



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

**CONVERTING A MANNED LCU INTO AN UNMANNED  
SURFACE VEHICLE (USV): AN OPEN SYSTEMS  
ARCHITECTURE (OSA) CASE STUDY**

by

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September 2014

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(USV): AN OPEN SYSTEMS ARCHITECTURE (OSA) CASE STUDY**

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## **ABSTRACT**

This thesis demonstrates the process by which the concepts of open systems architecture (OSA) might be applied within the context of an existing systems engineering methodology to result in a flexible system. This is accomplished by combining an existing systems engineering process model with OSA management and business principles to execute a successful asset-repurposing program. To demonstrate utility of this OSA approach to systems engineering management, this thesis analyzes an atypical asset-repurposing program: the conversion of a 1610 Class Landing Craft Utility to an unmanned surface vehicle.

This thesis shows that OSA technical architecture is best implemented by defining high-level, business and technical flexibility requirements. This thesis argues that proper up-front architecting can balance non-recurring acquisition costs with future recurring lifecycle and modernization costs. A reference model and open standards are used to show the value of interface flexibility.

This analysis makes the case for extending the useful service life of a Naval asset via repurposing rather than disposing of the asset, as is traditional. Furthermore, this analysis shows that strategic reuse or repurposing of assets represents an innovative alternative to the traditional sense of new-product acquisition, new-construction, and product modernization decisions.

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## LIST OF ACRONYMS AND ABBREVIATIONS

3D	three-dimensional
A2/AD	counter-anti-access/area-denial
ACU	Assault Craft Unit
AOR	area of responsibility
ASW	antisubmarine warfare
ASV	autonomous surface vehicle
ASTM	American Society for Testing and Materials
AT&L	Acquisition, Technology, and Logistics
ATC	Armored Troop Carrier
BBP	Better Buying Power
BCA	business case analysis
BDA	battle damage assessment
BII	Business Innovation Initiative
BSA	battle space awareness
C&C	command and control
C4I(SR)	command, control, communications, computers, intelligence, (surveillance, and reconnaissance)
CA	California
CAIV	Cost As an Independent Variable
CAN	controller area network
CARACaS	Control Architecture for Robotic Agent Command and Sensing
CDD	Capabilities Development Document
CNA	Center for Naval Analyses
CNO	Chief of Naval Operations
COLREGS	U.S. Coast Guard Collision Regulations
COMOX	early Canadian torpedo-UUV concept
CONOPS	concept of operations
COTS	commercial off-the-shelf
CRRC	Combat Rubber Raiding Craft

CRUSER	Naval Postgraduate School Consortium for Robotics and Unmanned Systems Education and Research
CUSV	Common Unmanned Surface Vehicle
DAG	Defense Acquisition Guidebook
DAGR	Defense Advanced GPS Receiver
DASN	Deputy Assistant Secretary of the Navy
DAU	Defense Acquisition University
DC-ARM	Damage Control Automation for Reduced Manning
Deg F	degrees Fahrenheit
DON	Department of the Navy
DST	depth/speed/temperature
ECU	engine control unit
EMILY	Emergency Integrated Lifesaving Lanyard
EMMI	energy, matter, material, and information
EOL	end of life
EW	electronic warfare
FAR	Federal Acquisition Regulation
FDNF	forward deployed Naval forces
FDO	flexible design opportunity
FFG	Oliver Hazard Perry-Class Frigate
FLIR	Forward-Looking Infrared (Radar)
FLO/FLO	float-on float-off
FOC	full operational capability
FY	fiscal year
GAO	Government Accountability Office
GPS	Global Positioning Satellite
GYRO	gyroscope
HA/DR	humanitarian assistance/disaster recovery
HLD	homeland defense
HPU	hydraulic power unit
IA/IS	info assurance/info security
ICD	Interface Control Document/Initial Capabilities Document

IEEE	Institute of Electrical and Electronics Engineers
IMINT	imagery intelligence
IO	information/intelligence operations
IOC	initial operational capability
IOT&E	initial operational test and evaluation
IPB	intelligence preparation of the battlespace
IQAN	trademark for electronic control systems for mobile machinery
ISEA	In-Service Engineering Agent
ISO	International Organization for Standardization
ISR	intelligence, surveillance, and reconnaissance
ISOGSS	in support of global security study
JPL	Jet Propulsion Laboratory (NASA)
K	thousands
Kts	knots
L&R	launch and recover
LASH	lighter aboard ship
LCAC	Landing Craft Air Cushion
LCM	Landing Craft Mechanized
LCU	Landing Craft Utility
LCS	Littoral Combat Ship
LHA	Landing Helicopter Assault
LO/LO	load-on load-off
LPD	Landing Platform/Dock
LRIP	low-rate initial production
LT	long tons
M1A1	variant designation for main battle tank of the U.S.
MAPC	Marine Applied Physics Corporation
MARAD	U.S. Maritime Administration
MASINT	measurement and signature intelligence
MC2	master controllers
MCM	mine countermeasures
MIW	mine warfare

MIL-STD	military standard
MNS	mission needs statement
MMOWGLI	Massive Multiplayer Online War Game Leveraging the Internet
MOCU	Mobile Operation and Control Unit
MOSA	modular open systems architecture
MP	master plan
MS	maritime security
MSHIPCO	M Ship Company (San Diego, CA)
NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NDI	non-developmental items
NHHC	Naval History and Heritage Command
NM	nautical miles
NMAWC	Naval Mine and Anti-Submarine Warfare Command
NMEA	National Marine Electronics Association
NOAA	National Oceanographic and Atmospheric Administration
NPS	Naval Postgraduate School
NRE	non-recurring engineering/expenditures
NSWC-CD-DN	Naval Surface Warfare Center, Carderock Division, Detachment Norfolk
NSW	Naval Special Warfare
O&S	operation and sustainment
OPNAV	Office of the Chief of Naval Operations
OSA	open systems architecture
OSD	Office of the Secretary of Defense
PC	Cyclone-Class Patrol Coastal Ship
PED	Processing, Exploitation, and Dissemination
PEO	Program Executive Office
PLC	programmable logic controller
PLAN	People's Liberation Army-Navy
PM	Program Manager/Management
PMS	Program Manager Sea (Naval Sea Systems Command)



PRC	People's Republic of China
PY	Planning Yard
RAND	Research And Development Corporation
RDT&E	research, development, test, and evaluation
RIB	rigid inflatable boat
ROI	return on investment
ROMO	range of military operations
SAE	Society of Automotive Engineers
SAR	search and rescue
SATCOM	satellite communications
SCAMP	Scalar Common Affordable Modular Platform
SC(X)R	Surface Connector (X) Recapitalization
SE	systems engineering
SEABEE	Sea Barge Carrier
SEACAT	Southeast Asia Cooperation Against Terrorism
SEALION	SEAL Insertion, Observation, and Neutralization
SECNAVINST	Secretary of the Navy Instruction
SIGINT	signals intelligence
SIS	Spatial Integrated Systems
SLEP	service life extension program
SOA	service oriented architecture
SOF	Special Operation Forces
SOP	standard operating procedure
SPECWAR	Special Warfare Command
SSC	Ship to Shore Connector
SSN	attack submarine (nuclear propulsion)
SSV	Semi-Submersible Vehicle
Std	standard
SWBS	ship work breakdown structure
T&E	test and evaluation
TOC	total ownership cost
TMLS	Textron Marine and Land Systems

TRL	technology readiness level
U	unclassified
UAV	unmanned aerial vehicle
UMS	unmanned maritime system
U.S.	United States
USCG	United States Coast Guard
USD	Undersecretary of Defense
USMTF	United States Message Text Format
USN	United States Navy
USV	unmanned surface vehicle
UUV	unmanned underwater vehicle
UXV	unmanned vehicle (unspecified type)
VA	Virginia
VBSS	visit, board, search, and seizure
WESTPAC	West Pacific

## **EXECUTIVE SUMMARY**

This work is an exemplar for effective conversions of manned craft into unmanned surface vehicles (USVs) utilizing Open Systems Architecture (OSA). This study provides a sufficient basis to initiate an in-depth examination and business case analysis of OSA asset repurposing by a forum such as the Defense Acquisition Research Symposium (DARS) or major Defense acquisition organization. The knowledge contained in this study alone may be sufficient justification to proceed with further analysis since the knowledge of how to effectively convert manned systems into unmanned systems is an enabler for rapid force reconstitution.

This thesis shows that OSA technical architecture is best implemented by defining high-level flexibility requirements. Not only does this leave more trade space for the designers and engineers, but it also helps keep system costs low by loosely defining the interfaces. Furthermore, it also allows the system to be upgraded at a later time. With these advantages considered, this thesis argues that proper up front architecting can balance non-recurring acquisition costs with future recurring lifecycle and modernization costs.

In the case of the landing craft utility unmanned surface vehicle (LCU USV), this analysis makes the case for extending the useful service life of a Naval asset via repurposing it, instead of traditionally disposing of the asset. Oftentimes, to satisfy a requirement in traditional DOD acquisition programs, acquisition authorities choose the lowest cost, most technically acceptable choice from amongst feasible, new design alternatives. Strategic reuse or repurposing of assets represents an innovative alternative to the traditional sense of new-product acquisition, new-construction, and product modernization decisions. OSA capabilities make such innovative reuse possible.

The LCU USV may be used for a plethora of missions if redesigned for OSA and flexibility. Although this thesis focuses mostly on the simple addition of unmanned navigation and maneuvering capability, a few simple architectural modifications can greatly increase the utility of this craft. Although the exact mission for the LCU USV in

the future remains undefined, implementing OSA throughout this end-of life (EOL) process ensures that accommodating potential missions is as cost effective as possible.

OSA has both business and technical aspects that must be addressed concurrently throughout the systems engineering process. In order to achieve maximum openness from a system, the right business and technical questions must be asked and those questions must be appropriately answered. While it is true that there is no single, guaranteed formula for successful systems engineering, there are a few questions that must be addressed when considering how to effectively repurpose and reuse existing assets. All questions must allow stakeholders to evaluate the program with respect to whether or not the program has achieved maximum openness. The answers to these questions are based on principles found in Better Buying Power (BBP), the DOD OSA Contract Guidebook, modular open systems architecture principles, as well as other heuristic notions. OSA principles may be used to provide the best chance of long-term program success, low program costs, low risk, and technically acceptable program performance.

At a fundamental level, the following overarching questions must be answered appropriately in order to satisfy the principles of open systems architecture when executing the traditional systems engineering (SE) methodology. All other questions follow from these simple, general questions.

- Can one or more qualified third parties add, modify, replace, remove, or provide support for a component of the system, based on open standards and published interfaces (DOD 2013)?
- Are qualified new entrants to the market for the task able to compete for the work immediately, and in every year moving forward (Musk 2014)?

These questions build the framework for executing OSA throughout an SE program. The OSA framework includes a set of principles, processes, and best practices that provide more opportunities for competition and innovation. This framework helps to field systems that are affordable, interoperable, minimize total ownership cost, optimize total system performance, are easily developed and upgradeable, and achieve component software reuse (DOD 2011).

In the case of system repurposing and reuse, it must be beneficial to the system owner to continue system operation instead of system disposal. In order to accept the feasibility of fielding the LCU USV, the US Navy must decide that it is worth the return on investment (ROI). There are several decisions that go into making this a reality. Implementation of OSA is essential to the future effectiveness and cost of these decisions. These decisions include the decisions not to dispose of the LCU although the craft are well beyond the intended service life. The decision must be made to maintain the current hulls in an operational state. A subsequent decision must be made to install equipment alterations that convert the LCU hull into a USV. Finally, operating an LCU as a USV likely requires the decision to add additional payload operations so that payloads can be operated remotely or autonomously.

This thesis demonstrates the process by which the concepts of OSA might be applied within the context of an existing, traditional SE methodology to result in the production of a flexible system that supports the Defense enterprise in maintaining a competitive advantage. This demonstration is accomplished by combining an existing systems engineering process model with the use of OSA management and business principles to execute a successful asset-repurposing program. Specifically, this work examines conversion of a manned asset into an unmanned system.

OSA facilitates interoperability between systems by effectively leveraging “common capability descriptions in system requirements; common, open data models, standards, interfaces, and architectures in system design, and common components in system acquisition strategies” (DOD 2011). Because the traditional approach to systems engineering must be considered as a contributing factor to the high cost, high complexity, and highly integrated systems that exist today, this thesis contends that traditional SE methodologies must be combined with OSA principles in order to realize systems that are open, flexible, and more affordable.

A reference model and open standards are used to show the value of interface flexibility. This study also shows that, when working with open systems, the systems engineering team can avoid major system changes, even if the system is already rigidly/maturely designed, by developing an open technical architecture within existing

design constraints. By defining key interfaces, modules, stations, and zones, the impact of alterations are anticipated to be less costly. This type of design methodology is especially effective for highly technical systems such as the LCU USV where technology advances may occur rapidly.

With respect to Naval and ship systems, more granularity may be added to the definition of open systems architecture in order to specifically address the maritime domain. OSA in U.S. Naval ship design is more fully described as “modularity and flexibility in open systems” (Marcantonio 2007). OSA principles have important implications for naval architects, and provide the basis for the first step of the flexible design process: identifying the sources of uncertainty. Flexibility is only valuable if it addresses an underlying uncertainty appropriately (Page 2011). The interchangeable architecture of system elements, modules, sea-frame zones, stations, and associated interfaces in an open system is what makes such architecture affordable and flexible.

To demonstrate utility of this OSA approach to systems engineering management, this thesis demonstrates an atypical asset-repurposing program. The Landing Craft Utility (LCU) was not intentionally or originally designed as a highly reusable platform (i.e., “truck”) with an inherent ability to be repurposed for future, yet-to-be-determined missions. However, this thesis demonstrates that there is value in design for reusability and repurposing of exiting assets as exemplified by the conversion of a manned LCU to an unmanned surface vehicle (USV).

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# **I. BACKGROUND**

## **A. PROBLEM STATEMENT**

This thesis explores the use of open systems architecture (OSA) as a tool for effective management of asset repurposing. It details the use of Open Systems Architecture (OSA) to convert a manned asset, the Naval Landing Craft Utility (LCU) 1610 class vessel, into an unmanned asset, an unmanned surface vehicle (USV).

The United States (U.S.) has been challenged in recent times, and is likely to be challenged in the foreseeable future, with the uncertainty of asymmetric threats, nontraditional military operations, and unprecedented calls to support its friends and allies in times of conflict and hardship. Maintaining the United States' military and diplomatic competitive advantage requires continued superiority in military operations. More importantly, beyond current national Defense objectives, the U.S. military must ultimately be prepared for operational requirements that cannot yet be predicted.

In preparing for threats, yet to be determined, the United States cannot have total certainty regarding what types of assets will be needed, and where they will be needed to meet these challenges. Furthermore, the United States cannot guarantee that the funding, manpower, or other resources will be available to meet each emergent military requirement.

One way to adjust immediately to these uncertainties is to leverage flexibility that currently exists. One of the most flexible assets in the U.S. military today is the landing craft. These craft have unrealized potential to serve the military in a wide variety of missions. Unmanned systems are another type of potentially flexible asset with the capability to reduce risk to personnel, take on new mission sets, and augment traditional objectives. Combining the flexible architecture and operation of existing landing craft platforms with the added capability and benefits of unmanned technology has the potential to bring unforeseen capability and affordability to current and future Naval operations.

## **B. MOTIVATION**

A major challenge for defining the future of military capabilities is to address new methods, tools, and skills needed in the early design efforts and systems engineering (SE) giving programs greater cost performance in maintaining the competitive advantage.

One of the greatest challenges in defining the platforms that can execute the uncertain missions of the future is establishing the processes, tools, and principles that are used today, in early system development, possibly for many years (or even generations,) before the system is designated for a particular mission. Because of this, strategic program planning, systems engineering and systems architecture strategies must be considered far in advance of making final design and business decisions. Early consideration of such strategies ensures a wide array of affordable, flexible, open, and competitive future capability options.

One method of developing these strategies is to define the technical rigor of building systems in a way that supports the Chief of Naval Operations' (CNO) vision of a future employment model, "Payloads Over Platforms." This open, and relatively unrefined, method for developing systems is especially challenging because the Navy has limited experience in building systems this way. Adequately preparing the acquisition workforce to utilize this method requires better definition of the Government's roles and processes prior to industry involvement.

In the July 2012 issue of *Proceedings* magazine, the Chief of Naval Operations (CNO) Jonathan Greenert asserted:

Navy platforms, particularly ships and aircraft, are large capital investments frequently designed to last for 20 to 50 years. To ensure our Navy stays relevant, these platforms have to adapt to the changing fiscal, security, and technological conditions they will encounter over their long service lives. It is unaffordable, however, to adapt a platform by replacing either it or its integral systems each time a new mission or need arises. We will instead need to change the modular weapon, sensor, and unmanned vehicle "payloads" a platform carries or employs. In addition to being more affordable, this decoupling of payload development from platform development will take advantage of a set of emerging trends in precision weapons, stealth, ship and aircraft construction, economics, and warfare. (Greenert 2012)

In many ways this is uncharted territory for Naval acquisitions. In some respects, this is the “Wild West” of Naval acquisition in that there is a tremendous amount of reward to be reaped from smart intellectual investments made now. By reducing, preparing for, and accommodating the uncertainty surrounding acquiring new technologies, the Navy can find ways to buy more capability with less money. In his memorandum on Better Buying Power (BBP), the Undersecretary of Defense for Acquisition, Technology, and Logistics (USD AT&L) stated, “the goal [is to] deliver better value to the taxpayer and warfighter by improving the way the Department does business” (Kendall 2012).

In 2013, the Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation (DASN RDT&E) testified before congress outlining the ways that Department of Navy (DON) acquisition leadership continues to promote the adoption of BBP and Open Systems Architecture (OSA) to support innovation, reduce the time needed to integrate improved technologies (cycle time), lower systems’ total ownership costs, and emphasize reuse via modularity (Lacey 2013).

More recently, in 2014, Assistant Secretary of the Navy for Research Development and Acquisition and the Commander of Naval Sea Systems Command testified before congress regarding several procurement, modernization, and sustainment initiatives to aimed to affordably and effectively enable the warfighters to operate as a more flexible force (Stackley, Mulloy, and Hillardes 2014).

Many of the Navy initiatives seem to focus on the high-value, high-visibility assets (i.e., ships, airplanes, submarines), and rightfully so, but there may be significant value in looking for potential existing flexibility in the subordinate supporting systems, infrastructure systems, cyber systems, and in other areas of the Navy fleet. The U.S. Navy, in recent times, has used highly valuable assets for missions on the lower range of military operations. One area that is uncultivated by current initiatives is opportunities for large-scale repurposing through technology insertion into existing assets. If the Navy can use repurposed, lower cost, or lower value assets for these missions, it is then able to provide potential cost savings and free up high-value resources for more critical missions.

Traditional, industrial-age Naval acquisitions practices produced systems that were highly specified and integrated. The Navy continues to operate with the products and assets of these practices. The Navy is likely to continue with these products and assets for the near future until the knowledge of flexibility, OSA, and BBP principles can become part of the tacit operational knowledge, and best practices of the acquisition community. In the meantime, there are existing systems that inherently contain a high level of flexibility. The Navy needs to find and exploit opportunities for flexibility now.

## **C. OPERATIONAL CLIMATE**

In order to further establish the background, an understanding of the operational climate is necessary. In this section, four (4) major elements of the operational climate are detailed including a discussion of their benefits and challenges.

### **1. Littoral and Coastal Operations**

Littoral and coastal operations represent the current presence of asymmetric and untraditional military operations. With the impending retirement of the Oliver Hazard Perry-class frigates (FFG-7), the Osprey-class costal mine hunter, Cyclone-class patrol coastal ship (PC) and the Avenger-class mine countermeasures ship, the U.S. Navy has an increasing need and an evolving strategy for new operational capabilities in the littorals. To meet this need, the Littoral Combat Ship (LCS) was introduced into the Navy fleet. The Undersecretary of Defense describes the LCS as a “smaller, less capable, and less expensive [ship] than an FFG, but larger, more capable, and more expensive than Patrol Coastal Ships (PCs) and Mine Countermeasure Ships (MCMs)” (Work 2013). He goes on to compare LCS to PC and MCM craft saying that “PCs and mine warfare ships—all to be ultimately replaced by LCSs—were single-purpose ships with useful littoral counter-anti-access/area denial (A2/AD) capabilities but very slow transit speeds” (Work 2013).

