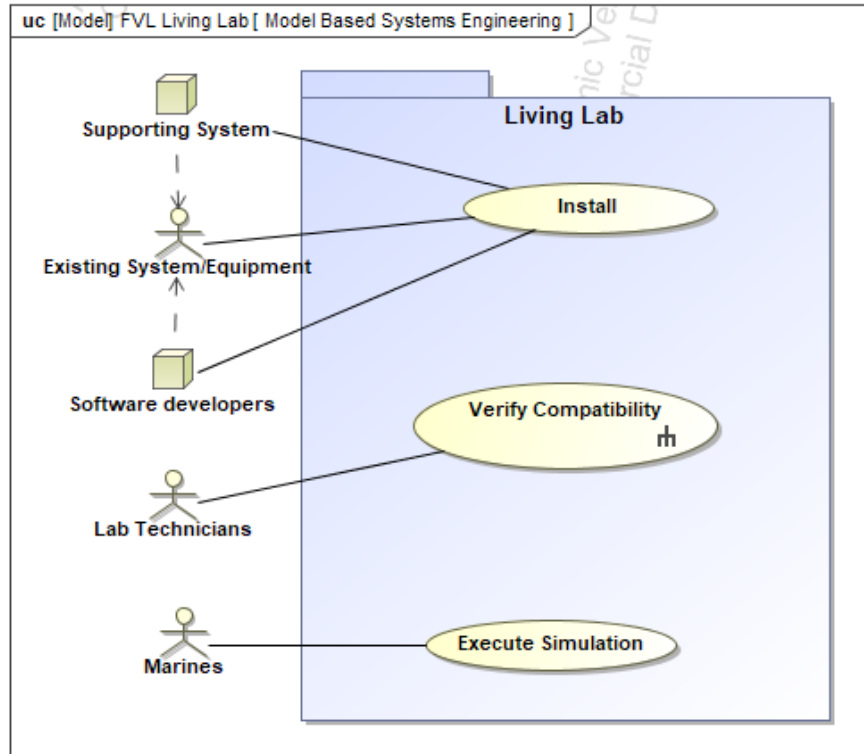


Figure 46. Use Case 4 Model: Model-Based Systems Engineering

3. User Story 4 Concept of Operations

a. Existing System Description

FVL with standard capabilities operating with BIT version 3.4

b. New Software Justification

The BIT software version 3.4 has reached EOL and needs to be updated with version 4.0. The new software fixes bugs in the system and contains security updates.

c. New System Description

FVL with standard capabilities operating with BIT 4.0.

d. LL Concept for User Story 4

Assume the LL environment is completely operational and programmed with any flight simulation. In accordance with Figure 47, the following events would occur:

1. The BIT software sponsor submits a proposal to the LL RC to test the software update.
2. The RC will use the documentation in the proposal to conceptualize the testing event and decides if funding level is adequate.
3. If approved, The Lab Development Team will perform a SOVT to ensure optimal performance of the LL Simulator.
4. The T&E Team along with the test event sponsor will design and develop the testing plan which includes the evaluation metrics and the addition of any sensors needed to record those metrics.
5. Concurrently with step 4 and since no alterations to the LL system is needed, the Lab Development Team will work with the sponsor update the software.
6. The T&E Team will test the software update on the simulator, simulating each failure that the BIT is designed to test. The team will also record the results of the test.
7. The data and operator feedback will be given to the test event sponsor and the FVL sponsor for analysis.
8. The Lab Development Team will review any feedback from the T&E Team and report to the RC any changes to the test event that may improve the test results.
9. The RC will decide whether to change the test event and continue testing or conclude the event testing.
10. If the recommendation is to change the event, the loop would repeat at step 3. If the recommendation is different, the sponsors would be notified.