Although LCS is planned to take over the mission set of several smaller, slower ships, that does not negate the potential value that still exists in these smaller vessels. The Naval landing craft, with its broad range of possible missions, has potential overlaps in CONOPS with the LCS. Advances in amphibious assault vehicles, and a potentially

repurposed landing craft can offer a reliable, rugged follow-on support to LCS missions. Having more options in the littoral and coastal regions can allow for better operational flexibility.

## **2. Riverine Operations**

With an increasing amount of inland and guerilla warfare, riverine operations are likely to become increasingly important. A 1990 Naval Special Warfare Command (NAVSPWARCOM) study recommended that the U.S. Marine Corps develop a joint riverine capability using only existing assets. Four (4) LCU 1610 Class craft were amongst the list of U.S. Naval assets in the final capability (quoted in CNA 2006).

Landing craft were last used in major U.S. Navy riverine operations during the Vietnam War. Lessons-learned and strategies from the Vietnam War are relevant to current U.S. Naval challenges. There were many commonalities between the Vietnam missions and today's Naval challenges. These commonalities include a varying array of missions, an international riverine advisory and cooperation effort, joint operations, use of U.S. in-house design capability, and the ability to "reach back" to Vietnam riverine-force veterans for expertise (CNA 2006).

During the Vietnam Conflict Era, landing craft were used to keep supply routes open and penetrate small waterways (see Figure 1).



Figure 1. Vietnam war era landing craft conducting inland waterway operations (from NHHC 2014).

In the late 1960s, the U.S. Navy employed a 23-ft craft, similarly configured to an LCU, to operate as a remotely controlled “chain drag” minesweeper (see Figure 2) (U.S. Department of the Navy [DON] 2007). Since that time, the U.S. Navy has participated in several similar joint riverine operations with the U.S. Army and U.S. Coast Guard in Bosnia, Bolivia, and Iraq.

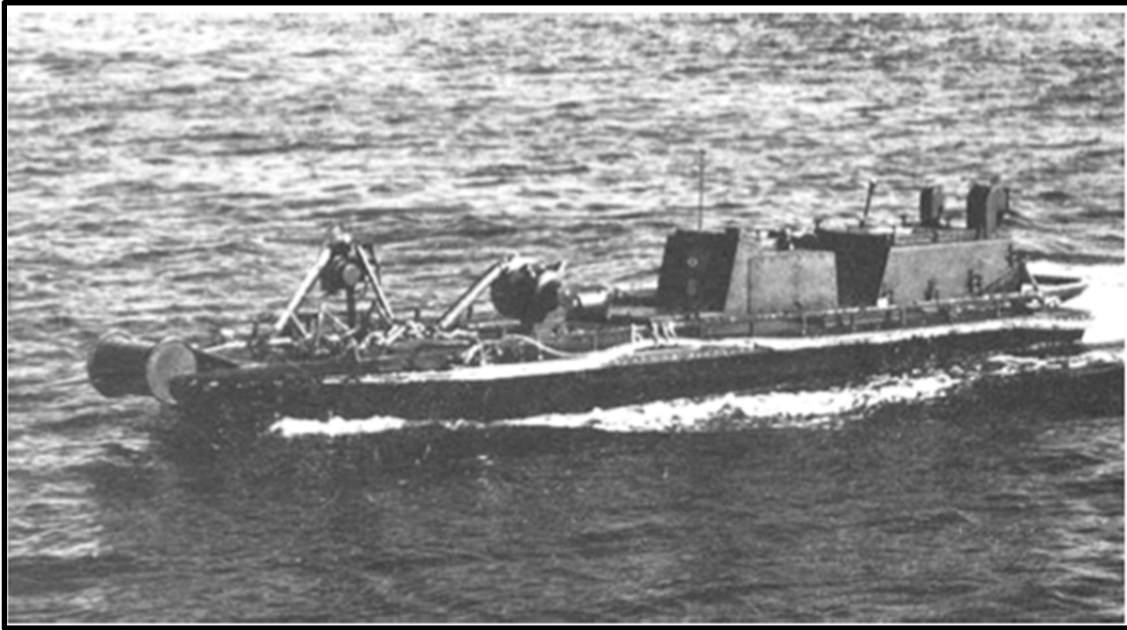


Figure 2. Vietnam era minesweeping drone (from DON 2007).

Examination of Vietnam War riverine operations also offers insight into the United States history of reconfiguring or repurposing landing craft to serve modern functions other than what was intended at design. Army troops were typically carried into battle aboard a Naval Armored Troop Carrier (ATC), a conventional landing craft with special added armor to protect the troops during close-in firefights. “A number of the ATCs were modified by the addition of a helicopter pad over the forward part of the boat, making them the Navy’s smallest ‘aircraft carrier.’ These ‘mini-carriers’ were used for quick resupply and for speedy evacuation of wounded personnel during combat” (NHHC 2014) (see Figure 3). Additionally, four Landing Craft Mechanized (LCM-6s) were reconfigured as “refuelers” that carried both helicopter and small-boat fuel. One “refueler” had a helicopter pad (NHHC 2014). Key takeaways from an analysis of

Vietnam era use of landing craft are the proven ability of landing craft to act as a resupply platform for U.S. troops, and also the added benefit of landing craft when used to control the flow of enemy supplies, and troops in riverine conflict.



Figure 3. Vietnam War era landing craft converted to a helicopter landing platform (from NHHC 2014).

### **3. Humanitarian Operations, Building Partnerships, and Global Security**

Natural disasters and political around the world in recent times have created instances in which the U.S. Navy is called by friends and allies to aid in the swift stabilization, protection, and restoration of their way of life. Often in these instances, countries need a reliable, heavy-lift, maritime asset capable of carrying large numbers of citizens and supplies. With the flexibility to carry 400 passengers or a 180 ton payload of equipment and supplies, the LCU and other similar landing craft are in high demand for humanitarian assistance, disaster recover (HA/DR) operations.

In 2006, in the midst of an international crisis, the United States evacuated thousands of U.S. citizens from Beirut, Lebanon to Cyprus with LCU craft at the core of the Naval operations moving thousands of people from the shore to the sea-based evacuation ships (GAO 2007) (see Figure 4). Later, when a catastrophic earthquake devastated the island nation of Haiti in 2010, the United States responded with an HA/DR operation including five LCU (Chief of Naval Operations Assessments Directorate (OPNAV N81) 2011).



Figure 4. U.S. evacuees leaving Lebanon in 2006 via LCU (from GAO 2007), taking advantage of the 400 passenger, 180 ton payload capacity.

Beyond assisting humans in distress, in HA/DR situations, the LCU USV may also be used for disaster recovery operations in which it is less likely that human life is at stake. In 2008, a manned LCU was used to deliver hay to stranded cattle on a beach in Galveston, Texas following Hurricane Ike (NavSource 2013). More recently, the Navy employed an unmanned maritime vehicle in the March 2014 recovery effort after the unexplained disappearance of a commercial airliner, Malaysian Airlines Flight 370



(Associated Press 2014). Combining the effectiveness of a USV with an LCU hull can bring significant added value to such Naval operations.

#### **4. Modern-Day International Naval Challenges**

There are two modern-day challenges for which the United States needs to account for present and future uncertainty. First, as other nations gain greater ability to project blue-water sea power beyond their borders and coastal regions, the United States must prepare sufficiently to mitigate new risks that arise as modern militaries make competitive gains. Second, the United States must make a concerted, deliberate effort to increase its ability to maintain Naval superiority against counterterrorism in the littorals, the deep-sea of the blue-water navies, and the rivers and inland waterways of the brown/green-water navies. These two issues are prevalent in present conflicts related to the South China Sea and international counterterrorism efforts.

##### ***a. South China Sea***

The United States has several areas of interest in or near Chinese territories, including the South China Sea and the Senkaku Islands in the East China Sea. “During their January 2011 summit, U.S. President Barack Obama and then-PRC President Hu Jintao jointly affirmed that a ‘healthy, stable, and reliable military-to-military relationship is an essential part of [their] shared vision for a positive, cooperative, and comprehensive U.S.-China relationship’” (DOD 2013). The U.S. DOD seeks to build a military-to-military relationship with China while encouraging China to cooperate with the greater international community in the delivery of public goods (DOD 2013).

Threatening this military-to-military relationship is the Chinese People’s Liberation Army-Navy (PLAN) formidable collection of sea-denial assets. These assets are designed to compete against and defeat U.S. military capabilities in the region. Thus, the United States must increase its ability to identify and defeat these forces if necessary.

As the PLAN capabilities increase, its strength is able to directly enhance China’s ability to enforce its interests and eventually alter the balance of power in the region. The United States needs to continue peaceful diplomatic approaches to China on issues of

territoriality, sovereignty, and trade in the South China Sea (Small 2002). In addition, the United States ought to contemplate supporting cooperative ventures between the American and Chinese navies, while continuing to maintain a viable naval presence in the Asia-Pacific to counter China's growing naval presence (Small 2002).

Although there is a need to maintain cooperative, peaceful relations with China, and other nations of the South China Sea, there is a concurrent need to be prepared for dissention and conflict. Speaking of a recent Chinese blockade of the South China Sea, Reuters said, "The United States says it is troubled by China's blockade, calling it a 'provocative move'. China's Foreign Ministry on Thursday criticized Washington for getting involved" (Reuters 2014).

As recently as 2007, the United States participated in exercises in support of Southeast Asia Cooperation Against Terrorism (SEACAT) 2007. SEACAT is a weeklong naval exercise between the United States and six Southeast Asia nations that allows participating nations to apply maritime security tactics in dynamic threat situations (Alvarez 2007).

The Future Unmanned Naval Systems (FUNS) Wargame Competition held in 2011 is an endeavor relevant to this topic. The FUNS wargame was designed to challenge and showcase the abilities of NPS students and faculty by working through problems of critical interest to the U.S. Navy. Three competitive teams of military officers explored the current and expected capabilities of unmanned systems to conduct coordinated operations, with minimal human supervision, posed in a naval conflict that was set five years in the future. Autonomous systems of interest include submerged, surfaced, airborne and space-based robots as well as advanced sensors and deployable networks. The FUNS wargame thus examined the key capabilities, challenges and shortfalls of unmanned systems as a major component of fleet operations. Multiple innovative developmental possibilities, concepts of operations, conclusions and recommendations for future work were produced. Lessons learned hold broad interest for both Navy and industry stakeholders (Brutzman et al. 2011).

“In concert with its allies and partners, the United States will continue adapting its forces, posture, and operational concepts to maintain a stable and secure Asia-Pacific security environment” (DOD 2013). The U.S. Navy operations in Asia are continuing to develop and evolve. Part of this development must include adaptable forces.

***b. International Counter-Terrorism***

With the proliferation of terrorist activities against the United States and its allies around the world, there is an increasing demand to be ready to respond to unpredictable attacks on citizens and natural resources. The United States regularly conducts international cooperative exercises to prepare for potential crime via the sea. For instance, the Navy conducted counter-terrorism exercises and deployments in Guantanamo Bay, Cuba in 2004 (Matlock 2004) and in the Mediterranean Ocean in 2006 (Cartwright 2006).

In recent years, the U.S. Navy has conducted Maritime Security Operations (MSO) in the Persian Gulf, Gulf of Aden, Gulf of Oman, Arabian Sea, Red Sea, and Indian Ocean which help set the conditions for security and stability in the maritime environment, as well as complement the counter-terrorism and security efforts of regional nations (U.S. Navy Chief of Information 2014).

**D. DEFINITION OF AN LCU**

To help explain the value of reuse and repurposing, this thesis details a case study utilizing a Landing Craft Utility (LCU). The Landing Craft Utility (LCU), 1610 class, was built in the 1970s as an update of the landing craft made famous during the island-hopping amphibious campaign of World War II. The LCU is 135 feet long and can carry 180 tons of equipment or 400 combat equipped Marines at 12 Knots. These vessels are normally transported into theater in the well decks of L-Class amphibious ships; however, organic messing and berthing facilities for its crew of 13 (including 2 Officers) enable self-sustained at sea operations in excess of seven days.

The LCU transports troops, equipment and sustainment to and from the shore and amphibious shipping or a seabase. In an amphibious operation, LCUs typically deliver personnel and equipment after the initial assault waves. Originally constructed for

amphibious assault operations, LCUs have proven to be highly adaptable for many uses including surf-zone salvage, large capacity movement of personnel and vehicles as in humanitarian assistance or non-combatant evacuation, as platforms for underwater testing, harbor and seabase security patrols, delivery of sustainment, coastal surveillance, riverine and boat haven operations.

These vessels have bow ramps for onload/offload, and can be linked bow to stern to create a temporary roll-through pier-like structure or perform stern-gate marriages to amphibious well deck ships. Welded steel hull construction and diesel propulsion provide high durability and fuel economy. The machinery layout also provides built-in redundancy in the event of battle damage, with two engine rooms separated by a watertight bulkhead to permit limited operation in the event one engine room is disabled. A stern anchor system is installed on the starboard side to assist in retracting after beaching.

The LCU affords heavy-lift, endurance and independent operations when speed is not the driving requirement. The LCU remains a valuable and complementary platform in the context of expeditionary operations and surface logistics support of forces ashore. The current U.S. Navy Landing Craft Utility (LCU) 1610 Class is planned for replacement between 2017–2023. Upon deactivation, conceivably, these assets can be repurposed as controllable USVs and used for many more years.

## **E. HISTORY OF THE USV**

The case study presented in this thesis converts an LCU to an unmanned surface vehicle (USV). Thus, it is necessary to understand the history and definition of the USV.

The first successful USV vehicle development and demonstration is credited to Nikola Tesla (see Figure 5). In 1898, Tesla designed, developed, patented, and demonstrated a remote controlled boat at an exhibition at Madison Square Garden in New York (Motwani 2012).



Figure 5. Radio-controlled boat built by Tesla (from Motwani 2012).

Unmanned surface vehicles have been used in U.S. Naval operations since the 1940s. “World War II saw the first experimentation with Unmanned Surface Vehicles (USVs). Canadians developed the COMOX torpedo concept in 1944 as a pre-Normandy invasion USV designed to lay smoke during the invasion—as a substitute for aircraft” (Quoted in Natter 2009). Following World War II, the United States developed and used USVs for purposes such as minesweeping and battle damage assessment (BDA) (James 2012).





At the same time, the U.S. Navy developed several converted landing craft intended for mine-clearing operations. It is unknown whether or not these craft, named the “Bobsled,” “Porcupine,” and “Woofus 120,” were ever successfully demonstrated or used in an operational environment. However, in the 1960s, the U.S. Navy did successfully conduct development of several USV target drones (Bertram n.d.)

While USVs date back at least to World War II, it is only in the 1990s that a large proliferation of projects appears (Corfield and Young 2006). This is a paradigm shift and technological progression in the U.S. Navy with an increased focus on littoral warfare

and anti-terrorism missions (Bertram n.d.). Successful missions of USVs in the global war on terrorism have increased interest in USVs within the U.S. Navy and several other modern, international navies.

#### **F. DEFINITION OF A USV**

In order to understand the problem of repurposing an LCU as a USV, it is first necessary to detail how unmanned surface vehicles are used in the Navy today. Understanding the definition and concept of employment for different types of USVs provides a benchmark for development of the capability set and concept of operations for an LCU USV. The 2007 Unmanned Surface Vehicle Master Plan defines four main classes of USV. USVs are typically defined with respect to their craft-type, hull size, and mission capability (see Table 1). Table 1 describes each of the four classes separating them in each column with a different color. For each class, the table presents its master plan priority, USV Joint Capability Area (JCA), Seapower Pillar, and USV Mission(s).

							
USV MP Priority	Joint Capability Area (JCA)	Seapower Pillar	USV Mission	X-Class (small)	Harbor Class (7M)	Snorkeler Class (7M SS)	Fleet Class (11M)
1	Battle Space Awareness (BSA) / Access/ Littoral Control	Sea Shield	Mine Countermeasures (MCM)		MCM Delivery, Search / Neutralization	MCM Search, Towed, Delivery, Neutralization	MCM Sweep, Delivery, Neutralization
2	BSA / Access/ Littoral Control	Sea Shield	Anti-Submarine Warfare (ASW)			Maritime Shield	Protected Passage and Maritime Shield
3	BSA, HLD, Non-Trad Ops, 7 Others	FORCEnet	Maritime Security		ISR/ Gun Payloads		7M Payloads
4	BSA / Access/ Littoral Control	Sea Shield	Surface Warfare (SUW)		SUW, Gun	SUW (Torpedo), Option	SUW, Gun & Torpedo
5	BSA / Access/ Littoral Control/ Non-Trad Ops	Sea Strike	Special Operation Forces (SOF) Support	SOF Support	SOF Support		Other Delivery Missions (SOF)
6	BSA, C&C, Net Ops, IO, Non-Trad Ops, Access, Littoral Control	Sea Strike	Electronic Warfare		Other IO	High Power EW	High Power EW
7	BSA, Stability, Non-Trad Ops, Littoral Control	Sea Shield	Maritime Interdiction Operations (MIO) Support	MIO USV for 11M L&R	ISR/ Gun Payloads		

Primary Missions supported by

X-Class	Harbor Class	Snorkeler Class	Fleet Class
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Secondary Missions of each class that are possible

Table 1. Four USV classes (from DON 2007).  
Missing: heavy-lift USVs.

There exists a capability gap in the present state of USVs as defined and utilized by the U.S. Navy. There is no class envisioned for large-hull, heavy-lift USVs. Given the current state of U.S. Navy USVs, this thesis elicits a requirement for a fifth class of USV defined as a class of rugged, large-hull, heavy-lift assets. The heavy-lift USV is able to perform well in Sea Shield Seapower Pillar for its most suitable missions. Furthermore, the heavy-lift USV might thrive in the capability gap left by current classes if USVs for USV MP priorities Maritime Security (#3), SOF Support (#5), and MIO Support (#7). Looking at the secondary mission set for Fleet Class USVs, there are several missions which can be classified as or overlap with logistics, and payload delivery mission sets (see Table 2).

**“X-Class”:** A small, non-standard class of systems capable of supporting SOF requirements and MIO missions. It provides a “low-end” Intelligence, Surveillance, Reconnaissance (ISR) capability to support manned operations and is launched from small manned craft such as the 11m Rigid Inflatable Boat (RIB) or the Combat Rubber Raiding Craft (CRRC) (U.S. Department of the Navy (DON) 2007).

**“Harbor Class”:** Based on the Navy Standard 7m RIB and is focused on the MS Mission, with a robust ISR capability and a mix of lethal and non-lethal armament. The “Harbor Class” USV can be supported by the majority of our Fleet, since it will use the standard 7m interfaces (U.S. Department of the Navy (DON) 2007).

**“Snorkeler Class”:** A ~7m semi-submersible vehicle (SSV) which supports MCM towing (search) missions, ASW (Maritime Shield) and is also capable of supporting special missions that can take advantage of its relatively stealthy profile (U.S. Department of the Navy (DON) 2007).

**“Fleet Class”:** A purpose-built USV, consistent with the handling equipment and weight limitations of the current 11m RIB. Variants of the Fleet Class will support MCM Sweep, Protected Passage ASW, and “high-end” Surface Warfare missions (U.S. Department of the Navy (DON) 2007).

Table 2. USV class definitions (from DON 2007).

This thesis defines a fifth class of USV notionally as the “Rugged-Class.” The “Rugged Class” of USV is a large-hull, heavy-lift, ruggedized USV. The class represents USVs that are at least the length of a patrol boat, ~30m or greater. It is primarily meant to operate at the lower-end of the Range of Military Operations (ROMO), although that likely depends on the variant (see Figure 6). Variants of the “Rugged Class” might be based on high-end combatant vessels in which case it may be suitable for missions in the higher ROMO. Arrows in Figure 6 show the operational trend or mission likelihood for a particular group. The colors show conflict intensity with green being the least intense and red being the most intense.



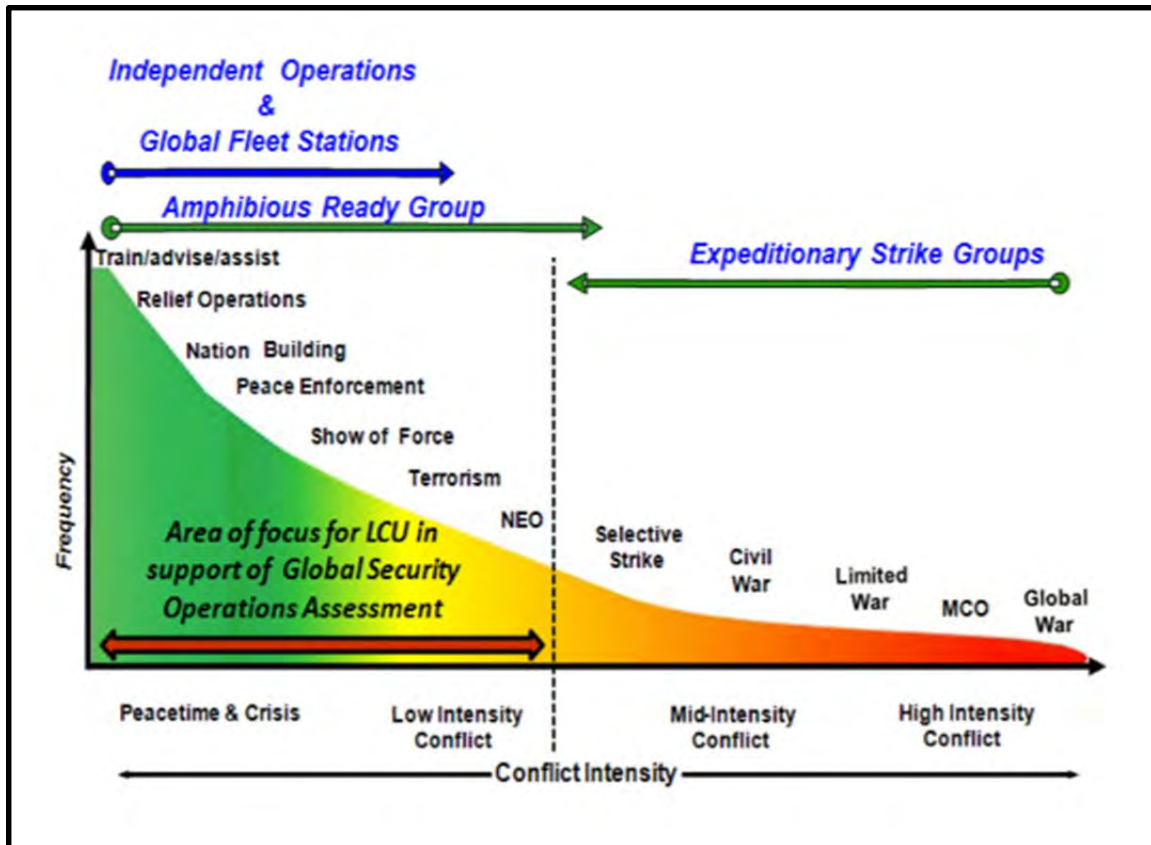


Figure 6. Range of military operations (ROMO) (from OPNAV N81 2011).

## G. LEVELS OF AUTONOMY

In order to repurpose and LCU as a USV, it is necessary to understand the options with respect to autonomy. In general, three levels of autonomy are defined: manual, semi-autonomous and fully autonomous (U.S. Department of the Navy (DON) 2007). However, to adequately describe autonomy within the context of this study, this thesis defines four levels of autonomy:

**Fully Autonomous:** Not remote controlled, completely preprogrammed mission from deployment to retrieval, monitored but no operator interference, no personnel onboard.

**Semi-Autonomous:** Personnel must control more difficult missions remotely (e.g., payload deployment, self-defense, and evasive maneuvers); easier missions and navigation are autonomous and preprogrammed, no personnel onboard.

**Remote Controlled:** Non-autonomous, all systems controlled by a remote operator, no personnel onboard.

**Autopilot:** Personnel onboard vessel with option to program and activate/deactivate autonomous system operations.

Autonomous vehicles have the ability to make decisions based on pre-programmed algorithms, or receive commands via tether or wireless signal, via line-of-sight or over-the-horizon transmissions. Although autonomy provides benefits such as manning reductions, the associated dangers are numerous. Any increase in autonomous behavior obviously increases the risks to safety of the USV and associated personnel (Naval Surface Warfare Center, Carderock Division, Detachment Norfolk (NSWC-CD-DN) 2012). Thus, it is important to realize that many autonomous systems can operate with varying types of autonomy depending on the mission need. Tradeoffs must be considered when examining levels of autonomy for USVs.

## **H. RESEARCH QUESTIONS**

This thesis examines the systematic, and effective application of Open Systems Architecture (OSA) principles as a tool for effectively managing a traditional systems engineering methodology. The thesis then goes on to illustrate this application via a case study in which an existing, flexible asset, the Landing Craft Utility (LCU) vessel is repurposed into a flexible unmanned surface vehicle (USV).

The primary question answered in this thesis is, “How must the concepts of open systems architecture (OSA) be applied within the context of a traditional systems engineering methodology to result in the production of a repurposed, flexible system that supports the Defense enterprise in maintaining the competitive advantage?”

Answering this larger question is accomplished by exploring the answers to several supporting questions. Table 3 presents the research questions examined in this thesis.

1. Can OSA be used as a management tool to make the SE process more effective?
2. How must OSA be applied to SE methodology to produce effective asset repurposing?
3. What are the critical decisions involved in leveraging OSA to manage SE?
4. What questions must be asked throughout the systems engineering process in order to elicit effective implementation of OSA in systems acquisition?
5. How must these questions be answered in order to produce optimal results?
6. Can an OSA approach be effectively applied to the SE process of repurposing an LCU to a USV?

Table 3. Research questions for thesis.

## **I. SCOPE AND METHODOLOGY**

This thesis focuses on the derivation of a generalizable set of considerations and processes for the effective implementation of OSA. It marries the existing principles and methodologies of OSA and SE to derive new principles, considerations, and concepts. Although a specific case study is presented, this thesis is not intended to present an in-depth engineering analysis and design of the LCU USV system. Any principles put forth from the case study are meant as illustrations for proof and substantiation of general concepts.

The case study in this thesis examines the systems engineering process for developing LCU USV. This thesis does not focus heavily on a particular final design for the LCU USV. It does not significantly address production and fabrication of a final design. This thesis does not examine the reengineering of payloads to marry with the LCU USV. This thesis does present a template for further program management, using OSA, which is applicable to the LCU and possibly other vessels of opportunity as identified.

## **J. THESIS ORGANIZATION**

Chapter I presents an overview of the problem, and gives basic information to establish a frame of reference for the reader.

Chapter II presents related work on the subjects of Open Systems Architecture; unmanned and autonomous vehicle concepts; and repurposed, flexible, and modular naval systems.

Chapter III builds upon previous work to develop the most important questions that must be asked in implementing OSA. It goes on to explain how these questions must be answered for effectiveness within the context of the systems engineering process.

Chapter IV presents a case study in the applying the principles of OSA within the systems engineering process of converting an LCU to a USV.

Chapter V presents a business case analysis (BCA) that analyzes feasibility of converting an LCU to a USV, and analyzes the effectiveness of applying the OSA principles within the process of converting an LCU to a USV.

Chapter VI summarizes the conclusions from this thesis, and offers recommendations for further study.

## **II. RELATED WORK**

This chapter presents several related works that may be leveraged to explain, and guide the use of OSA and SE in reusing existing Naval assets, including the development of unmanned technologies. In order to understand the methodology, and potential end-goal for developing the LCU USV, it helps to understand what work has been completed to-date regarding related concepts. The LCU USV concept crosses multiple high-value Defense and Naval initiatives. These initiatives include the development of unmanned systems; the development flexible, modular ship systems; and the development of open systems architecture (OSA) practices.

### **A. DEFINITIONS**

In order to adequately present previous works, this thesis first defines terms that have been used throughout the literature with respect to the payloads over platforms concept. There seems to be significant overlap in the definitions of flexible design, open architecture, and modular design. Understanding the differences and interplay between these concepts helps to understand the detailed implications of previous works. Defining these terms aids in differentiating between several closely related concepts throughout this analysis.

#### **1. Flexibility**

Flexibility in a system is characterized by the ability of the system's internal components to adapt in response to a change (Wilds 2008). A Flexible Design Opportunity (FDO) is a physical component enabling flexibility in a system (Cardin 2008).

#### **2. Open Architecture**

Open Architecture (OA) is the concept of maintaining non-proprietary interfaces, government data rights, and interoperability protocols in the contracting, architecture, and business process methodology used to develop and acquire systems (DOD 2011, DOD 2013).

### **3. Service-Oriented Architecture**

Service-oriented architecture (SOA) is a specific way of designing software, in a standardized architecture, that uses interchangeable and interoperable software components called services (DOD 2011).

### **4. Module**

A module is an “independent building block of a larger system with well-defined interfaces. A module is connected to the rest of the system in a manner that allows independent development of the module as long as the interconnections at the interfaces meet the established standards” (Cheung 2010).

### **5. Module Station**

A module station is “a volume reserved within a controlled portion of a functional area and designed to accommodate the installation of a module. The station [provides] support connections that mate with the module; both module and module station conforming to the same interface standard” (Cheung 2010).

### **6. Modularity**

The term modularity is used to characterize “a design approach in which a system is functionally partitioned into discrete, scalable and reusable modules consisting of isolated, self-contained elements. The system is designed with standardized interfaces, dimensions, and performance parameters for easy assembly, repair and flexibility” (Cheung 2010).

### **7. Open System**

An open system is “a system that employs modular design and uses consensus-based, non-proprietary standards for key interfaces” (Cheung 2010).

## **B. UNMANNED AND AUTONOMOUS VEHICLE CONCEPTS**

Extensive research has been conducted on unmanned systems for the maritime domain. Surface vessels account for a large part of these works. It is imperative to

understand the successes, challenges and lessons-learned from these works in order to appropriately establish a baseline for development of the LCU USV.

## **1. Tailorable Remote Unmanned Combat Craft**

In a 2012 Naval Postgraduate School (NPS) capstone project, a team designed and conducted a systems engineering analysis of a family of USVs that can be integrated with manned and other unmanned forces to augment, support, and improve a broad spectrum of missions (Loren 2014). The project presents three designs for USVs of varying sizes and capability. The largest of the designs is depicted in Figure 7. The report provides insight into the unique architectural, operational availability, and legal issues surrounding large USV development.



Figure 7. USV Model-Large (91–200 feet in length). Compared to an existing naval vessel of similar size (from Loren 2014).

This thesis recommends that further study be conducted to continue the pursuit of an open architecture standard for connecting USVs with other, dissimilar systems. The thesis goes on to recognize that open architecture (OA) is valuable to fielding a USV system, but OA is not the sole factor in achieving full autonomy.

With respect to survivability and availability requirements, the study recommends implementing large numbers of lower-cost vessels in order to achieve greater combat capability. In order to establish metrics for reliability, the report proposes use of reliability paradigms from aviation and space industries, because mid-mission system failures are mission critical for USVs.

Finally, the capstone project recommends developing legal test cases to explore the consequences of autonomous machines, specifically highlighting the issues of foreseeable harm and tort liability.

## **2. MSHIPCO Mistral USV**

MSHIPCO, a commercial company from San Diego, CA, has designed and built an advanced 15-meter unmanned platform, the Mistral USV, featuring the Stiletto M-hull Technology, user-friendly control interface and composite material (PRWEB 2013) (see Figure 8). This company proves the importance and effectiveness of using existing naval designs combined with open architecture, flexible configurations, and commercial standards. This work also presents the concept of waypoint control or mother-ship control for a convoy or swarm of USVs acting in concert.



Figure 8. Mistral USVs in formation to perform a mission in coordinated formation (from PRWEB 2013).



### 3. Development of Unmanned Surface Vehicle for Sea Patrol and Environmental Monitoring

A 2012 study conducted an analysis of structural elements, control systems, software, and hardware necessary for development of a USV sea patrol and environmental monitoring (see Figure 9) (Yaakob 2012). This work shows that the state-of-the-practice has advanced to the point where a USV can be suitably built and operated with simple, affordable, commercially available technologies. Figure 9 shows a representative electronic control system. Boxes enclose the two parts of the system, and thin lines represent wired connection. The thick line represents a wireless connection.

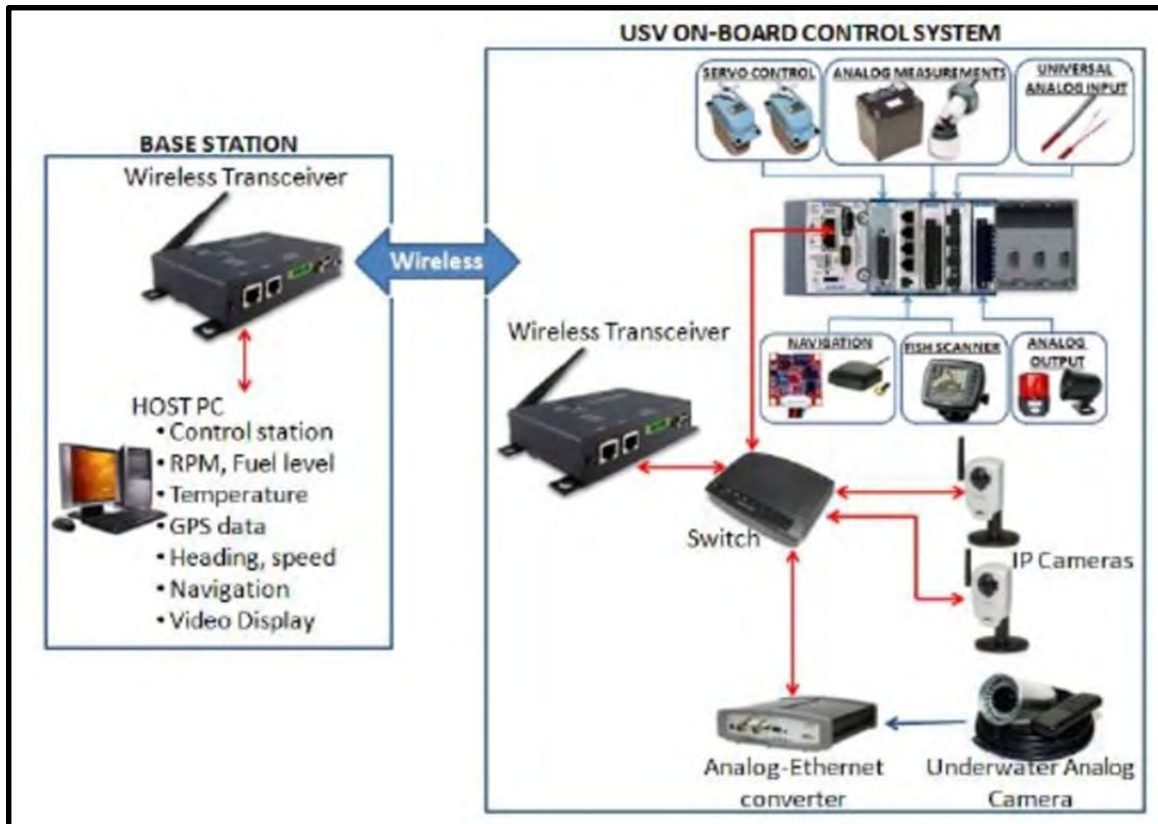


Figure 9. Hardware setup for a commercial USV control system (from Yaakob 2012).

#### **4. Mine Hunter Sweeping Vessel**

In his Naval Postgraduate School master's thesis, Tom Gough (2013) examined the notion of designing a vessel around its internal systems instead of first designing a hull form, and then attempting to backfit the internal systems. The main idea is that the payload determines the size, capability, and power requirements of the host vessel. The thesis applied this idea within the context of a notional, commercially available, mine countermeasures vessel called the mine hunter sweeping vessel (MHSV).

This thesis suggests looking for cost-effective ways to monitor surface and subsurface events on a national level as well as increasing intelligence on threats. It also suggests that, for mine sweeping missions, future studies need to examine removing humans from the mine countermeasures (MCM) platform vessel, backfitting an autonomous control system in order to lower risk and increase mission flexibility. Given that the LCU may be a suitable platform for mine countermeasures payloads and missions, it stands to reason that the LCU USV, for use in MCM and other missions, ought to be examined as a potential solution to the requirements set put forth by Tom Gough.

#### **5. Repurposed Naval Asset: SSN USV Launch Tube**

A capstone project (Calvert et al. 2011) from the Naval Postgraduate School demonstrated the use of the systems engineering methodology to repurpose an existing asset, a Naval submarine torpedo tube, for future missions involving an integrated mechanism for the launch and recovery of unmanned underwater vehicles. The LCU, by original design, is a platform that can support a wide array of payloads. With the alteration to make the LCU into a USV, the options for these payloads become even broader.

Calvert et al. (2011) draw attention to the fact that many technologically advanced payloads such as UUVs or USVs may not yet be mature. Furthermore, the payloads may have rapidly evolving architectures that must be accommodated by the platform.

The key takeaway from this work is that studies need to focus on the flexibility and modularity of platforms in order to support incremental changes to technologically

advanced payloads. This project also suggested that maintaining close relationships with payload designers and manufactures is necessary in order to limit the risks to acquisition and performance.

Extending this notion to the LCU USV suggests that every effort need to be taken to ensure that the inherent flexibility in an LCU is used to the maximum extent when operating as a manned or unmanned platform. Additionally, a key to ensuring this takes place is identifying the correct stakeholders, and maintaining a close relationship with them to track changing requirements and capabilities.

## **6. NPS Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) and the Wave Glider USV**

The Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) at the Naval Postgraduate School provides an interface for academia to address the unmanned systems needs of the Department of Defense. Many of the CRUSER initiatives aim to advance the study and fielding of unmanned systems, including USVs.

CRUSER has several projects that are conceptually related to the LCU USV. Notable CRUSER studies include the U.S. Coast Guard Unmanned Maritime System (USCG UMS) and the Wave Glider USV. The concepts, results, and suggestions from these studies can be used in the methodology to develop the LCU USV.

In 2013, U.S. Coast Guard LT James B. Zorn completed a thesis, in association with the CRUSER, which presented a systems engineering analysis of unmanned maritime systems for U.S. Coast Guard missions. This thesis stepped through the systems engineering analysis of such a system by performing a capability analysis, an analysis of alternative architectures, and a feasibility analysis of certain key system enablers. This study laid a foundation for future study of key enabler costs, and life cycle costs associated with unmanned maritime systems. This study also highlighted the need to put further study into UMS policy, interoperability, and mission overlap (Zorn 2013).

The CRUSER has a variety of studies that examine increasing the utility of Unmanned Surface Vehicles. Another program of note in the CRUSER is the Wave

Glider USV Program (NPS 2014). The Wave Glider USV highlights the robust, reconfigurable, open systems architecture payload possibilities of USVs for cross-domain scientific and operational missions. The CRUSER Wave Glider studies prompt further study of the use of USVs in acoustical tracking, command and control, communication, environmental data collection, and at-sea visualization support. The University of Hawaii is also conducting such research using Wave Gliders (see Figure 10). The research at this university shows the open architecture of the Wave Glider USV platform, its ability to accommodate varying payloads, and the simplicity of the unmanned control systems.

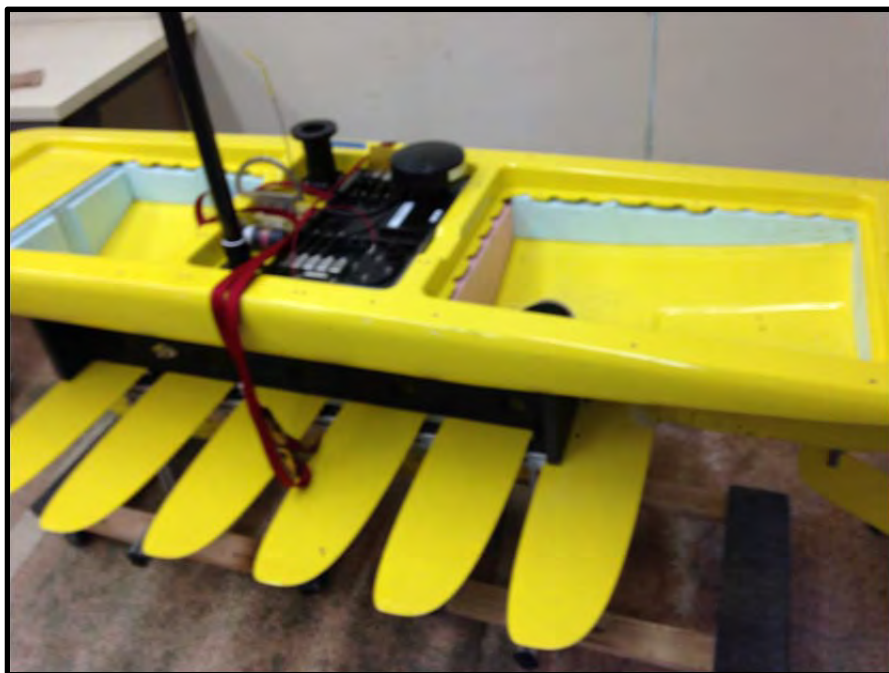


Figure 10. Wave Glider USV from the University of Hawaii shown with open payload bays and exposed command and control systems (photo taken by author).