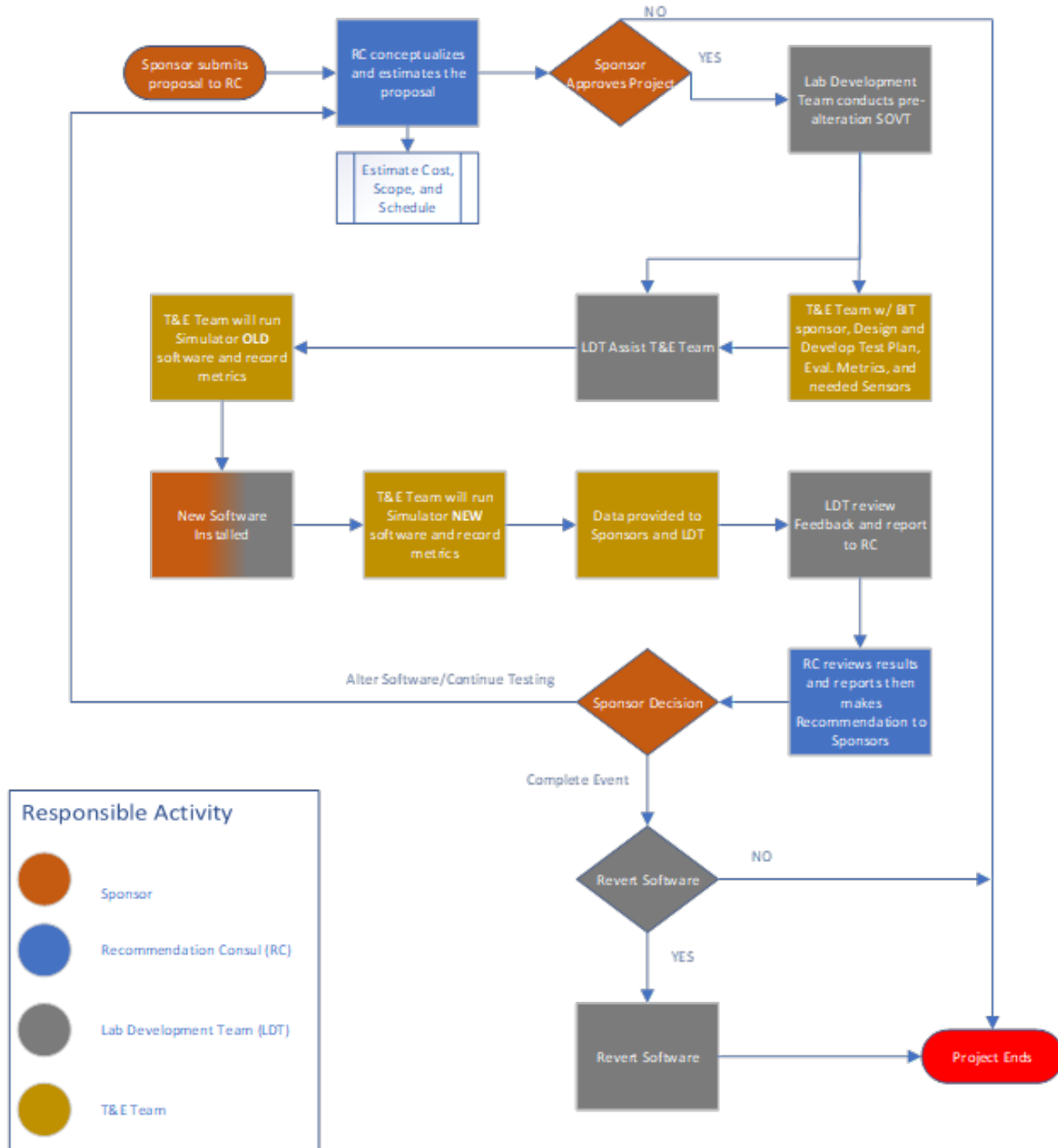


Figure 47. Scenario 4 Flow Chart

F. SCENARIO 5

1. User Story 5

The USMC is preparing to employ the FVL as an airborne command and control (C2) platform. Roll-on/roll-off radio suites, antennae, and antennae jacks will be installed through the fuselage of the aircraft. The simulation will integrate with Marines performing

a live exercise and utilize the FVL aircraft's ability to transmit and receive UHF, VHF, HF, SATCOM, Link-16, MUOS, and wireless SIPR and NIPR internet, at different airspeeds and altitudes, over different ranges, and under different environmental conditions (thunderstorms, sandstorms, tropical humidity) based on data from actual component performance. The FVL command and control aircraft will also be expected to integrate with other ground and airborne ISR platforms. Additionally, the exercise will include utilizing the FVL as a relay for fire support coordination from troops or aircraft deep inland to Naval fire support assets over the horizon. This method of training will reduce the cost of performing the exercise, avoid spending man-hours to conduct pre- and post-flight maintenance, and minimize the risk of damage or injury to the aircraft and personnel as they conduct a mass training event.

2. Use Case 5: System of Systems simulation

Use Case: USMC leadership has planned a large-scale training exercise for the MAGTF that includes USN assets and will employ the FVL as a C2 platform.

Primary Actors: LL, FVL, aircrew, C2 equipment operators

Secondary Actors: Lab Technicians, Marine air and ground forces, ISR sensors (ground and air), Fire Support Coordination Centers (FSCC)

Goal: Integrate the FVL LL in a live exercise and test new capabilities for FVL employment.

Preconditions: Reliable communication between remote simulators, LL, supporting USMC simulators, and Marine ground and air forces

Scenario:

1. Mission suite is installed on the LL mockup.
2. LL technicians ensure compatibility with the lab environment.
3. Test communication with USMC training event participants.
4. Deploy simulation data to remote simulators and conduct training for the allocated time (varies).

5. Users at LL site debrief on the performance of FVL simulator, equipment, crew performance and submit feedback for Lab Technicians.
6. All exercise participants debrief on the training event results and employment of the FVL's C2 capabilities.
7. Feedback is submitted to the FVL program office to improve capabilities.

Figure 48 represents a model for the use case described above. This SysML model includes activity diagram (not shown but included in the SysML package) for further instruction on the process for verifying compatibility.

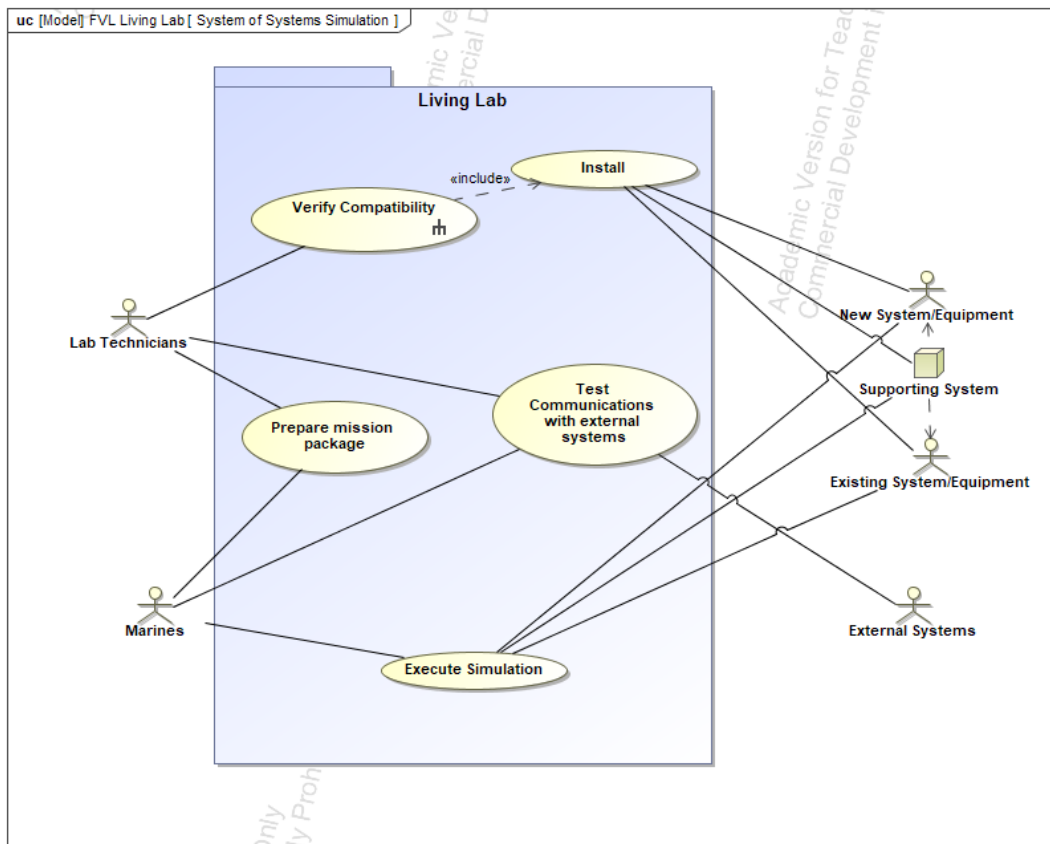


Figure 48. Use Case 5 Model: System of Systems Simulation

3. User Story 5 Concept of Operations

a. Existing System Description

FVL with standard capabilities operating without C2.

b. New System Justification

The FVL ability to function as an airborne C2 center will be highly valuable. To accomplish this mission the FVL must support all types of communications. A roll on-roll off command and control center would be vital in changing warfare environment.

c. New System Description

FVL with standard capabilities operating with C2 modules.

d. LL Concept for User Story 5

Assume the LL environment is completely operational and programmed with any flight simulation. In accordance with Figure 49, the following events would occur:

1. The C2 sponsor submits a proposal to the LL RC to run simulations with the C2 system.
2. The RC will use the documentation in the proposal to conceptualize the testing event and decides if funding level is adequate.
3. If approved, The Lab Development Team will perform a SOVT to ensure optimal performance of the LL Simulator.
4. The Lab Development Team will create a design of the alteration, develop any interfaces or module changes needed, and implement the TEMPMOD to the LL.
5. Concurrently with step 4, the T&E Team along with the FVL sponsor will design and develop the testing plan which includes the evaluation metrics and the addition of any sensors needed to record those metrics.

6. With modification for C2 in place, perform a second SOVT to ensure the FVL LL Simulator is functioning as designed and identical as before the alteration.
7. The test subjects will roll on the C2 modules and the T&E Team will run simulations on several teams, record metrics, and collect operator feedback.
8. The data will be given to the test event sponsor and the FVL sponsor for analysis.
9. The Lab Development Team will review any feedback from the T&E Team and report to the RC any changes to the test event that may improve the test results.
10. The RC will decide whether to change the test event and continue testing or conclude the event testing.
11. If the recommendation is to change the event, the loop would repeat at step 3. If the recommendation is different, the sponsors would be notified.