### C. REPURPOSED, FLEXIBLE, AND MODULAR NAVAL SYSTEMS

There are several works that demonstrate the value in aiming for flexibility and modularity in both new and repurposed naval systems. These works span the range of naval systems from combatants, to amphibious, to notional research systems.

## **1. LCU as a Force Multiplier in the Littorals**

Other scholarly works have recognized the Landing Craft Utility as an underutilized platform for Naval operations. One 2001 NPS master's thesis presented a case for the use of LCU as a force multiplier in the littorals (Bottelson 2001). Scholarly works such as this highlight the value of strategic repurposing of existing Naval assets. It examined "ways to make more effective use of scarce assets in the areas the Navy/Marine Corps team is most likely to conduct future operations in the littorals" (Bottelson 2001). This paper proposed that "a small amphibious landing craft like the Landing Craft Utility (LCU) can be used as a more cost-effective alternative to close exposure to enemy attack" (Bottelson 2001).

This paper also mentioned many suitable missions for the LCU operation in littoral waters. Amongst those missions named as the most suitable are riverine operations, maritime prepositioned force onload/offload, maritime interdiction operations, force protection operations; deception and platform operations; crypto, signals, intelligence and electronic support platform; communications relay platform; and choke point monitoring and surveillance.

While this paper does not address the value of a landing craft repurposed as a USV, it does highlight the value of continued use of these assets as an augmentation to an existing battle group, ready group, or strike group asset or mission.

In the event that a successful enemy attack is carried out, the loss of or damage to a \$15 million landing craft with a crew of 11 will be easier to mitigate than the loss of a \$1 billion state-of-the-art destroyer and a crew of 350. It may also have less overall effect on strategic and operational decision-making and the will to respond. Though this seems a callous approach, the overriding concerns of military leaders are to limit the loss of life and equipment while attaining mission accomplishment. (Bottelson 2001)

This paper draws attention to the fact that the LCU, unmanned or manned, can handle much wider scope of missions than a traditional USV as currently exists in the Navy fleet. The LCU can also supplement a small subset of the missions with which

surface combatant ships may be tasked in the littorals. Finally, the LCU missions can be extended into smaller, shallower riverine environments.

Bottelson suggests that the true value of the LCU may be in its mission flexibility and low consequence of realized damage/loss. Furthermore, this thesis sets the stage for investigating an LCU USV by highlighting the inherent reduction of risk via reduced manning.

## **2. Scalar Common Affordable Modular Platform (SCAMP)**

In his 2012 Massachusetts Institute of Technology master's thesis, Jon Page conducted an analysis of options for flexibility in early stage design of U.S. Navy ships (Page 2011). The basis of this thesis is a notional vessel called the Scalar Common Affordable Modular Platform (SCAMP).

This thesis recognizes that future demands on Navy assets, such as new missions, altered missions, and increased capability needs, are likely to be unknowns at the time of the vessel's design. It presents methodologies with which to avoid costly engineering changes by incorporating flexibility into the design and architecture of Naval vessels. The thesis applies a rigorous analysis framework to examine the cost effectiveness of flexible options.

In the conclusion of the thesis, the author mentions that the Navy might benefit from application of this type of flexibility analysis to platforms other than medium displacement surface combatants. Amphibious vessels provide an interesting platform for studying service life allowances and design margins. Analysis of design options has the potential to alter future amphibious designs, including landing craft, to account for these types of changes.

## **3. Flexible Ship War Room and Roadmap**

In 2013, the Director of Surface Warfare (OPNAV N96) led a 90-day effort called the Flexible and Common Warship War Room to examine the feasibility of building future ships with increased levels of modularity, commonality, and open systems with an

objective of achieving greater flexibility and cost-efficiency over the life cycle (Program Executive Office Ships (PEO Ships) 2014).

This effort notes several concepts and technologies that contribute to accomplishing the flexible ships objectives in the Flexible Ships Roadmap. The roadmap details that a flexible system includes aspects of flexibility, modularity, scalability, and commonality. It goes on to discuss payload-platform decoupling, flexible payloads, flexible ship technologies and architectures, flexible acquisition strategies, and key flexibility enablers. This document suggests that any good flexibility-based systems engineering approach accounts for as many tenets of the flexible ship concept as possible while striking the optimal balance between opportunities and return on investment to the system sponsor (i.e., the Navy).

#### **D. OPEN SYSTEMS ARCHITECTURE**

There are several initiatives that are important to the discussion of open systems architecture as defined above. Better Buying Power, the OSA Guidebook, and the NPS Business Innovation Initiative are amongst those initiatives.

##### **1. Better Buying Power (BBP)**

Better Buying Power (BBP) is a DOD initiative that encourages system managers to set cost targets below independent cost estimates and manage with the intent to achieve them. The DOD Better Buying Power initiative suggests that the combination of open architecture and an open business model permits the acquisition of open systems architectures that yield modular, interoperable systems allowing components to be added, modified, replaced, removed and/or supported by different vendors throughout the life cycle in order to drive opportunities for enhanced competition and innovation (DOD 2014).

In this age of increasingly software-centric systems, it is important to make sure that future architects have access to all of the information needed to properly rearchitect systems that are built today. If obstacles are in place preventing access, then consequences can be costly, and architects are forced to reinvent previous achievements.

Open architectures help program managers, and end users avoid vendor lock. Vendor lock, or vendor lock-in, is the situation in which customers are dependent on a single manufacturer or supplier for a product (i.e., a good or service), or products, and cannot move to another vendor without substantial costs and/or inconvenience. This dependency is typically a result of standards that are controlled by the vendor (i.e., manufacturer or supplier). It can grant the vendor some extent of monopoly power and can thus be much more profitable than be experienced in the absence of such dependency (The Linux Information Project. 2006).

## **2. DOD OSA GUIDEBOOK FOR PMS**

The DOD Open Systems Architecture Contract Guidebook for Program Managers provides guidance for program managers to properly utilize OSA business and technical practices in system acquisitions. The guidebook prompts PMs to incorporate OSA-based principles into program requirements, statements of work, contract line items, intellectual property and data rights negotiations, and ongoing life cycle competition considerations. (U.S. DOD OSA Data Rights Team 2013)

Properly fielding the LCU USV requires cooperation amongst both the technical systems engineering and program management disciplines. Bringing program managers into sync with the technical OSA guidance requires altering traditional program management techniques. A major tool for doing this is the DOD Open Systems Architecture Guidebook for Program Managers (see Figure 11).



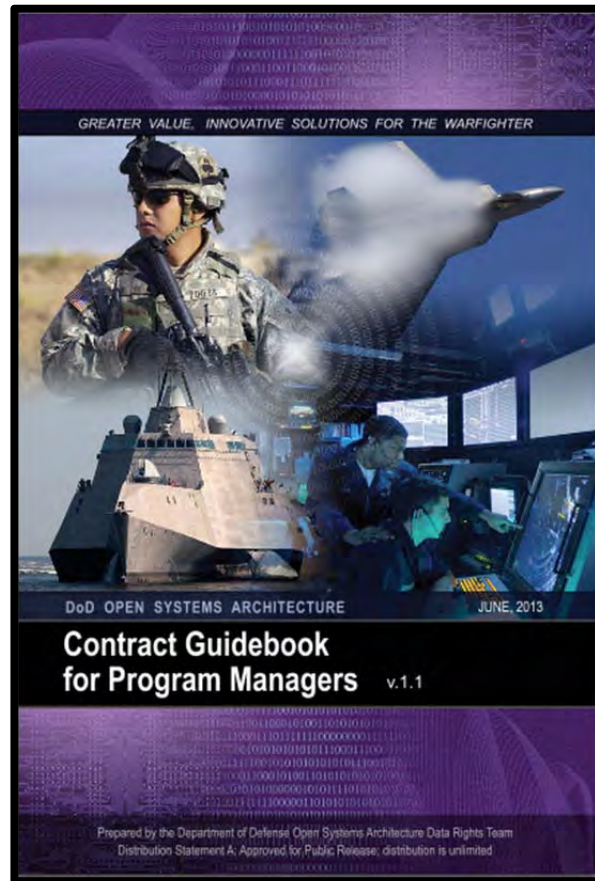


Figure 11. Contract Guidebook for Program Managers v1.1  
(from U.S. DOD OSA Data Rights Team 2013).

### 3. Bii MMOWGLI OSA War Game

A key factor in developing the LCU USV system is the implementation of new business practices for government and industry. Maximizing the value of such an asset requires not just a sound engineering approach, but complementary business considerations as well.

One such effort to develop these business approaches is the Open Architecture (OA) Business Innovation Initiative (BII) Massive Multiplayer Online War Game Leveraging the Internet (MMOWGLI) sponsored by the DASN RDT&E and NPS. The BII aims to move the Naval Enterprise and acquisition community towards an innovative business model that supports the “Payloads Over Platforms” open systems architecture vision. Initiated in 2012, the OA-BII generates, tests, and deploys recommendations for

changes to Government business models that motivate industry to participate in Naval OSA strategies (DASN RDT&E and NPS 2014).

Results from the OA-BII to date recommend that programs aiming to implement OSA need to coordinate their OSA strategy across the Naval Enterprise, require competition in acquisition, require coordinated technical frameworks, utilize published OSA-centric guidance, and address the profit motives of industry (DASN RDT&E and NPS 2014). All of these considerations are a key part of developing an optimized business environment for fielding the LCU USV system; a business environment in which there is decreased life cycle cost and decreased delivery time (Guertin 2014).

See Appendix E for Bii MMOWGLI Action Plans as derived for the notional LCU USV program by several professional players that participated in a recent Bii game conducted over the course of two weeks during July 2014.

## **E. SUMMARY**

This chapter explained several related works that may be leveraged to guide the use of OSA and SE in reusing existing Naval assets, and the development of unmanned technologies. This chapter began by showing that it is important to first understand how the historical body of literature defines several related terms within the practice and study of OSA and unmanned systems. This chapter then showed several related works that demonstrated the feasibility of heavy-lift, flexible, and open USVs with simple controls. All of these works have direct applicability to the OSA SE efforts necessary for the LCU USV. Finally, the chapter explained several business-related OSA works. The BBP initiative and Bii MMOWGLI war game give several considerations key to developing an optimized, OSA technical and business environment for fielding the LCU USV system.

### **III. SYSTEMS ENGINEERING CONSIDERATIONS**

The following chapter provides details regarding how the concepts of open systems architecture may be leveraged and applied within the context of an existing, traditional systems engineering methodology to result in the production of a flexible system that better maintains competitive advantage in the Defense enterprise. Because of the broad generality of applying SE methodology and OSA principles to the conversion of a manned asset into an unmanned system, this chapter may have wide applicability to the potential upgrade of other Naval systems.

#### **A. GENERAL SYSTEMS ENGINEERING APPROACH**

The Department of Defense issued a directive stating that “Acquisition programs shall be managed through the application of a systems engineering approach that optimizes total system performance and minimizes total ownership costs. A modular, open-systems approach shall be employed, where feasible” (DOD 2003).

The Department of Defense further explained its Systems Engineering approach stating:

Rigorous systems engineering discipline is necessary to ensure that the Department of Defense meets the challenge of developing and maintaining needed warfighting capability. Systems engineering provides the integrating technical processes to define and balance system performance, cost, schedule, and risk within a family-of-systems and systems-of-systems context. Systems engineering shall be embedded in program planning and be designed to support the entire acquisition life cycle. (DOD 2008)

Department of Navy Systems Engineering guidance is given in SECNAVINST 5000.2E, 1 September 2011. The Navy guidance is drawn directly from DOD Directive 5000.01 of 12 May 2003 and DOD Instruction 5000.02 of 8 Dec 2008. The United States Navy (USN) implements this overarching guidance focusing on its application to program management saying, “The Program Manager (PM) shall institute a rigorous systems engineering discipline necessary to ensure that the Department of Navy (DON) meets the challenge of developing and maintaining needed warfighting capability. The

systems engineering approach shall be managed to optimize total system performance and minimize Total Ownership Cost (TOC)” (DON 2011).

## **B. NAVAL SYSTEMS ENGINEERING APPLICATION METHODOLOGY**

Both the DOD and DON utilize the Defense Acquisition Guidebook (DAG) to conduct Systems Engineering in a cohesive manner across the DOD Enterprise. DOD Directive 5000.01, DOD Instruction 5000.02, and SECNAVINST 5000.2E provide mandatory DOD and DON policy. The Defense Acquisition Guidebook (DAG) aids program stakeholders in implementing the mandatory policy. The DAG provides the best practices and other methods by which to develop the information required by policy (Defense Acquisition University (DAU) 2014).

The DAG states that implementation of the SE processes begins with the identification of a validated operational need. The DAG models the SE process with the V-diagram (see Figure 12). The Diagram models 16 technical processes that comprise a systematic approach to managing the success of a program. The technical processes ensure that the delivered capability accurately reflects the stakeholder’s needs. The diagram guides the systems engineer through the methodology roughly by following the arrows as the engineer moves from left to right, and along the “V.” The upper-left of the point of the “V” represents the beginning of the systems engineering process. The upper-right of the point of the “V” represents the beginning of the systems engineering process. The two-way arrows show linkages between phases, and that there may be many iterations between phases. The steps contained in boxes with headings may be considered the steps necessary for a “balanced approach for delivering capability to the warfighter” (DAU 2014).

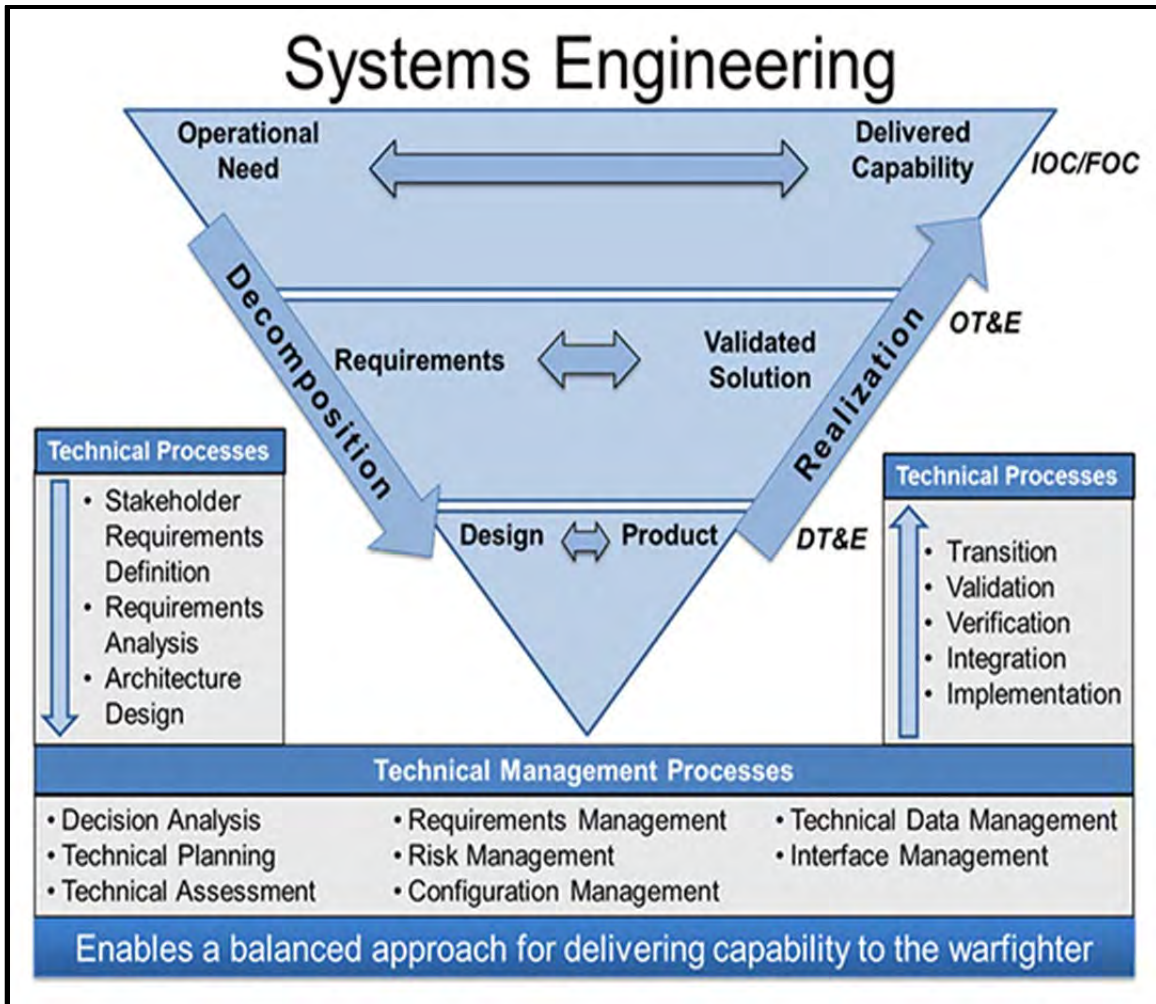


Figure 12. DOD SE process model as of 2014 (from DAU 2014).

This thesis uses the DAG systems engineering process model as a basis to identify and deliver a fully validated capability. Recognizing that the traditional approach to systems engineering may be one contributing factor to the high cost, high complexity, and highly integrated systems that we have today, this thesis puts forth the notion that traditional SE methodologies must be combined with OSA principles in order to realize systems that are open, flexible, and more affordable.

### **C. CRITICAL CONSIDERATIONS WHEN LEVERAGING OPEN SYSTEMS ARCHITECTURE (OSA) IN ASSET REUSE**

OSA facilitates interoperability between systems by effectively leveraging “common capability descriptions in system requirements; common, open data models, standards, interfaces, and architectures in system design, and common components in system acquisition strategies” (DOD 2011).

In order to achieve maximum openness from a system, the right questions must be asked and those questions must be appropriately answered. While it is true that there is no guaranteed formula for systems engineering, there are a few questions that must be addressed when considering how to effectively repurpose and reuse existing assets. All questions must allow stakeholders to evaluate the program with respect to whether or not the program has achieved maximum openness.

OSD defines OA as a multifaceted strategy providing a framework for developing joint interoperable systems that adapt and exploit open-system design principles and architectures (DOD 2011). This framework includes a set of principles, processes, and best practices that provide more opportunities for competition and innovation. This framework helps to rapidly field systems that are affordable, interoperable, minimize total ownership cost, optimize total system performance, are easily developed and upgradeable, and achieve component software reuse (DOD 2011).

With respect to Naval and ship systems, more granularity may be added to the definition of open systems architecture. OSA in U.S. Naval ship design is more fully described as “modularity, and flexibility in open systems” (Marcantonio 2007). OSA principles are important implications for naval architects, and provide the basis for the first step of the flexible design process: identifying the sources of uncertainty. Flexibility is only valuable if it addresses an underlying uncertainty appropriately (Page 2011). The interchangeable architecture of system elements, modules, sea frame zones, stations, and associated interfaces in an open system is what makes such architecture affordable and flexible.

The Program Manager's Guide for the Modular Open Systems Approach (MOSA) to architecture outlines five principles that lay the foundation for effective incorporation of modularity and open systems. Figure 13 depicts the overall vision of MOSA, the five principles, and their associated benefits. The five straight arrows in the figure show that there are five principles that must be implemented to achieve the combined benefits. The curved arrows show that both business and technical indicators contribute to successful implementation of the MOSA principles.