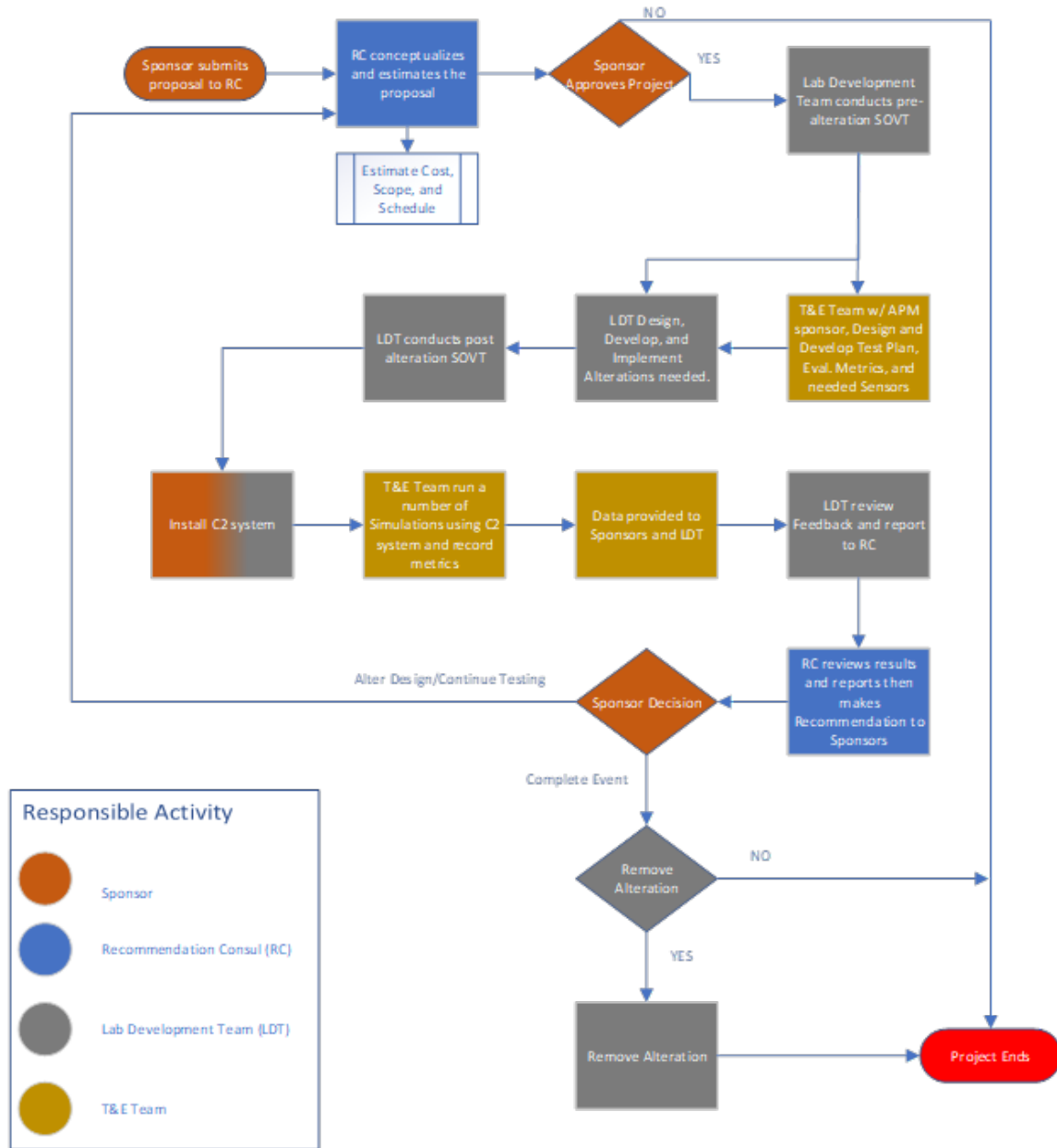


Figure 49. Scenario 5 Flow Chart

G. CHAPTER SUMMARY

This chapter describes in detail how the FVL LL would operate across five different use cases. In each scenario, the requirements for how well the LL must mirror the actual FVL platform varies. For instance, in scenario one, the FVL LL must fly similarly to the FVL to show results, but in scenario 4, not only must the LL provide a representative model

of the FVL, but it also needs to be a digital twin to provide relevant and applicable results, since the BIT is checking the nuances of FVL subsystem operational performance. Scenarios two and three show how, if designed well, the LL will make comparing technical options not only feasible, but easy to conduct, saving the program office years of troubles addressing user complaints.

Scenario 5 requires the LL to be more than a model. In this scenario, the LL serves as a “flightless” aircraft that is still capable of performing the same as the aircraft would during an exercise where the only simulation is being conducted in the cockpit but still transmitting the simulation’s flight path to other participants, while the rest of the cabin is receiving and transmitting real time data. Lastly, making these comparisons may not require a high level of FVL fidelity. In these cases, perhaps a virtual reality environment can provide that level of evaluation capability at a more affordable cost. These use cases demonstrate that the conops is adaptable to various LL uses.

VI. CONCLUSIONS

The development of a LL can offer early insight into the capabilities and limitations of the FVL and its associated technologies. The USMC and DOD will benefit from creating and implementing a LL environment for experimenting with new technologies and testing FVL capabilities. A LL will provide a source of invaluable data and insights into the utility of new technologies and concepts for FVL platforms. The ability to quickly gather this data and provide testing opportunities will save on scheduling and cost, and will streamline the acquisition process through rapid experimentation, testing, and deployment of new technologies.

The capstone team's needs analysis provides a baseline set of requirements for the FVL LL. The inherent "living" nature of the FVL LL implies that the LL will be an evolving laboratory that changes to support the future changing needs of the FVL platforms and the future changing opportunities of advances in technologies. This evolution needs to be inherent in the FVL LL requirements. The team's baseline set of requirements needs to be periodically reviewed and updated to support future experimentation and testing. This will involve an evolutionary systems engineering life cycle that continues to engage stakeholders, elicit evolving needs and requirements, and incorporate these requirements into updates to the LL.

The capstone team developed a system of systems (SoS) conceptual architecture for the FVL LL based on the need to have a set of geographically distributed sites located at USMC bases. The FVL LL SoS requires data sharing, interoperability, compatibility and integrated experimentation, simulation, and testing. The primary objective of the FVL LL is to foster innovation for future aircraft platforms and their missions. The FVL LL is intended to enhance the processes of development, qualification, verification, and validation of future aircraft platforms. Essentially, the LL will be more than a simulator for the FVL alone. The FVL LL should be viewed as a USMC asset capable of participating in real world exercises. As an example, Figure 50 illustrates how the FVL LL could support a C2/ISR exercise as described earlier in scenario 5 in Chapter V. In this example, the LL

acts as a fully integrated asset to the exercise by greatly reducing operational costs and man hours to conduct the training while also offering personnel safety.

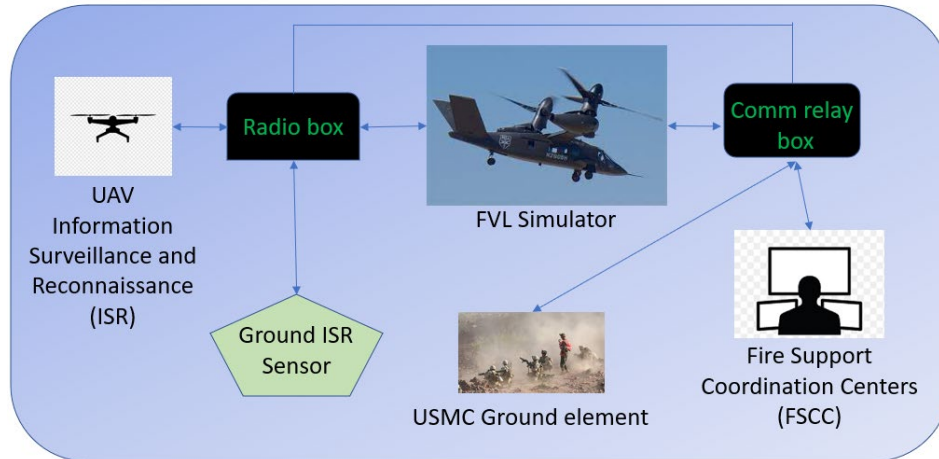


Figure 50. OV-1 FVL LL C2/ISR Exercise

This example shows one of the many ways that the LL can turn an ordinary FVL simulator into an operational asset. Over time, and as needs, strategies, technology, and adversarial capabilities change, the LL will act as the test grounds to experiment with new solution concepts and capabilities. The LL will provide an opportunity for the USMC to test the talent and ingenuity of Marines around the world as well as allowing the user to be a part of the sustainment and development phase of new FVL systems. The FVL LL will open new doors for the USMC and DOD to expand upon.

A. RECOMMENDATIONS

After researching current and potential uses for a LL, the team recommends that the USMC develop the FVL LL in parallel to the development of the FVL program itself. An operational LL will help the USMC evaluate the performance of the current proposed FVL platforms based on their stated specifications. Moreover, the USMC can use the LL environment to identify maintenance considerations for the FVL, commence training and familiarization, gain early user feedback, and begin testing new missions and capabilities before the FVL joins the Corps.

As the LL is developed, technological issues may arise when considering data transfer requirements, such as bandwidth, and interoperability with existing simulators and platforms of other USMC systems as well as other military branches to support joint operation exercises. The following are specific areas to consider as the LL is developed and operational.

1. Interoperability

The USMC has connected simulators in their CCS systems therefore the precedent and capability to ensure interoperability of the LL exists. Research and planning need to be completed to implement the interoperability. An area of consideration is whether the other services could also develop LLs such that it would be incumbent upon the USMC to prepare for cross-service interoperability, particularly with the USN.