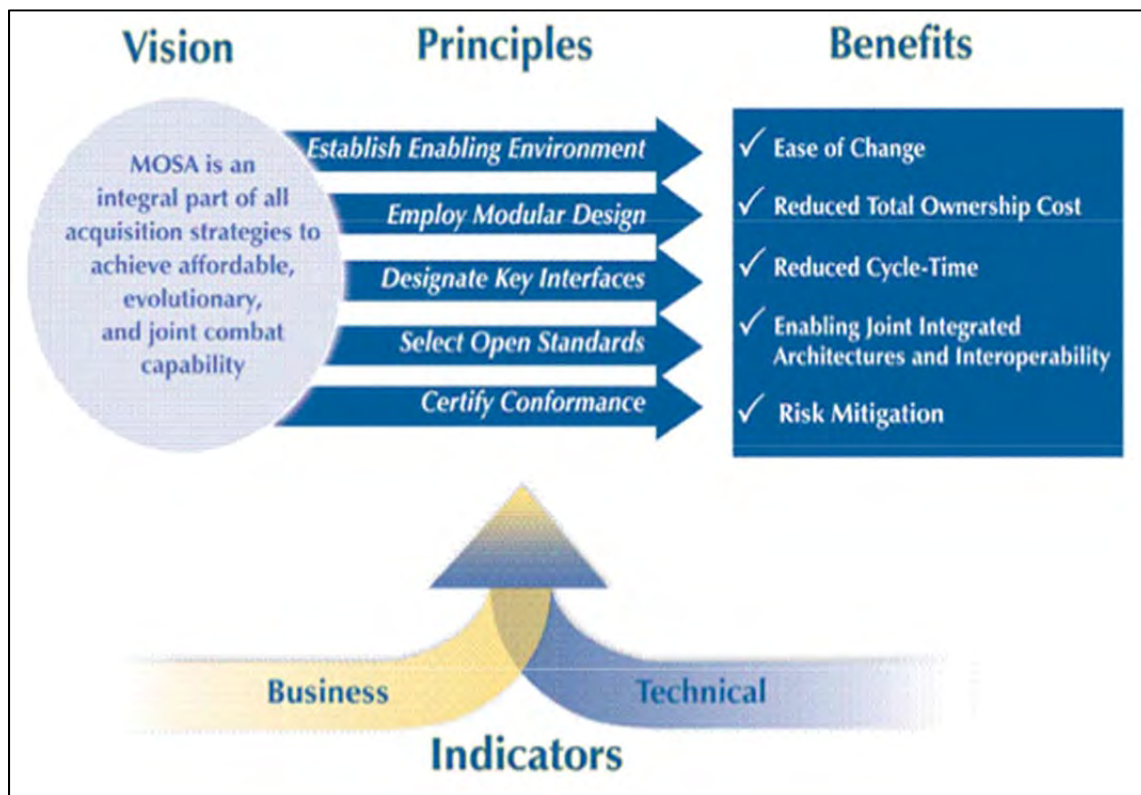


Figure 13. Principles and benefits for effective incorporation of modularity and open systems (from DOD 2004).

Table 4 explains the each principle of MOSA in detail. These detailed explanations are used as the starting point to derive several critical considerations for OSA.



<p><b>Principle 1:</b> Establish an Enabling Environment. The Program must establish supportive requirements, business practices, technology development, acquisition, test and evaluation, and product support strategies needed for effective development of open systems.</p> <p><b>Principle 2:</b> Employ Modular Design. Partitioning a system appropriately during the design process to isolate functionality makes the system easier to develop, maintain, and modify or upgrade. Given a system designed for modularity, functions that change rapidly or evolve over time can be upgraded and changed with minor impact to the remainder of the system.</p> <p><b>Principle 3:</b> Designate Key Interfaces. MOSA manages the interfaces by grouping them into key and non-key interfaces. Key interfaces should utilize open standards in order to produce the largest lifecycle cost benefits.</p> <p><b>Principle 4:</b> Use Open Standards. Interface standards specify the physical, functional, and operational relationships between the various elements (hardware and software), to permit interchangeability, interconnection, compatibility and/or communication, and improve logistics support.</p> <p><b>Principle 5:</b> Certify Conformance. The program should prepare validation and verification mechanisms such as conformance certification and test plans to ensure that the system and its component modules conform to the external and internal open interfaces.</p>
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Table 4. Details of the principles of modular open systems architecture (MOSA) (from DOD 2004).

Today's principles of OSA have matured out of earlier work like MOSA. OSA has both business and technical aspects that must be addressed concurrently throughout the systems engineering process. The following questions may be derived to apply the principles of OSA to the traditional SE methodology. These questions must be answered according to OSA principles in order to provide the best chance of low cost, low risk, and technically acceptable program performance. The answers to these questions are based on principles found in Better Buying Power, the DOD OSA guidebook, MOSA, as well as other heuristic notions that can be applied to optimally answer the questions.

The following overarching questions must be answered appropriately in order to satisfy the principles of open systems architecture. All other questions follow from these simple, general questions (see Table 5).



OSA OVERARCHING QUESTIONS	Question 1	<b>Can one or more qualified third parties add, modify, replace, remove, or provide support for a component of the system, based on open standards and published interfaces (DoD 2013)?</b>
	Answer	Yes.
	Question 2	<b>Are qualified new entrants to the market for the task able to compete for the work immediately, and in every year moving forward (Musk 2014)?</b>
	Answer	Yes.

Table 5. Critical overarching OSA considerations.

Following from these overarching questions several more specific business and technical OSA questions may be applied to a program management approach (see Tables 6, 7, and 8).

CRITICAL OSA BUSINESS QUESTIONS	Question 1	<b>Is the system acquisition process open to all entities with the ability to compete for the mission (Musk 2014)?</b>
	Answer	<b>YES.</b> Acquisition needs to be open to all entities in order to get the benefits and cost reductions of competition.
	Question 2	<b>Does the acquisition process account for creating incentives for competitors to meet time and budget goals? Likewise, does the contracting strategy eliminate unfair advantages for any incumbents (Musk 2014 and Wilds 2008)?</b>
	Answer	<b>Yes. Yes.</b>
	Question 3	<b>Where possible, is the work such that a FAR Part 12 commercial contract structure may be used creating rational incentives for both the contractors and the government to achieve reliable, cost effective on-time deliverables (Musk 2014)?</b>
	Answer	<b>Yes.</b>
	Question 4	<b>Does the acquisition program eliminate or account for payments, incentives, or subsidies that are exclusively in support of an incumbent provider (Musk 2014)?</b>
	Answer	<b>Yes.</b>
	Question 5	<b>Is there a cost sharing strategy between industry and Government for dividing the cost of flexibility (Wilds 2008)?</b>
	Answer	<b>Yes.</b>
	Question 6	<b>Does the system lifecycle management and sustainment plan incorporate proven technology insertion and product upgrade strategies/guidance (DoD 2013)?</b>
	Answer	<b>Yes.</b>

Table 6. Critical OSA business considerations.

CRITICAL OSA BUSINESS QUESTIONS	Question 7	Does the contractor have a proven record of allowing open lines of communications and open access to data items for the Government (Musk 2014)?
	Answer	Yes.
	Question 8	Are the enterprise investment strategies for the system based on collaboration and trust amongst stakeholders (i.e., versus distrust, reservation, and self-protection.) In other words, does the investment strategy promote flow of skill, ideas and information (DoD 2013)?
	Answer	Yes.
	Question 9	Does the program have a strategy for the procurement of intellectual property rights (Wilds 2008)?
	Answer	Yes.
	Question 10	Do the system data rights, and intellectual property permissions allow for fair competition, and access to alternative solutions and sources across the lifecycle (DoD 2013)?
	Answer	Yes.
	Question 11	Are proprietary system aspects limited, and well defined (DoD 2013)?
	Answer	Yes.
	Question 12	Does the program have a strategy for eliminating minute details such as burdensome legislative requests, standard operating procedures (SOPs), and Cost as an Independent Variable (CAIV) accounting requirements (Wilds 2008)?
	Answer	Yes.

Table 7. Critical OSA business considerations (continued).



CRITICAL OSA TECHNICAL QUESTIONS	Question 1	Does the acquisition strategy allow for transparency of system design through peer reviews involving government, academia, and industry (DoD 2013)?
	Answer	Yes.
	Question 2	Does the enterprise investment strategy and system design maximize the reuse of proven designs (DoD 2013)?
	Answer	Yes.
	Question 3	After establishing the requirements, does the government dictate HOW the requirements should be met (Musk 2014)?
	Answer	No, but conformance requirements are likely to be set that match operational requirements.
	Question 4	Are the requirements and specifications (i.e. metrics for the requirements) clear (Musk 2014)?
	Answer	Yes.
	Question 5	Are the requirements/metrics traceable to an open standard?
	Answer	Yes.
	Question 6	Are modules and components based on standards that allow for loose coupling to other components and the overall system (DoD 2013)?
	Answer	Yes.
	Question 7	Does the system employ modular design via appropriately partitioning the system during the design process to isolate functionality (DoD 2004 and DoD 2013)?
	Answer	Yes.
	Question 8	Does the design approach identify key interfaces of the system, and employ open standards at those key interfaces (DoD 2004 and DoD 2013)?
	Answer	Yes.
	Question 9	Are there validation and verification mechanisms to ensure that the system and its component modules conform to the external and internal open interfaces (DoD 2004)?
	Answer	Yes.

Table 8. Critical OSA technical considerations.

After the questions are established, they must be appropriately applied within the traditional SE methodology. It ought to be noted that the questions presented in Tables 5, 6, and 7 are not comprehensive. There are many other questions that may be asked as part of an OSA management approach, and each question must be appropriately tailored to the applicable program. Multiple questions may apply to each step of the SE process, and many questions can be used for more than one step. In general, the OSA technical questions need to be asked during the “Technical Processes” steps of the DOD SE Process Model. Likewise, OSA business questions need to be asked during the “Technical Management Processes” steps of the DOD SE Process Model. See Figure 14 showing how each set of question is roughly combined with a particular phase of the SE methodology. It is the job of the systems engineering manager to appropriately apply the OSA approach to managing the program at hand.

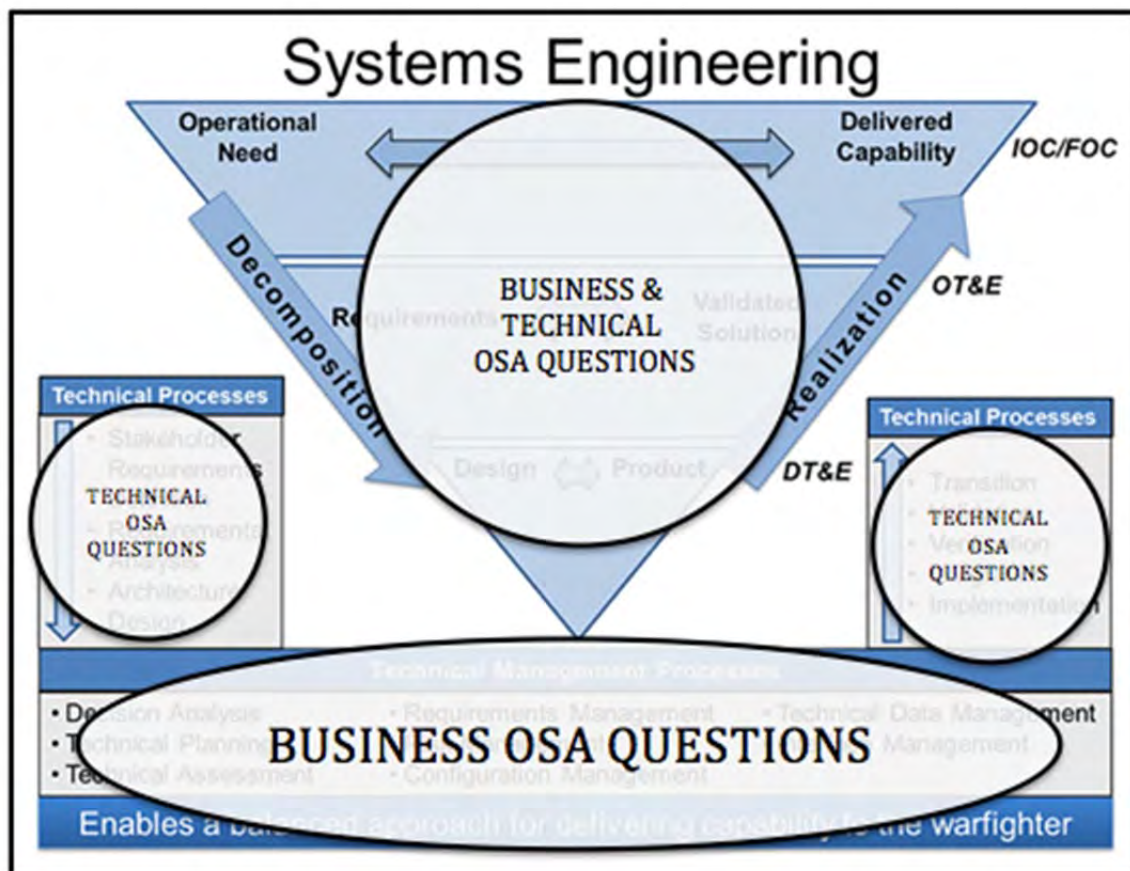


Figure 14. Application of OSA questions to the DOD SE process model (after DAU 2014).

## **D. SUMMARY**

This chapter explained how to combine the principles of OSA with the SE process methodology. First, this chapter detailed the state-of-the-practice systems engineering methodology widely accepted by many Defense organizations. Next, several critical considerations for the use of OSA in asset repurposing and reuse were explained. Central to this discussion was the understanding of the principles of MOSA. Following, from the discussion of MOSA, this chapter detailed several business and technical questions that may be used to guide the implementation of OSA across the SE process. Important to the discussion of the OSA questions, is understanding that these questions must be appropriately answered in order to prove valuable within the SE process. Finally, this chapter showed those certain questions are best applied to specific phases of the traditional SE process. The next chapter applies this methodology in a case study.

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## **IV. SYSTEMS ENGINEERING APPLICATION AND ANALYSIS: LCU USV MISSION**

This chapter applies the principles of OSA to systems engineering methodology of converting an Landing Craft Utility (LCU) to an Unmanned Surface Vehicle (USV).

### **A. STATEMENT OF PROBLEM**

Reuse is the highest form of waste reduction and has the potential to increase the product's end-of-life value. Reuse may be most easily justified in the case of [...] high manufacturing costs, long innovation cycles or lifetimes, [...]. (Blanchard and Fabrycky 2011, 556)

The goal of this thesis is to present a variation on the traditional systems engineering methodology, in that this work is a reengineering analysis that aims to repurpose an existing Naval platform rather than simply to repair or modernize the existing platform for use in the same mission set.

This analysis examines the use of an existing LCU converted into an unmanned surface vehicle (USV) for employment as a low cost, high capacity, rugged force augmentation to the existing USVs. Furthermore, this analysis examines the unmanned LCU's suitability as a truck for various payloads. The analysis concentrates on changes necessary to rearchitect the LCU platform to be autonomous and accommodate varying traditional and non-traditional USV payloads. The goal is to avoid rearchitecting existing, traditional payloads that are designed for operation from a USV. In other words, this analysis examines rearchitecting the platform to accommodate unaltered, existing payloads.

### **B. DEFINITION OF PROBLEM**

In order to further define and understand the problem, it is necessary to clearly ascertain the given inputs that define the starting point. For this purpose, the givens may be modeled through the use of a systems engineering black box model, initial system requirements, and existing LCU characteristics.

## 1. Input–Output Model

The Systems Engineering Black Box Model is the starting point for ensuring that the end-goal of the systems engineering process is clearly understood. The black box is the place where the requirements are strategically combined with energy, matter, material, and information (EMMI) to produce the desired outcome. In the case of system reuse, there is another element input to the black box that is not found in systems engineering applications for newly acquired systems. The original system must be an input to the black box. Its current condition, scope, and purpose largely influences what is possible for the output. In the case of the LCU USV, the inputs are the LCU, EMMI, and requirements as applied through the process of open systems architecture (OSA) (see Figure 15).

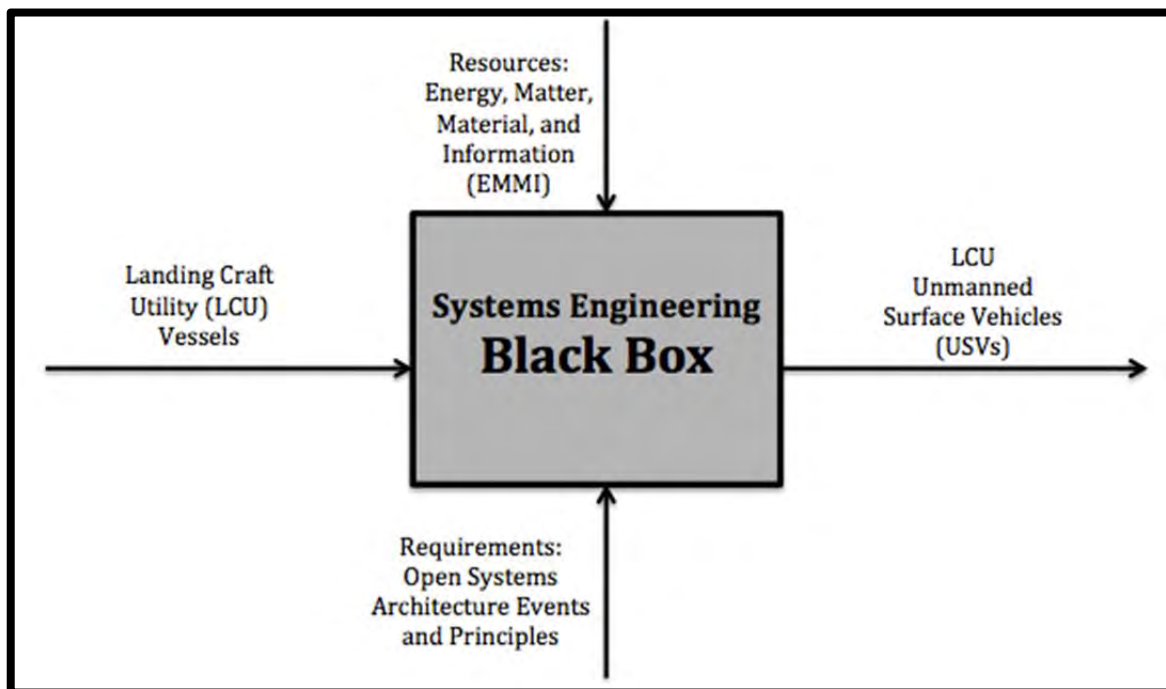


Figure 15. LCU USV systems engineering black box.

## 2. Requirements

There are several documents that emphasize the need for a craft like the LCU USV. Because the need is plainly stated in several DOD references to date, the DOD may



naturally draft requirements for a program of record for the LCU USV. The requirement for an LCU USV is also rooted in a tenet of the 21<sup>st</sup> Century Seapower doctrine, “preventing war is just as important as winning wars” (U.S. Department of the Navy and U.S. Department of the Coast Guard 2007).

The National Military Strategy (NMS) amplifies this need. The NMS explains that the military must field modular, adaptive, general-purpose forces and systems that play a role in covering the full range of military operations. These forces and systems must pose an increasingly expeditionary capability. They must have a smaller logistics footprint, and they must help reduce fuel and energy demands. Additionally, the forces and systems must ensure access and freedom of maneuver. Finally, these forces and systems must be increasingly interoperable with other services (DOD 2011).

Unmanned systems have provided an unprecedented force multiplier to troops to date. The Joint Unmanned Systems Roadmap for 2011–2036 further corroborates the need for a vessel such as the LCU USV by emphasizing the need for affordable, convergent unmanned systems. The Roadmap says that the cost of unmanned systems must be low enough to be expendable, and allow commanders to take risks. It goes on to say that unmanned systems must support diverse mission sets through the use of joint, interoperable payloads, platforms, architectures, and capabilities (DOD 2011).

### **3. LCU General Characteristics**

The LCU is a simple, rugged and reliable platform that the Navy has entrusted to be the workhorse of the amphibious fleet for over four decades. With the proper care and maintenance, the steel-hulled vessel can likely last another forty (40) years. See Table 9 for the general characteristics of the LCU 1610 Class vessel.