2. Policy

Local policies may need to be generated with regards to proper use and operating hours for remote simulators. Based on research and the design of the LL, implementing a policy that promotes training using the LL remote simulators could provide evidence and support for HMT technology integration. Lastly, once the LL is operational and quantitative data on costs and efficiency are generated, policy makers may be able to use the LL as a standard for acquisition processes.

3. Training

As the USMC pursues LVC-TE development, it should be researched whether the FVL LL can be a part of that system to support simulated training. Also, schoolhouses and training facilities should develop curricula to be used for each level of pilot, mechanic, and other operator training to ensure uniformity. These curricula can be developed as the LL prototype is developed to fully utilize the new capabilities provided.

4. Security

Network and communications security must be maintained with the most current network and encryption protocols for the LL. Research and testing will need to heavily

focus on preventing data leakage and adversary access to the system. A suggestion may be to conduct security assessments on a weekly or monthly basis based on current cyber security directives. In addition to network and communications security, physical security needs to be managed. The physical security may be achieved through the installation of vault doors with limited personnel access, alarm systems, and internal network security cameras for entrances and exits. Security training must be established for personnel working directly on the LL.

5. Operations

When the FVL LL is in full operation, user feedback will need to be considered when making improvements. User manuals and personnel training documentations need to be updated as system modifications are implemented. A lot of research and development will be carried out as technology advances and new capabilities arise. Operational test and evaluation criteria must be constructed to guarantee accurate performance, reliability, and sustainability of the system. Quarterly operational maintenance such as regression testing on the controls, devices, and possible human machine interactions should be performed.

6. Communication

PMA 276 will oversee FVL LL operations and provide funds to the various entities working directly on the system. With various stakeholders and their diverse backgrounds, there may be some conflicts on their vision of how to use the FVL LL and lab schedule for each mission. The greatest challenge the stakeholders will face will be maintaining transparent and fluid communication. The stakeholders will need to communicate with each other through dedicated meetings to review system requirements, funds, timeline, and resource availability.

B. FUTURE WORK

There are several topics that this capstone did not cover that should be considered and explored further. These include cost analysis, system alternatives, cyber security considerations, and a more thorough investigation on how the LL concept could change or

integrate with the acquisition life cycle. Table 9 identifies future areas of research and prioritized them highest to lowest. Topics ranked higher in priority were due to relevance to DOD and Marine Corps mission needs and how well the topic lent itself to justifying the system to obtain funding and leadership buy-in. The topics in the middle of the list aligned with the systems engineering phase of detailed design. Once funding is secured, these studies will be vital in the implementation of the FVL LL. Finally, the last topics were not seen as an urgent need, but truly to show the scalability and robustness of the FVL LL after it has proven to be successful. Several of these studies may develop or provide foundations for other topics to build upon. In Figure 51, a mapping of possible future work routing is provided.

Table 9. Table of Future Work Topics arranged by Suggested Priority Level

Priority	Topic	Phase Required
1	Cost and Benefit Analysis	Proposal Package and Funds Justification
2	Cybersecurity	Proposal Package and Funds Justification
3	Acquisitions	Proposal Package and Funds Justification
4	Alternatives	Detailed Design
5	Trust Factors	Detailed Design
6	Optimal Network Interoperability Factors	Detailed Design
7	FVL Modular Component Analysis	Detailed Design
8	AI/ML Considerations	Detailed Design
9	Network Architecture Modeling	Detailed Design
10	Staffing Factors	Detailed Design
11	Supply Chain	Detailed Design
12	Integrating Non-FVL Marine Corps Air Vehicles	Growth and Scalability
13	Integrating Multiple Branch Sensors Under a Single Combat System	Growth and Scalability

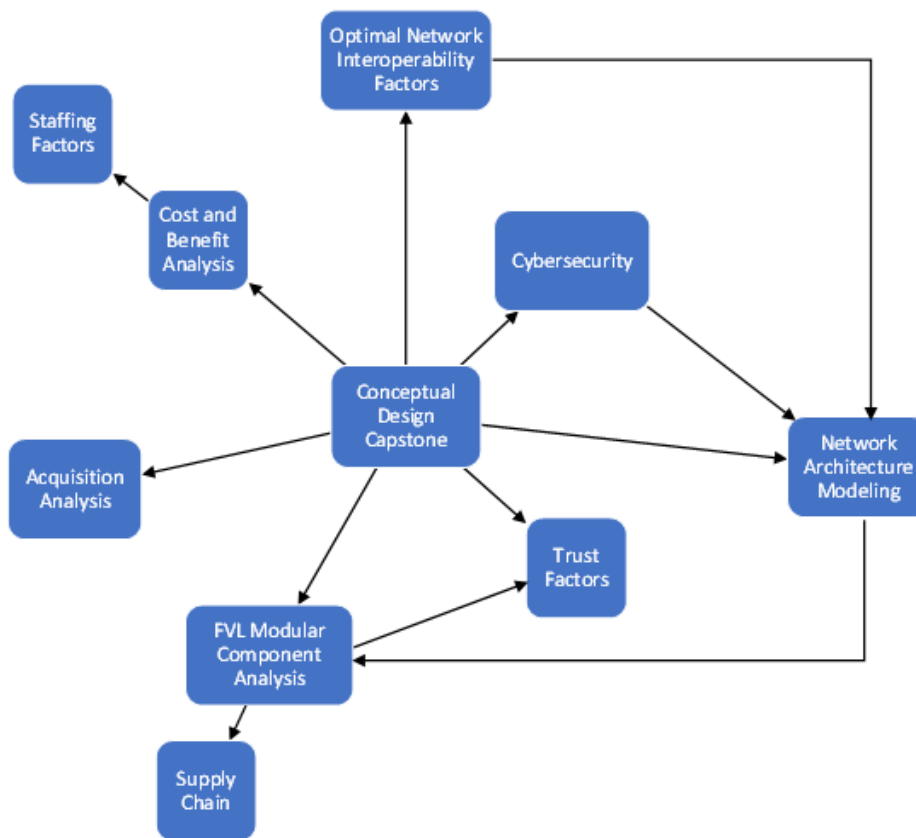


Figure 51. Future Work Routing and Development

1. Cost and Benefit Analysis

Despite the cost benefits to be obtained from future upgrades to the FVL, the LL itself still requires a supporting Cost and Benefits analysis. This is the highest priority as the LL can be considered a major acquisition and would follow the typical DOD acquisition cycle, meaning proper proof and justification will be needed to obtain funds to see the LL through to a prototype. Preparing the cost and benefit analysis increases the chances of achieving success in deploying the LL. Candidates to perform this analysis include the NPS's Graduate Students within the Master of System Analysis Program. Within this program exists a cohort specializing in cost estimating and analysis.

2. Cyber security

As stated in the USMC Force Design 2030, the Commandant of the Marine Corps identified shortcomings within pursuing maritime “grey zone” strategies, which, when combined with cyber-attacks, it is pertinent to consider embedding cybersecurity measures within all components of the FVL (USMC 2020). The National Defense Strategy also states, “space and cyberspace as warfighting domains” (Mattis 2018), further highlighting the importance of cyber dominance on a national level. The FVL LL as considered within this capstone report, has the fundamental design and testing capabilities, and would only require cybersecurity SMEs to collaborate with the FVL LL engineers to ensure cybersecurity requirements are included in the design. Candidates to perform this analysis include the students of cyber systems and operations program or the applied cyber operations program within the Graduate School of Operational and Information Sciences within NPS. The team should use the SysML model developed in this report to generate a comprehensive cybersecurity plan with strategies to secure information assets. They should also identify any impacts to acquisition and the FVL LL infrastructure as it relates to cybersecurity.

3. Acquisitions

Further recommended study in how the FVL LL can lend itself to quicker acquisition will be essential for securing funding for the lab. These studies prove how the FVL LL supports the Marine Corps Aviation Plan in supporting combat readiness and advantage over adversaries. Candidates to perform this analysis include NPS Systems and Program Management of Graduate School of Engineering and Applied Sciences with support from a contracting officer within the Expeditionary Contracting Platoon, such as the one in 1st Marine Logistics Group. This analysis will be conducted by applying knowledge of the Joint Capabilities Integration and Development System (JCIDS) process, specifically using the Middle-Tier Acquisition (MTA) path, and system models from this FVL LL conceptual design. This team should develop and analyze timelines within the various FVL LL process flows from procuring materials for prototypes to deploying large scale upgrades.

4. Alternatives

An analysis of alternatives needs to be conducted to compare tradeoffs between commercial technologies and ground-up solutions. Research should be conducted on existing augmented reality and virtual reality as well as gaming engines. Current programs such as the Integrated Visual Augmentation System (IVAS) prototype recently acquired by the U.S. Army through Microsoft could provide some lessons learned on the military's move towards virtual and augmented reality for training. This analysis provides options and flexibility for decision makers, allows for cost reduction, and shortens development and testing timelines. Candidates for performing this analysis are the graduate students in the Systems Engineering Program with feedback from a representative of the USMC HQ Future Technologies Department. This team should conduct the analysis by identifying technologies that meet these requirements and capabilities listed in this capstone report.

5. Trust Factors

One of the major capabilities of the FVL LL is allowing for the larger reach and "touch time" to FVL operators to test new technologies to incorporate into the FVL. An effective way to quantify the reduction of cognitive load based on updates provided is to conduct Human-System Integration studies. These measurements determine what upgrades may not have the highest value added to mission success rates due to the low trust rates humans may have with the machine or module. The team identified Dr. Mollie McGuire from NPS, and graduate students of Human Systems Integration Program in NPS. This team should design experiments and data gathering methods of how cognitive load is affected by modular components defined within the FVL modular component analysis and within this capstone report.