<ul style="list-style-type: none"> <li>• Hull: Steel</li> <li>• Length: approximately 135 feet Beam: 29 feet 10 inches</li> <li>• Draft (Fully Loaded): <ul style="list-style-type: none"> <li>– Forward: 4 ft</li> <li>– Aft: 6 ft 7.5 inches</li> </ul> </li> <li>• Power Plant: Diesel propulsion with Kort nozzles, 2 shafts</li> <li>• Max Speed: 12 knots (in significant wave height (3.5ft - 5 ft))</li> <li>• Endurance at Sustained Speed: 1200 NM at 8 knots</li> <li>• Lift Capacity: 170 short tons cargo, or 400 passengers, or 350 troops or 2 M1A1 Tanks (with mine plow)</li> <li>• Bow and Stern Ramps (capable of repeated beach landing impacts)</li> <li>• Accommodations: 14 (13 for Crew, plus 1 if a Boat Group Officer is embarked)</li> <li>• Independent Operations: 10 Days (habitability, provisioning support)</li> <li>• Full Load Displacement: 401 long tons</li> <li>• Stern anchor and winch</li> <li>• Redundant mechanical systems, segregated critical systems, firefighting, dewatering, first aid</li> </ul>	
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Table 9. LCU general characteristics (from Program Executive Office Ships (PEO Ships) 2012).

The LCU 1610 Class vessel is a vessel capable of independent operations and heavy lift. It has heavier lift capability than air cushioned cargo vehicles or similarly sized aircraft.

It has significantly greater range than any other connector, can serve as staging base for small boats, salvage support, port clearing, platform for Buoyant Hose Fuel Systems, and a passenger ferry for 400 personnel (Program Executive Office Ships (PEO Ships) 2012). It has accommodations for embarked overnight. See Figure 16 for a schematic of the LCU 1610 below-deck configuration.

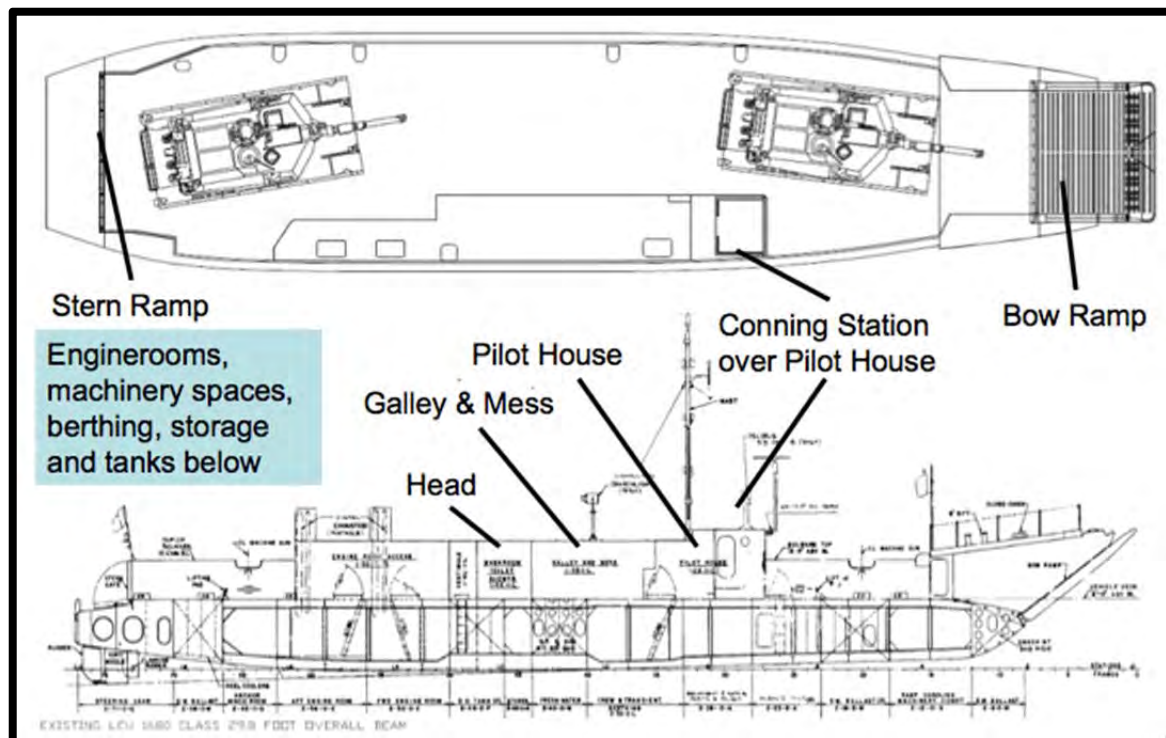


Figure 16. Navy LCU 1610 Class schematic (from Program Executive Office Ships (PEO Ships) 2012).

The general characteristics of the LCU 1610 Class vessel are significant and repurposable. Because landing craft have been in production for long periods of time by many entities, there is a wide array of design variants that utilize the traditional displacement landing craft hullform, general arrangements, and functionality. See Appendix A for a survey of landing craft. Beyond landing craft, there are a number of other maritime assets that may also leverage some concepts from the conversion of an LCU to a USV. Such opportunities are left for further study.

### C. CONSTRAINTS AND ASSUMPTIONS

In undertaking any systems engineering effort, there are certain constraints to which the analysis must adhere. In the case of the LCU USV, the most obvious of the constraints is the constraint of the physical and functional limits of the existing platform such as volumetric space capacity, general arrangement of structural bulkheads, and cargo weight capacity of the hull form.

The following are other constraints and assumptions that have been determined for this systems engineering analysis of the LCU USV (see Table 10):

- There is an operational need as stated by the (LCU ISOGSS, UUV Master Plan, OSD Unmanned Systems Roadmap).
- Only the LCU 1610 class craft will be considered as the host USV platform for this analysis.
- Because of the age of the LCU fleet, there are many small, subsystem-level variations in craft configuration. For this analysis, we will assume that all of the LCU craft are the same general configuration.
- Systems will operate in a safe, non-hostile, low range-of-military-operations (ROMO) environment.
- Systems will be buildable using existing, preferably commercial off the shelf (COTS), or Navy-standard items.
- Systems will maintain a defined span of operating hours with clear end and beginning.
- System will survive detracting stakeholders, and system/program/mission will not be preempted (i.e., system will be fielded).
- System will survive and adjust to all external influences (i.e., weather and sea state).
- The base LCU USV vehicle will be an existing LCU with repairs, modifications, modernizations, and other service life extension program (SLEP)-type alterations.
- Payloads hosted and deployed from the LCU USV will be those developed for existing, traditional systems, or those developed in the future for use in multiple systems.
- The LCU USV will not provide for its own self-defense. It will not need self defense or will be defended by external systems.

Table 10. LCU USV systems engineering process constraints and assumptions.

Although this analysis makes several assumptions and constraints, it still remains careful not to assume a particular architectural solution too soon in the design cycle.

#### **D. STAKEHOLDERS IDENTIFICATION AND SURVEY (USERS)**

There are a number of stakeholders that have influence in a system such as the LCU USV. Stakeholders may be categorized into several categories to help determine their influence in the systems engineering process. First order stakeholders are considered

to be those who have direct contact with the system, directly influence the system. Second order stakeholders are defined as those who work with or are associated with a person in direct contact with the system, or who directly influences the system. Third order stakeholders are all others with any minor, or indirect interest in the system.

The customer, and user of the system, is the first stakeholder touch point. In the case of the LCU USV, the customers are the warfighters and other military personnel who are responsible for accomplishing the various missions that this vessel is responsible for. The warfighters, and users of this system input materials, manpower, and information into the system in order to produce and execute the desired mission output.

System engineering requirements generation requires extensive research and conversation with the customer and other members of the stakeholder population. The systems engineer must be sure to account for customer uncertainty in exactly what they desire in form and function of a final product.

A selection of first order stakeholders are listed here: Office of Naval Research (ONR), Naval Sea Systems Command, Naval Surface Warfare Centers, Office of Secretary of Defense (OSD), Sailors, Congress, Amphibious Warfare Commanders, Public USV contractors. There are many first order stakeholders who can be involved in development of this system in some way including persons in test and evaluation, contracting, legislation, environmental design, regulatory, budgeting, taxpayer concerns, and more.

The following paragraphs identify several categories of stakeholders involved in the DOD Acquisitions Management Framework. They include system users, technology development agencies, acquisition agencies, contractors, planning agencies, test and evaluation agencies, policymakers, and academia. The paragraphs discuss the roles each stakeholder plays, and can be used as a reference in understanding the subsequent explanation of the SE processes.

**System Users:** The user community consists of those soldiers and sailors who operate the equipment in the AOR, and who best understand the evolving war fighting needs. The user community defines the systems and tactics that are required to maintain



the competitive advantage in current military operations. Because of their superior knowledge of the current operational environment, it is also the user community who is the first, and most important voice in establishing funding priorities for military systems. See Table 11 for a partial list of users.

<b>User Group</b>	<b>Function</b>
<b>Naval Expeditionary Combat Command</b>	Employs self-sustainable, adaptive troops and systems to meet new and evolving Naval mission requirements in riverine and maritime security operations
<b>Amphibious Squadrons</b>	Employs the Marine Corps and Navy in maritime littoral, and inland environments
<b>Assault Craft Units</b>	Employs landing craft in support of Naval missions
<b>Fleet Commands</b>	Provides and administers Naval services and assets
<b>U.S. Coast Guard Commanders</b>	Employs assets for U.S. port security
<b>Department of Transportation</b>	Acquires and operates vessels for transportation
<b>Department of Homeland Security</b>	Employs boats and other assets in the protection of U.S. citizens
<b>National Oceanographic and Atmospheric Administration (NOAA)</b>	Acquires and operates ocean research and survey vessels

Table 11. User community stakeholders.

**Technology Development Agency:** The technology development agency is in charge of managing a system as it evolves from concept to reality. In the case of the LCU, USV, and other military systems, the technology development agency is typically a government research laboratory, engineering agent, or authoritative technical organization. The agency's engineers, subject matter experts, and managers must assess the technology readiness levels of the system until it reaches maturity. After the system is transitioned to operational use, the agency is often charged with providing in-service, helpdesk-type support to the system throughout the system's life cycle. The development agency must necessarily interact with other stakeholder groups to ensure that stakeholder

needs are not compromised as the system technology is developed, integrated, and fielded. See Table 12 for a partial list of Technology Development Stakeholders.

<b>Technology Development Group</b>	<b>Function</b>
<b>Office of Naval Research</b>	Promotes the progression of basic research, science, and technology development initiatives of the Navy
<b>Naval Warfare Centers (Surface, Undersea, and Air)</b>	Provides research, development, test, evaluation, in-service engineering, and maintenance service for Naval systems

Table 12. Technology development stakeholders.

**Acquisition Agency:** Acquisition agencies consist of Program Offices, and Systems Commands. Acquisition agencies are responsible for ensuring that all statutory and regulatory laws, as derived from the Constitution, are enforced in meeting the user needs. The agency employs experts in program management, project management, law, finance, accounting, contracting, engineering, and other disciplines. It may be noted that other stakeholder groups such as technology development agencies, and test agencies may be subordinate entities of an acquisition agency. Acquisition agencies are in charge of spending the resource sponsor's (i.e., the user's) appropriated funds. These funds are allocated by the acquisition agency to both government and contractor entities. See Table 13 for a partial list of Acquisition Agency stakeholders.

<b>Acquisition Agency</b>	<b>Function</b>
<b>Naval Sea Systems Command</b>	Designs, builds, delivers and maintains ships and systems for the U.S. Navy
<b>Program Executive Offices (i.e., PEO Ships, and PEO Littoral Combat Ship)</b>	Provides administration for all aspects of program acquisition and lifecycle management

Table 13. Acquisition agency stakeholders.

**Contractors:** When in the best interests of the user and the taxpayer, the acquisition agency elects to employ contractors to perform portions of the work of system acquisition. Contractors are responsible for providing a wide range of products and services to the acquisition agency. In turn, the acquisition agency must closely manage

the contracts to ensure that the user needs are being met. In the case of the LCU USV, the contractors may be used in research, development, concept studies, test, evaluation, construction, fabrication, outfitting, business, finance, program management, logistics, and many other disciplines.

**Planning Agency:** When a system must be modified, the Government employs agents to manage the work. Often, these roles may overlap with the technical agency or the acquisition agency. The planning agency is responsible for ensuring that the vessel is built or modified in a manner that proves efficient for program sponsors and fleet resources. The agency may be involved in a number of activities including design, drawing, alteration planning, test and evaluation, and negotiating with subcontractors.

**Test & Evaluation Organizations:** Test & Evaluation (T&E) organizations can be Governmental or independent. They are charged with verifying system performance and validating all system requirements before the system is put into operation. Testers may also keep measures of system performance throughout the life cycle of the system to ensure that measures of effectiveness are improving, or to influence other programmatic decisions. The test and evaluation community must work closely with the acquisition agency. Furthermore, a test organization may be a subordinate entity to a technology development agency, acquisition agency, or planning agency.

**Policymakers:** Policymakers include a broad range of both executive and legislative organizations and individuals who make and enforce the laws that govern the system engineering process. These individuals have the authority to influence program direction, requirements, and funding in many different ways. See Table 14 for a partial list of Policy Stakeholders.

<b>Policy Stakeholders</b>	<b>Function</b>
<b>Senate and House of Representatives Committees (e.g., armed services, and appropriations committees)</b>	Makes legislation including legislation influencing Naval systems
<b>Government Accountability Office</b>	Evaluates government programs for fiscal and financial stewardship

Table 14. Policy stakeholders.



**Academia:** As an extension of the technical community, universities and other academic institutions provide for research and development capabilities that augment those capabilities organic to Government Technology Development Agencies.

## **E. STAKEHOLDER ANALYSIS**

“Identifying and analyzing the needs of the stakeholder is referred to as stakeholder analysis” (Langford 2012, 259). Stakeholder analysis helps to gauge whose interest primarily affects the design, and whose interest is given a smaller level of consideration (Langford 2012, 260). Within the context of the principles of OSA, all stakeholder influence on a system must be considered. If a stakeholder’s influence is not accounted for, then the system may not be as adaptable or changeable. This thesis study analyzes stakeholders according to, but not limited to, the following: current interest, future interest (changes in policy), objectives, motives, and values (Langford 2012).

An LCU USV system potentially has hundreds of stakeholders, and it is beyond the scope of this report to analyze each individual according to the criteria. This thesis categorizes many of the potential stakeholders according to one area of commonality for each. The category is used here as the differentiator for analyzing the stakeholders. Many stakeholders fit into more than one category, further complicating the task of stakeholder analysis.

The stakeholder analysis resulted in new relationships amongst program and system elements for consideration during the systems engineering process. The stakeholder analysis also resulted in the following: uncovered complexities, influences, multiple-use objectives, conflicting requirements, architecture alternatives, and new stakeholders (Langford 2012).

After drafting an initial list of stakeholders and a few use-case scenarios, customer needs may be derived therefrom. Fulfilling the customer need, in this case, may take on a wide variety of materiel manifestations given the number of stakeholders that must be satisfied. There may also be non-materiel solutions that fulfill the customer need. As a result of the stakeholder analysis, the information exists with which to begin formulating the system functions. Identifying additional stakeholders and additional

customer needs is a continuous activity throughout the systems engineering process, and the potential solution always needs to account for this.

In traditional systems engineering, the stakeholder needs are regarded as a tool to develop a novel solution to a set of requirements. However, in the case of asset repurposing and reuse, the stakeholder requirements must be used as a threshold for evaluating the base system for repurposing and reuse. Thus, this thesis does not search for a particular, original solution to satisfy the stakeholder needs and requirements. It does, rather, assess the suitability of one particular solution, the LCU USV, for use in satisfying as many of the customer needs as feasible.

#### **F. OSA CONSIDERATIONS FOR STAKEHOLDER IDENTIFICATION AND ANALYSIS.**

OSA considerations must be implemented to properly account for the varying interests of system stakeholders and their influences on long-term program supportability and viability. This mandates that the system incorporate appropriate considerations for “reconfigurability, portability, maintainability, technology insertion, vendor independence, reusability, scalability, interoperability, upgradeability, and long-term supportability” (U.S. DOD OSA Data Rights Team 2013). First, the program must “ensure that external information exchange requirements are implemented in a standard and open manner” (U.S. DOD OSA Data Rights Team 2013). Second, the program shall ensure that it promotes the use of open standards at an architectural level, and then tailor the standards to meet specific Service and Joint requirements (U.S. DOD OSA Data Rights Team 2013). See Chapter III, Table 5 through Table 8, for a list of considerations that aid in applying these OSA principles.

#### **G. TOP-LEVEL USE CASES/CONOPS**

USVs in the current marketplace perform a clearly defined set of missions. For the LCU USV, this uses, as a basis, a mission taxonomy developed by OPNAV N81 and RAND Corp (see Figure 17). There are currently 16 distinct types of missions, and 63 USVs in the marketplace (RAND 2013).

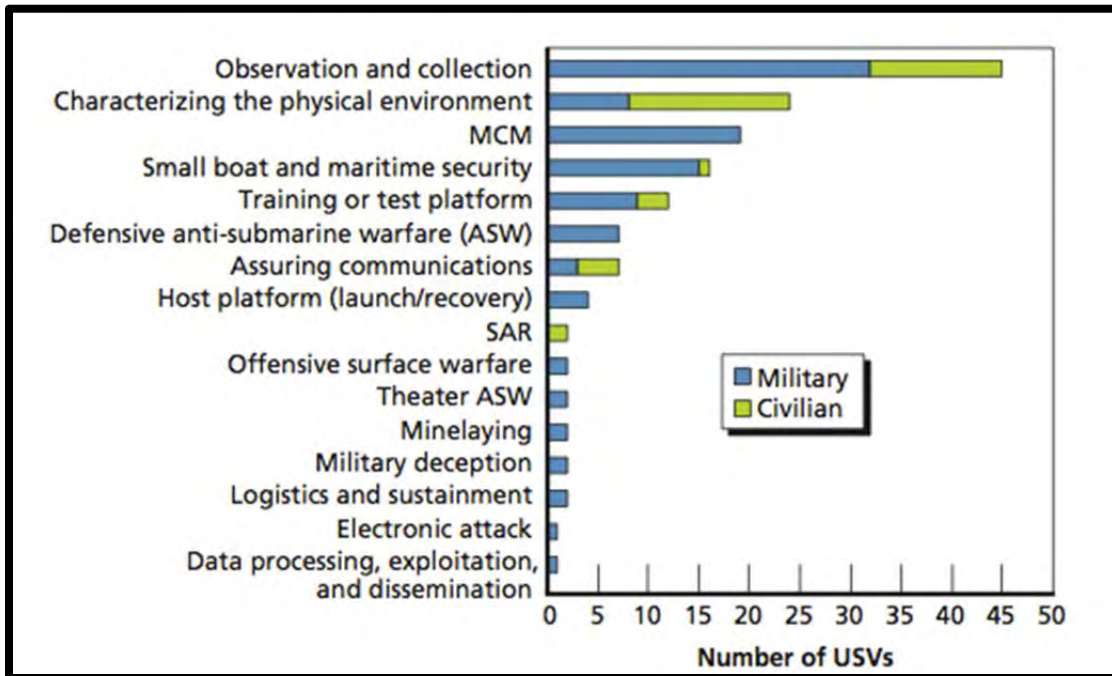


Figure 17. USV mission taxonomy in the current marketplace (from RAND 2013).

This thesis uses as a starting point for LCU USV concept-of-operations analysis those missions that are considered highly suitable (RAND 2013). These missions are also those that have been verified as desirable by LCU and USV program stakeholders. A highly suitable mission is one that has the following characteristics (RAND 2013):

1. Increases effectiveness significantly
2. Addresses capability gaps
3. Reduces risks, costs, need for capital assets, time lines
4. Is more appropriate than alternative unmanned or manned platforms
5. Provides acceptable transportation, hosting, and support requirements
6. Has programmatic compatibility

In order to explain how missions in this analysis were chosen, this analysis must first establish a convention for classifying missions. There are three levels of technological development for USV missions (RAND 2013):

**In or near market:** Greater than, or equal to Technology Readiness Level 8 (TRL 8)  
**Emerging:** TRL 4 to TRL 7  
**Incipient:** Less than or equal to TRL 3

See Appendix B for an explanation of Technology Readiness Levels (TRLs).

The LCU USV expands the scope of the traditional USV mission set to include several other top-level mission sets. It does this by increasing the suitability and technological development level of certain missions as defined by RAND 2013. Missions that were previously defined as emerging or incipient (i.e., less than TRL 8) may now be considered closer to market (i.e., TRL 8) because of the utilization of the LCU USV for that particular mission. For example, the RAND (2013) study classifies the autonomous ship-to-shore connector mission as incipient (i.e., less than or equal to TRL 3). The implementation of an LCU USV for execution of this mission may make that mission more technologically ready for implementation.