6. Optimal Network Interoperability Factors

The FVL LL is comprised of multiple remote simulators allowing for greater Marine reach and ensuring training events include Marines in the Indo-Pacific region. Successful simultaneous training runs for Marines in foreign countries with those physically located in the United States rely on secure, reliable, and robust internet connectivity. The best candidates to perform this study are PMA-205 training simulator

experts, Christopher Fitzpatrick from NPS and students in the Modeling Virtual Environments and Simulations (MOVES) program of the Computer Sciences Department of the Graduate School of Operational and Information Sciences within NPS. The team's research should include legacy, existing, and new training simulator network needs to meet the global connectivity requirements defined in this capstone report. A few network requirements to be explored will be bandwidth, existing Marine Corps infrastructures, data speeds, and internet protocols required for each simulator. Incorporating 5G technologies from the MCAS Miramar LL should also be considered. Cyber security must also be considered as stated earlier in this section.

7. FVL Modular Component Analysis

The FVL Modular component analysis is required to identify FVL components ideal for rapid upgrades. This analysis will aid in the project proposal as it aligns with the USMC Force Design 2030. To quote the Commandant, "Our experimentation must be deliberate and iterative, informed by both threat developments and technology advancements" (USMC 2020). To perform this work, the team identified students in the Systems Engineering program in NPS with guidance from the FVL Chief Engineer. This team should build upon the SysML model created for this capstone to capture which components or modules are critical to FVL missions and operations, have minimal interfaces, and have clear and definable upgrade goals and iterations.

8. AI/ML Considerations

Future studies in Artificial Intelligence/Machine Learning (AI/ML) are crucial to the FVL LL mission because its application may significantly reduce FVL operator cognitive load, allowing them to focus on mission execution and reserve mental efforts on maneuver tactics and threat management. Candidates to perform this work are graduate students in the Systems Engineering Program or Computer Science Program at NPS. Students will survey common actions of FVL operators and identify processes best suited for automation and generate AI/ML solutions to include the hardware and software required.

9. Network Architecture Modeling

Network Architecture Modeling will be critical in aiding the FVL Modular Component analysis and is also built from the various simulator needs. It identifies the exact equipment and infrastructure of the FVL LL to aid in cost determination. Candidates to perform this analysis are the graduate student in the Systems Engineering Program, Network Operations and Technology Program, and/or Computing Engineering Program at NPS. This team should take the SysML model developed in this capstone report and expand it to include networking details.

10. Staffing Factors

A human resourcing analysis with regards to staffing the FVL LL is best conducted after the cost benefit analysis is completed. The cost benefit analysis along with this report's conceptual design, which identified subject expertise required to operate the FVL, illuminate the constraints of the total workforce the FVL LL can support. The best team to perform this analysis will be graduate students in the Operation Analysis Program of the Operations Research Department in NPS with inputs and collaboration with the Staffing/Human Resource department of PMA-205 or a representative from the HQMC Total Force Structure Division. The team will define specialized FVL LL functional teams and analyze the most effective and efficient group size and skill sets to meet iterative release timelines without overburdening the budget.

11. Supply Chain

Further studies in how the FVL LL will conduct its supply chain management will assist in ensuring rapid prototyping and deployment stay "rapid." Without clear plans on how and when the prototype materials, replacements, and spares will affect final module or component delivery. Candidates to perform this analysis are the graduate students in the Logistics Analysis program under the Operations Research department at NPS with guidance and collaboration with Marine Corps representatives from the ALS Branch. This team should use the FVL component analysis together with this capstone report to determine supply chain implementations and shortfalls to avoid.

12. Integrating Non-FVL Marine Corps Air Vehicles

Once proven successful in supporting FVL releases, the FVL LL will have proven infrastructure in place to support more Marine Corps aircraft models. Future studies can be conducted to identify the next aircraft model's modular components and training simulators. The studies will also identify integration processes for the new modules to be implemented into the existing FVL LL workflow processes. Candidates to best conduct this integration and interoperability research are graduate students in the Systems Engineering Program at NPS with feedback from lead systems engineers of the FVL and of the aircraft next slated to use the FVL LL. Ideally, the team will develop a component analysis similar to the FVL component analysis, interoperability considerations, and identify resource burden load.

13. Integrating Multiple Branch Sensors Under a Single Combat System

As mentioned in Chapter II, the work that The Forge has done on digital twin technology may be a useful tool for integrating legacy systems into the modern battle picture. Once the LL is operational and successfully implements digital twin technology for the FVL and its systems, the LL may become a launch site for the development of digital twins for other USMC systems. If successful, future studies can be conducted to analyze the benefits of implementing a digital twin lab as an independent or as part of the FVL LL's on-site manufacturing branches. Candidates to best conduct this research are graduate students in the Systems Engineering Program at NPS with lessons learned from The Forge. The team will develop a cost-benefit analysis, staffing requirements, and identify resource burden load based on the future performance of digital twin technology.

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