Generally, the LCU USV can be used to perform command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR); mine warfare; and functional support activities. Performance of an in-depth CONOPS analysis can further reveal and explain potential LCU USV missions.

## **H. DETAILED USE-CASES AND CONOPS**

The intended physical operating environments for USVs are in and around harbors, strategically placed within major shipping routes such as the Strait of Hormuz, or possibly out in the open ocean (DOD 2013). In all environments, the USV must meet operational requirements that are both common and uncommon to traditional maritime operations. In the absence of onboard, manned intervention, the USV must be able to navigate waypoints, staying within designated waterway lanes, and avoiding obstacles in the maritime environment. The USV system must also ensure that its payloads are deployed, operated, and recovered without onboard, manned intervention. Furthermore, USVs must operate in compliance with the maritime statutory and regulatory mandates of its operational environment.

Because of the open architecture nature of the LCU platform, the number of potential missions is quite broad. This analysis highlights only the most effective missions in terms of suitability, technology readiness, and customer needs.

## **1. Functional Missions**

Functional missions are those that lie outside the scope of combat operations, often representing those that are in support of larger, or more complex operations. These missions include, but are not limited to, test mission support, operational training support, search and rescue, hosting and support of other unmanned vehicles, heavy-lift cargo transportation, and acting as an information-signal relay station.

### ***a. Test Platform***

The LCU USV is a suitable platform for testing support missions. Manned vessels are usually utilized in support of operational research, development, test and evaluation missions. However, large ships are often in high demand, and not available to support such missions. The LCU USV can suitably fulfill this mission.

The CONOPS for test support missions involves executing several actions. The LCU USV is first be loaded with a payload of test equipment, on the shore or on a mothership, prior to deployment. A crew of expert personnel ensures that the equipment and required operations were installed, tested, and verified before deployment. The personnel also preprograms the LCU USV and test equipment payload to the desired level of autonomy. If a low level of autonomy is chosen, then the LCU USV can be controlled from a station aboard a mothership or on the shore. Once deployed, the platform transits via waypoints under autonomous direction or under the control of a remote operator. According to the mission need, the testing can be conducted while underway, when the vessel has arrived on station, or both. Any data collected during this mission can be wirelessly transmitted back to station or stored onboard until the end of the evolution. After the test support mission is completed, the vessel transits back to the shore or the mothership for recovery, data retrieval, maintenance and preparation for the next mission. Such flexibility can be especially useful for battle group predeployment workups and evaluations at sea.

***b. Training support***

USVs can support all levels of training for the U.S. Navy and Marines from unit-level to joint force interoperability training. The LCU USV can be used in simulated attacks, visit, board, search, and seizure (VBSS) evolutions, and piracy training missions. Sensor packages that can be installed on USVs to assist training include active/passive acoustics, passive/active radar augmentation, flares, electro-optical/infrared cameras, full-motion video, and strobe lights (to simulate firing) (RAND 2013).

Manned LCU vessels have traditionally been used in training exercises. Adding the unmanned capability to the existing CONOPS for LCU training support missions increases the value of the LCU platform to the Naval community.

The CONOPS for training support missions involves executing several actions. The LCU USV is first be loaded with a payload of training support equipment, on the shore or on a mothership, prior to deployment. A crew of expert personnel ensures that the equipment and required operations were installed, tested, and verified before deployment. The personnel also preprograms the LCU USV and training equipment payload to the desired level of autonomy. If a low level of autonomy is chosen, then the LCU USV can be controlled from a station aboard a mothership or on the shore. Once deployed, the platform transits via waypoints under autonomous direction, or under the control of a remote operator. According to the mission need, a remote operator operates and controls onboard equipment. After the training support mission is completed, the vessel transits back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

***c. Search and Rescue of Conscious Victims***

This analysis discusses several instances of a manned LCU or a USV being used in humanitarian assistance/disaster recovery (HA/DR) in Chapter I. Adding USV capabilities to the LCU allows for execution of a broader HA/DR mission set. USVs have been used in several instances in the recent past to conduct search and rescue, and save lives in civilian contexts. One prominent rescue USV is the Emergency Integrated Lifesaving Lanyard (EMILY) (RAND 2013).

The CONOPS for SAR missions involves executing several actions. The LCU USV might first be loaded with a payload of search and rescue equipment, on the shore or on a mothership, prior to deployment. Such payloads include fixed sensors, signal devices, sensors, lifesaving flotation equipment, and towed arrays amongst other assets. A crew of expert personnel ensures that the equipment and required operations were installed, tested, and verified before deployment. The personnel also preprograms the LCU USV and SAR payload to the required level of autonomy. If a low level of autonomy is required, then the LCU USV can be controlled from a station aboard a mothership or on the shore. Once deployed, the platform might transit via waypoints under autonomous direction, or under the control of a remote operator. According to the missions need, a remote operator can optionally operate and control onboard equipment according to the SAR mission needs. Because SAR is a dynamic evolution with many changing variables, the vessel and payload needs to respond to track changes, condition changes, and course alterations. Additionally, SAR missions may need to accommodate a human life onboard the LCU USV if a conscious victim is found and recovered aboard the USV. In this case, a sailor is the best person to operate the USV in the traditional manner if the operational risk-level allows. After the SAR mission is completed, the vessel transits back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

*d. Unmanned Vehicle Support*

The LCU USV system is a suitable platform to serve as a barge-like, untraditional, alternative host vessel for other unmanned vehicles (e.g., UUVs, USVs, and UAVs). The motivation for examining this alternative is that the LCU USV has a high likelihood of being a low cost, high capacity, rugged complement to the existing UUV host vessels and UUV missions. The LCU USV can facilitate the integration and operation of networks of other unmanned vehicles. Unmanned vehicle networks or swarms can leverage the LCU USV's large payload capacity, long endurance, and large power supplies.

Both in practice, operational environments, academia, and popular culture, unmanned vehicles (i.e., drones) have been gaining more attention and use. In order to support this increase in the use of unmanned systems for various applications, more innovative means of supporting these systems need to be employed. Highlighting this need, the Department of Defense says, “An organic support infrastructure for configuration control, supply support, maintenance, storage, and transportation is essential to bring efficiencies and cost effectiveness to these critically important systems” (DOD 2013). It is essential that the hosted high-value unmanned systems have options in terms of effective system sustainment.

This analysis does not focus on any particular missions or unmanned vehicle set, but rather focuses on the ability of the LCU USV to host, deploy, retrieve/recover, recharge, and conduct data transfer with the hosted unmanned vehicle (UXV). Notionally, the LCU USV craft carries varying payloads of UXVs (see Figure 18). Ideally, the LCU USV capability also includes deployment and recovery of the unmanned vehicles, and recharging and data transfer from the UUVs.

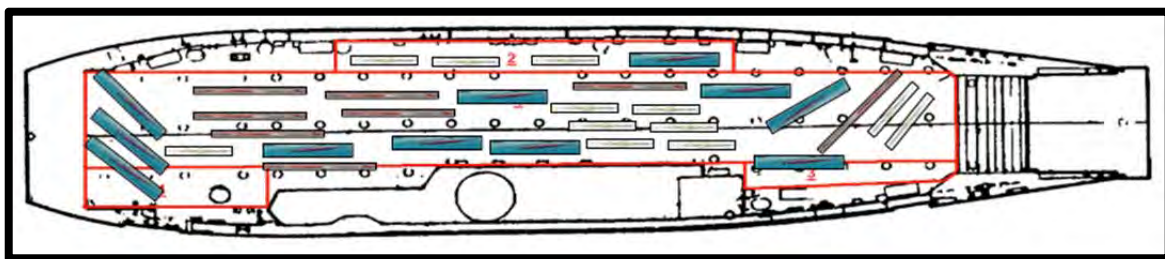


Figure 18. Schematic of notional LCU USV carrying payload of varying unmanned vehicles, plan view. Deck space might also accommodate custom launch and recovery equipment.

The CONOPS for unmanned systems support missions involves executing several actions. The LCU USV is loaded out with a pre-determined mission set of unmanned vehicles, likely unmanned underwater vehicles (UUVs), or unmanned surface vehicles (USVs). The LCU USV departs from the pier or well deck following a pre-programmed route to the area of responsibility (AOR). Once at the AOR, the LCU conducts launch and recovery (L&R) of unmanned vehicles. According to the missions need, a remote



operator might also operate and control onboard equipment. Alternatively, the unmanned systems payload can be preprogrammed to different levels of autonomous operation. It is worth noting that some UXV payloads are disposable, and not designed to be recovered. If required by the mission, the LCU USV can recover the payload, or else leave the payload on station. If recovered, the UXV payload is subsequently recharged, repaired, and undergoes data transfer. After the UXV support mission is completed, the LCU USV vessel can transit back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

*e. Payload Delivery, Autonomous Ship-to-Shore, or Shore-to-Shore Connector Payload Delivery*

With the increase in innovative product development, additive manufacturing, and advanced technology, the Navy needs more platforms and more options for delivering the necessary parts, supplies, and systems to the AOR. The LCU USV is a suitable platform to carry prepackaged payloads (e.g., conex boxes, white box trucks, pallets, and shipping containers) of inexpensive, but necessary supplies (see Figure 19). For example, the LCU USV might carry much-needed water pallets to troops on an unrefined beach, or else might carry containers of raw material for additive manufacturing (e.g., 3D printed spares for miniature quad rotors and other UAVs). Such a raw-material payload has a low risk level, and allows for disposability if the payload becomes jeopardized or compromised.



Figure 19. LCU Carrying payload of three (3) white-box delivery trucks (from Workboats International 2014).

The concept of employment for payload delivery and autonomous ship-to-shore movement is as follows: The LCU USV is loaded out at the pier or well-deck with a pre-determined payload of cargo (e.g., 3-D printed materials, machines, and spares) and supporting logistics equipment. The LCU USV departs from the pier or well-deck following a pre-programmed route to the delivery area. Once at the delivery point, the LCU is unloaded autonomously via crane or forklift, or manually by a crew of personnel. After the mission is completed, the LCU USV vessel transits back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

The LCU USV is also extremely valuable without a payload onboard. It is worth noting that the LCU USV, itself, might be the payload, acting as a choke point or a harbor/riverine defense barrier unit.

***f. Information Processing, Exploitation, and Dissemination (PED)***

The LCU has a mast, a large cargo-deck area, and below-deck volume that may be used for hosting communications and signal-relay systems. Thus, the LCU USV can be suitable for information and signal processing, exploitation, and dissemination.

In this CONOPS, the LCU USV transits autonomously via waypoints to an area of responsibility loaded out with C4ISR equipment for the desired mission. Alternatively, the LCU USV might conduct this mission from pier-side or else a beached shore location. The LCU USV can act as an information processing and intermediary decision point for command and control of downstream mission needs. After the mission is completed, if required, the LCU USV vessel transits back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

**2. C4ISR Missions**

There are a number of CONOPS and platforms with which the Navy conducts operations for Command, Control, Communications, Computers, Intelligence, and Reconnaissance (C4ISR). There exist several manned and unmanned platforms for such missions. In popular culture, the UAV has gained notoriety for its ability to perform in

this type of mission. The USV is a critical asset that proves a high value to these missions, and it needs to be considered for increased utility as such.

***a. Persistent ISR in Permissive Environments***

The LCU USV platform provides a low-risk means to accomplish persistent ISR missions. Typically, this type of mission is executed using an unmanned platform that hosts or tows sensor systems to gather data about threats in the surrounding environment. The LCU USV and associated sensors can detect, intercept, and collect images of marine structures, images of adversarial operations, shipping-lane obstructions, harbor debris, geographical information, topographical measurements, electromagnetic signature information, radio signals, and other various data. This is not only valuable in Naval missions, but also possibly even more valuable to routine port security operations.

The CONOPS for Persistent ISR missions involves executing several actions. The LCU USV is first loaded with a payload of ISR equipment and sensor packages, on the shore or on a mothership, prior to deployment. This includes towed sensors, fixed sensors, and signal devices amongst other assets. A crew of expert personnel ensures that the equipment and required operations were installed, tested, and verified before deployment. The personnel also preprogram the LCU USV and ISR payload to the required level of autonomy. If a low level of autonomy is required, then the LCU USV may be controlled from a station aboard a mothership or on the shore. Once deployed, the platform transits via waypoints under autonomous direction, or under the control of a remote operator. According to the mission's need, a remote operator operates and controls onboard and towed equipment. The vessel and payload can then carry out the required combination of signals intelligence (SIGINT), imagery intelligence (IMINT), and measurement and signature intelligence (MASINT) operations. After the ISR mission is completed, the vessel transits back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

***b. Environmental Collection in Permissive Environments***

The environmental collection mission is very similar to that of the C4ISR mission. However, it is worthy of mention as its own entity because it highlights the

utility of the LCU USV in a civilian, commercial or military weather application scenario. These missions typically happen outside of a theatre of military operation, within the context of routine data collection.

The CONOPS for environmental collection missions involves executing several actions. The LCU USV is first be loaded with a payload of environmental measurement equipment and sensor packages, on the shore or on a mothership, prior to deployment. This includes towed sensors, fixed sensors, and signal devices amongst other assets. A crew of expert personnel ensures that the equipment and required operations were installed, tested, and verified before deployment. The personnel also preprograms the LCU USV and sensor payload to the required level of autonomy. If a low level of autonomy is required, then the LCU USV may be controlled from a station aboard a mothership or on the shore. Once deployed, the platform is able to transit via waypoints under autonomous direction, or under the control of a remote operator. According to the missions need, a remote operator can control onboard, towed, and nearby equipment. The vessel and payload can then carry out the required combination of weather measurements, bathometric surveys, and other types of hydrological analysis (RAND 2013). After the ISR mission is completed, the vessel is free to transit back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

### **3. Mine Warfare Missions**

There are a number of mine warfare missions for which the LCU USV is suitable. Mine proofing and MCM intelligence preparation of the battle space (IPB) missions are examined in this section. MCM requisition, mine neutralization, mechanical minesweeping, influence minesweeping, and mine harvesting are other missions that may prove somewhat suitable for the LCU USV.

#### ***a. Minefield Proofing***

Because of the rugged nature of the LCU USV and the inherent dispensability as a vessel from which the Navy has already drawn its intended service-life value, the LCU USV is a suitable craft for minefield proofing operations. It is highly capable of surviving mine blasts, and may be made more survivable by filling the steel hull with buoyant

materials (e.g., Styrofoam, or heavy-duty air bags). The as-built steel mono-hull design, draft, acoustic signature, and magnetic signature make the LCU USV an outstanding candidate for minefield proofing missions. “If desired, the USV’s draft and signatures could be enhanced by attachments (e.g., a large rake to increase effective draft, wire coils to increase magnetic signature, a very loud speaker system)” (RAND 2013).

The CONOPS for Minefield Proofing missions involves executing several actions. If required, the LCU USV is first be loaded with a payload of sensor packages, on the shore or on a mothership, prior to deployment. The void below decks also needs to be filled with buoyant material. A crew of expert personnel can ensure that the equipment and materials were installed, tested, and verified before deployment. The personnel can also preprogram the LCU USV to the required level of autonomy. If a low level of autonomy is required, then the LCU USV may be remotely controlled from a station aboard a mothership or on the shore. Once deployed, the platform can transit via waypoints under autonomous direction, or under the indirect control of a remote operator. The vessel might sustain damage from exploded ordinance, if encountered. After the minefield-proofing mission is completed, the vessel can then transit back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

***b. MCM Intelligence Preparation of the Battlespace***

The MCM Intelligence Preparation of the Battlespace( IPB) mission is similar to that of the C4ISR mission. However, the MCM IPB mission focuses specifically, and directly on identifying new threats via sonar contacts. These missions are typically carried out during peacetime. This allows new threats (e.g., new mine types) to be better identified and countered during times of conflict.

The CONOPS for Minefield Proofing missions involves executing several actions. The LCU USV is first loaded with a payload towed sonar arrays, on the shore or

on a mothership, prior to deployment. A crew of expert personnel ensures that the equipment and materials are installed, tested, and verified before deployment. The personnel can also preprogram the LCU USV to the required level of autonomy. If a low level of autonomy is required, then the LCU USV may be remotely controlled from a station aboard a mothership or on the shore. Once deployed, the platform can transit via waypoints under autonomous direction, or under the control of a remote operator. The towed sonar array gathers intelligence information, and stores it for later recovery or send it back to a host wirelessly. After the MCM IPB mission is completed, the vessel can transit back to the shore or the mothership for recovery, maintenance and preparation for the next mission.

## **I. STATEMENT OF CUSTOMER NEEDS**

The discussion of OSA SE methodology in Chapter III gave insight into the basic principles that satisfy the customer need from a business and technical perspective. At this point, this analysis further refines those principles and needs into systems and engineering functions that can be input into the engineering design process.

After completing the stakeholder analysis, the current and future interests of the stakeholder provide insights into previously unrealized needs. For example, the stakeholder analysis revealed that basic security of the cargo and the craft is a customer need. At this point, this analysis remains open to all use-case scenarios. Remaining open to all highly suitable missions ensures that any emergent customer needs are considered. Customer needs are developed based on review of the literature, notional missions, speaking with subject matter experts, market research, the principles of OSA, and experiential knowledge of the subject. Table 15 presents implicit, basic customer needs.

- Conduct joint, interoperable non-combat mission support operations
- Navigate autonomously or under remote control
- Host and operate payload
- Deploy and recover payload autonomously to the host vessel (LCU USV)
- Recharge and transfer data autonomously from payload
- Align and mate connectors robotically to the payload while on the LCU USV
- Operate in a flooded well-deck, in the presence of saltwater, motion, and vibration
- Use commercial off the shelf (COTS) technologies
- Use standard interfaces
- Adhere to published, open standards
- Implement GPS encryption
- Maintain low electromagnetic interference
- Implement data encryption
- Account for force structure analysis in system design

Table 15. Initial, top-level customer needs for the LCU USV.

The expectation is that these needs may change over time as additional information surfaces that has not yet been considered. After establishing the customer needs, it is the duty of the systems engineer to derive requirements that in turn produce a system that meets these customer needs.

## **J. REQUIREMENTS ANALYSIS (WITH METRICS)**

After establishing top-level customer needs, system requirements may be derived by quantifying and bounding the customer needs with metrics. In identifying systems requirements, this analysis considers customer needs in conjunction with the salient factors (e.g., assumptions, independent variables, dependent variables, measures, and measurement) (Langford 2012, 259).

Requirements definition is especially challenging within an open systems architecture (OSA) context because the architect must be careful not to assume a particular physical solution to the problem too early in the system engineering process. Therefore, the requirements and corresponding metrics must be defined loosely enough to allow for future, changing missions.



The requirements and metrics for the LCU USV are largely determined by the base characteristics of the LCU craft (see Chapter IV, Section B.4). Those metrics that remain likely change with respect to craft operation are those requirements that alter the craft for autonomous navigation and control, autonomous payload operation, and those metrics which were originally limited by the presence of human personnel onboard (i.e., mission duration limitations because of food provisions). Note that some requirements can be quantified numerically, while others are measured with a “yes” or “no” answer. Table 16. presents the initial LCU USV requirements.

<b>Requirement/MOE</b>	<b>Measure of Performance</b>	<b>Metric</b>
<b>Ability to carry cargo capacity equal to that of suitable missions</b>	Weight capacity and deck square footage, cargo throughput rates.	-Deck capacity in tons ≤170 short tons -Cargo throughput in tons per nm per minute
<b>Ability to maintain a sufficient mission transit and cycle time</b>	Time to get on station and back, ship-to-shore, shore-to-shore movement time.	-Speed of vessel in knots: 8-12 kts
<b>Compatibility with current U.S. Naval amphibious, combatant, and logistics assets.</b>	Capability to load in a well-deck, tie to a pier/dock,	-Compatibility with LPD, LHA, FLO/FLO, LO/LO, LCS, and as many other Naval ship systems as possible.
<b>Compatibility with allied nations</b>	Intrusiveness, decibel/noise level, beach accessibility.	-Lower decibel level of ambient craft noise Higher Number of beaches accessible
<b>Ability to operate and navigate autonomously</b>	Accuracy when plotting and following course via waypoints. Ability to send and receive remote signals.	-95 to 99% accuracy with respect to adhering to programmed waypoints or following remote commands
<b>Ability to operate in a range of weather conditions</b>	Sea state, temperature, draft/depth	-Operate up to Sea State 3 -25 to 120 deg. F air temp -Operate in 6'8" of water or greater.
<b>Ability to exercise C4I via current Naval signals and systems.</b>	Ability to be equipped with and operate current C4I equipment.	-Has state-of-the-practice C4I technology
<b>Ability to maintain craft integrity</b>	Survivability, Maintainability, Availability	-65-99% craft availability and survivability. -High mean time between failures.
<b>Ability endure operationally</b>	Length of independent mission ability.	-10 to 14 days or 1200nm at 8kts
<b>Ability to operate safely</b>	GPS encryption Low electromagnetic signature Data Encryption	-Has GPS encryption -Has degaussing capability -Has data encryption
<b>Ability to maintain low-costs</b>	Adherence to Standards Standard Interfaces Uses COTS	Yes. Higher number of standard, common interfaces.
<b>Ability to accommodate various payloads</b>	Host and operate payloads	Yes. Higher number of varying payloads.

Table 16. Initial LCU USV system requirements.



In DOD and U.S. Navy systems, after establishing requirements from discussion with the stakeholders, those requirements must be traced back to high-level policy documents, instructions, directives, or other official guidance. In flexible, modular architecture, requirements must be defined in such a way that they allow room for future accommodation of unknown missions and modules. Further discussion of requirements traceability to requirements documents, instructions, and directives is presented later in this analysis.

#### **K. OSA CONSIDERATIONS FOR SYSTEMS REQUIREMENTS ACCOUNTABILITY**

In implementing OSA when determining program requirements, systems engineers and program managers must ensure that all system requirements (including those contained in an Initial Capabilities Document, Capabilities Development Document, Capabilities Production Document, and certain contract sections) are accounted for through a demonstrated ability to trace each requirement to one or more modules that consist of components that are self-contained elements with well-defined, open and published interfaces implemented using open standards (U.S. DOD OSA Data Rights Team 2013). See Chapter III, Table 5 through Table 8, for a list of considerations that aid in applying these OSA principles.

#### **L. SYSTEM BOUNDARIES**

Concurrently with the consideration of system requirements this analysis also derived and identified additional, broad design constraints and assumptions that bound the system design. Understanding the constraints and assumptions often directly influence the development of requirements and functional decomposition. This analysis is careful to be sensitive to the possibility of implicit constraints. While there can be a small difference between constraints and assumptions, here they are considered to be interchangeable.

When considering natural/environmental constraints, assumptions must be made regarding local maritime traffic patterns. When considering physical constraints, assumptions must be made regarding acoustic signatures, magnetic signatures, craft size, craft profile physical limits, noise limits and visual limits (i.e., lights). When considering operational constraints, assumptions must be made regarding Navy standard operating procedures, Naval Vessel Rules, safety, force structure, manpower, physical security, surveillance systems/cameras, and operational security. When considering political constraints, assumptions must be made regarding the ability of officials to limit program funding. Finally, when considering C4I constraints, assumptions must be made regarding signals, bandwidth, info assurance/info security (IA/IS), signal jamming, sending and receiving classified signals, and data encryption.

#### **M. STRUCTURE AND FUNCTIONS OF THE LCU USV**

This sections presents both the structural and functional decomposition of the LCU USV.

##### **1. Structural Decomposition**

The structural/object decomposition associated with the LCU USV is closely tied to the Ship Work Breakdown Structure (SWBS). The LCU USV SWBS in this analysis was derived by combining elements of the Heavy Lift Army Landing Craft (HLALC) SWBS (Carderock (NSWC0-CD) 2010) with a general NAVSEA SWBS (Hills 2012). Table 17 is a representation of the SWBS showing mainly those elements of the craft that are affected by the repurposing of the craft as an autonomous vehicle.

<b>100-Level SWBS Objects</b>		<b>10-Level SWBS Objects</b>	
<b>100</b>	<b>General Requirements for Hull Structures</b>	<b>160</b>	Special Structures (Bow/Stern Ramps, etc.)
<b>200</b>	<b>General Requirements for Machinery/Propulsion Plant</b>	<b>202</b>	Engineering (Machinery) Control System
		<b>252</b>	Propulsion Control Systems
<b>300</b>	<b>General Requirements for Electric Plant</b>	<b>331</b>	General Requirements for Lighting Systems – Distribution and Control
<b>400</b>	<b>General Requirements for Electronics Systems, Command and Surveillance</b>	<b>402</b>	Security Requirements
		<b>410</b>	Command and Control Systems
		<b>414</b>	Integrated Control System
		<b>420</b>	Navigation Systems (GPS)
		<b>421</b>	Navigation Aids, Non-Electrical/Non-Electrical
		<b>422</b>	Navigation Lights and Searchlight
		<b>423</b>	Electronic Navigational Systems, Radio
		<b>426</b>	Electrical Navigation Systems
		<b>428</b>	Navigation Control Monitoring
		<b>436</b>	Control and Alarm Monitoring System
		<b>438</b>	Integrating Control System
		<b>441</b>	Radio Systems
		<b>443</b>	Audible Alarm
		<b>446</b>	Security Equipment Systems
		<b>450</b>	Surveillance Systems/Surface Surveillance Systems
		<b>451</b>	Surface Search Radar
		<b>455</b>	Identification System/IFF
		<b>499</b>	Electronic Systems Special Tools and Miscellaneous Parts
<b>500</b>	<b>Auxiliary System</b>	<b>510</b>	Climate Control
		<b>555</b>	Fire Extinguishing Systems
		<b>560</b>	Ship Control Systems
		<b>561</b>	Steering Systems
		<b>573</b>	Cargo Handling Systems
		<b>575</b>	Military Vehicle Handling and Stowage Systems
		<b>580</b>	Mechanical Handling Systems
		<b>581</b>	Anchor Stowage and Handling
		<b>583</b>	Stowage and Handling for Lifeboats
		<b>590</b>	Special Purpose Systems
		<b>593</b>	Environmental Pollution Control System
<b>600</b>	<b>Outfit and Furnishings</b>	<b>640</b>	Living Spaces
		<b>642</b>	Non-Commissioned Officers Bunkroom and Mess
		<b>644</b>	Sanitary Spaces and Fixtures
		<b>660</b>	Seating (Crew/Passenger/Troop)
		<b>662</b>	Machinery Control Centers Furnishings
		<b>671</b>	Lockers and Special Stowage
		<b>672</b>	Storerooms and Issue Rooms

Table 17. LCU USV structural decomposition via SWBS (after Carderock (NSWC0-CD) 2010), Hills 2012).

## **2. Functional Decomposition**

Although this study examines mainly the most suitable missions, many of the functions overlap for the postulated missions. Thus, this study does not analyze the functions for each of the missions, but rather performs an overarching functional analysis that covers the scope of the potential mission set. This functional decomposition is partially adapted from the *Required Operational Capabilities And Projected Operational Environment For Navy Expeditionary Intelligence Command Forces* (OPNAV N85 2010) and from *NPS-SE-11-006 Capstone Project/Thesis* (Calvert 2011). See Table 18. Note that functions 1, 2, 3, 5, and 6 may also be represented as subordinate functions to each of functions “4.X.” However, it is presented in this manner to facilitate comprehension. See Appendix C for a more detailed functional decomposition.

- 1. Load/Recover/Retrieve/Receive Payload**
  - 1.1. Load/Receive/Recover/Retrieve cargo or UXV for MIW, ISR, or support missions while underway
- 2. Transit/Operate/Maintain LCU USV Platform**
  - 2.1. Employ safety countermeasures
  - 2.2. Perform seamanship, airmanship and navigation tasks
- 3. Unload/Deploy/Launch Payload including MIW, ISR, and Functional mission equipment.**
  - 3.1. Deploy/Launch/Load USV/UUV/UAV for MIW, ISR, or support missions while underway, or while anchored.
- 4. Execute Missions**
  - 4.1. Execute environmental collection in permissive environments
  - 4.2. Execute Persistent ISR in permissive environments
  - 4.3. Execute Processing, Exploitation, and Dissemination
  - 4.4. Execute Payload Delivery, Autonomous ship-to-shore, or shore-to-shore connector payload Delivery
  - 4.5. Execute Unmanned Vehicle Support
  - 4.6. Execute Search and rescue (SAR) of conscious victims
  - 4.7. Execute Training Support
  - 4.8. Execute Test platform missions
  - 4.9. Execute MCM intelligence preparation of the battle space (IPB)
  - 4.10. Minefield proofing
- 5. Host/Maintain Payload on Platform**
  - 5.1. Receive fuel while underway or docked
  - 5.2. Provide all necessary systems, services, programs, and facilities to safeguard classified material and information.
- 6. Maintain LCU USV Platform**
  - 6.1. Provide upkeep and maintenance of LCU USV
  - 6.2. Provide organizational level maintenance
  - 6.3. Repair own unit's equipment
  - 6.4. Receive fuel while underway or docked
  - 6.5. Provide all necessary systems, services, programs, and facilities to remotely monitor the LCU USV system condition.

Table 18. LCU USV 2-level functional decomposition (after OPNAV N85 2010, Calvert 2011).

## **N. INTERFACE MANAGEMENT**

The interface definition step in system architecture is an iterative process that identifies the details and standards for the key interfaces. It builds on the results of the previous steps and repeats them when needed. Key interfaces must be defined functionally and physically. These steps are particularly important for OSA design.

After establishing the requirements, system components, and functions, the systems engineer must then be concerned with how to join the boundaries seamlessly between system elements. The interfaces between system elements must be defined and managed before the process of system architecting and design begins. System failures are most likely to occur when energy, matter, material, or information must cross a boundary within a system (see Chapter IV, section B.1). “Failures often occur at the interfaces between system elements, in many cases, between interfaces thought to be separate” (DOD 2011).

Open standards must be utilized when considering interfaces within a system. “Interface standards specify the physical, functional, and operational relationships between the various elements, hardware and software, to permit interchangeability, interconnection, compatibility and/or communication, and improve logistics support” (DOD, 2004).

With respect to the LCU USV, it is of particular importance to focus on those interfaces that are altered from human-machine interface to a robotically controlled, unmanned interface. The utilization of open architectures (OA) is necessary to overcome problems associated with proprietary robotic system architectures (DOD 2011). Furthermore, open interface specification helps to achieve “modularity, commonality, and interchangeability across payloads, control systems, video/audio interfaces, data, and communication links” (DOD 2011). This openness can also lead to lower life cycle costs, and more capability for the end user.

The primary human to machine interfaces (HMI) in the traditional LCU system are the navigation systems, craft steering and control systems, machinery monitoring and control systems, safety and alarm systems, radio and communications systems, damage



control systems, climate control systems, cargo and payload mechanical handling and stowage systems, anchor and ramp systems. In converting the LCU into a USV, all of these systems need to be designated as requiring complete autonomy, partial autonomy, or sufficient risk mitigation. This means that the human-to-machine interface associated with each one of these systems may need to be reengineered to be electronic and controlled by software command in such a way that OA and open interfaces are included.

Research has shown that there are not many standards, instructions, or handbooks that establish requirements for open architecture solutions to common, major naval systems. The following are open standards that have been published that may guide the systems engineering effort for primary interfaces (see Tables 19 and 20). Further experience by other OSA programs may offer additional insights.

<b>System</b>	<b>Open Standard</b>	<b>Description</b>
<b>Navigation Systems (Electronics)</b>	SAE J1939	Recommended Practice for a Serial control and Communications Vehicle Network
	IEEE Std 45	Recommended Practice for Electric Installations on Shipboard; Recommendations for the design, selection, and installation of equipment on merchant vessels with electrical apparatus for lighting, signaling, communication, power, and propulsion are provided
	SAE J1939	Recommended Practice for a Serial control and Communications Vehicle Network
	NMEA 2000	Standard in marine electronics data protocol, established by the National Marine Electronics Association, for networking multiple instruments on boat
	Modbus	Messaging structure developed by Modicon in 1979. It is used to establish master-slave/client-server communication between intelligent devices. It is a de facto standard, truly open and the most widely used network protocol in the industrial manufacturing environment
	NMEA 0183	Interface Standard defines electrical signal requirements, data transmission protocol and time, and specific sentence formats for a 4800-baud serial data bus
	COLREGS	U.S. Coast Guard Navigation Regulations

Table 19. Open interface standards for LCU USV navigation systems.

<b>System</b>	<b>Open Standard</b>	<b>Description</b>
<b>Craft steering and control systems</b>	MIL-STD-1399/300A	Interface standard for shipboard systems (section 300a) electric power, alternating current
<b>Machinery monitoring and control systems</b>	MIL-STD-1399	Defines the standard interface requirements for the constraints on the design of shipboard user equipment that will utilize shipboard alternating current (at) electric power
<b>Safety and alarm systems</b>	IEEE Std 45, NMEA 2000, Modbus, NMEA 0183	Same as Above
<b>Signals, radio and communications systems</b>	Messaging Standard	US Message Text Formatting (USMTF), Military Standard (MIL-STD)-6040: the mandated standard for messages when communicating with the Joint Staff, combatant commands, and Service component commands.
<b>Damage control systems</b>	DC-ARM	Damage Control Automation for Reduced Manning
	IEEE Std 45, NMEA 2000, Modbus, NMEA 0183	Same as above
<b>Climate control systems</b>	IEEE Std 45, NMEA 2000, Modbus, NMEA 0183	Same as above
<b>Cargo and payload mechanical handling and stowage systems</b>	ISO 7166	Aircraft -- Rail and stud configuration for passenger equipment and cargo restraint
	ASTM F2541-06	Functional Allocation of Major UUV Autonomy and Control Components"
<b>Anchor and ramp systems</b>	IEEE Std 45, NMEA 2000, Modbus, NMEA 0183	Same as above

Table 20. Open interface standards for LCU USV systems.

There are other key interfaces external to the system including that of the overall craft interface with the shore structure. If the current LCU craft remains in service as the LCU USV, then the shore infrastructure must be considered. The Navy currently has plans to replace the current fleet with no accompanying plan for building a new shore infrastructure needed to accommodate and support the new fleet. Therefore, the old fleet assets (i.e., the LCU USV) may eventually need to be hosted elsewhere. This requirement and other external interface aspects are addressed in more detail in the Intersystem Interfaces and Business Case Analysis (BCA) sections of this thesis.

## **O. OSA CONSIDERATIONS FOR INTERFACE DESIGN AND MANAGEMENT**

In managing the interface design and maintenance throughout the system development, the program manager and systems engineer must account for several considerations. First, all of the interfaces must be defined clearly using open standards. Second, the program must be sure to “define and document all subsystem interfaces, and configurations to provide full functional, logical, and physical specifications” (U.S. DOD



OSA Data Rights Team 2013). Finally, the program shall identify processes for “specifying the lowest level at below which it intends to control and define interfaces by proprietary and or vendor-unique standards and the impact of the upon its proposed logistics approach” (U.S. DOD OSA Data Rights Team 2013). These interfaces shall include subsystems, hardware, software, mechanical, and electrical amongst others. See Chapter III, Table 5 through Table 8, for a list of considerations that aid in applying these OSA principles.

## **P. SUBSYSTEM INTEGRATION**

The key to achieving OSA principles in subsystem integration requires designation of functional component areas, establishment of an open architecture design with zones and stations, and identification and definition of key interfaces at the subsystem level (Marcantonio 2007). Upon completion of the functional analysis, different LCU USV subsystems can be divided into their common components. Components that perform a similar function (e.g., craft control) are grouped into the same functional component areas.

Following the establishment of architecture stations and zones, it is important to define the potential interfaces. In DOD practice, this is usually done via an interface control document (ICD), initial capabilities document, and/or capabilities development document (CDD) (Marcantonio 2007).

There are no existing reference documents that specifically define LCU USV interfaces. Nevertheless, criteria must be established for identifying key interfaces. This study uses the same criteria as Marcantonio in establishing the LCU USV key interfaces. The criteria are as follows (Marcantonio 2007):

1. Where the technology for the system components is evolving
2. Where the system components have high usage rates and are often replaced

Key system interfaces information is best presented, controlled and managed via detailed installation drawings, and technical specifications that define key interfaces for specific installations. Using this approach, this study derives a LCU USV reference

model to help better understand the key interfaces (see Figure 20). In Figure 20, the solid, two-headed arrows represent physical, wired connections between modules, systems, or zones. The dashed lines in Figure 20 represent the sea frame. It is important to note that key to the implementation of OSA in subsystem integration is considering the connections between all subsystems within the overall LCU USV, both below and above deck.

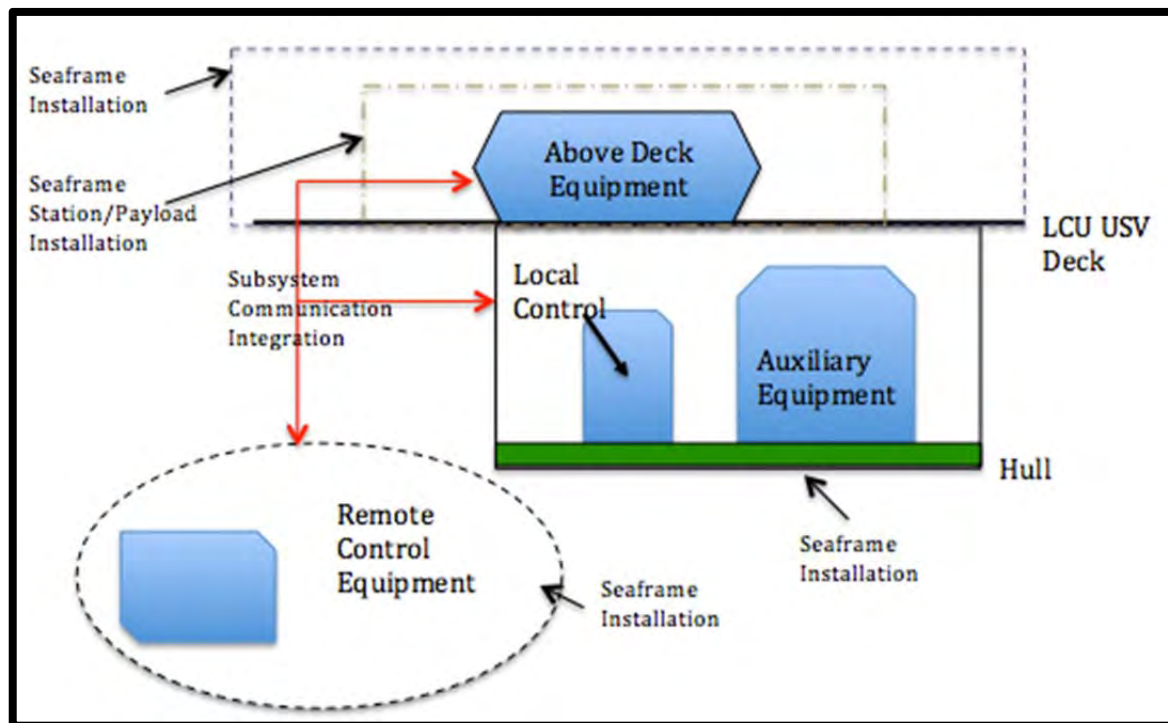


Figure 20. LCU USV functional component areas (after Marcantonio 2007).

The functional component areas identified for the LCU USV are the above deck equipment, local control, remote control and auxiliary equipment. Component areas may contain multiple components, but all support a common function. In general, components and equipment are grouped according to physical characteristics and functional characteristics.

The LCU USV incorporates internal functional arrangement practices that support changing the capabilities of the craft. The model designates each of the spaces adjacent to the module spaces to support equipment for their respective modules and includes

installation of FlexTech architecture, which allows the supporting equipment to be installed in a modular, open, nature as well (DeVries, Levine and Mish Jr 2010). Further, the model allocates the space volume adjacent to the modules for other equipment associated with the module (Page 2011).

Dividing the system into functional areas helps accommodate variable physical geometries, flexibility, and open systems design. This type of modularity breaks down the LCU USV into functional elements that are common to multiple systems, such as weather deck components, below deck components, and remote components.

#### **Q. OSA CONSIDERATIONS FOR SUBSYSTEM INTEGRATION**

When implementing OSA principles in subsystem integration of a system, the systems engineer and program manager must consider both module coupling and module cohesion. OSA mandates the use of loosely coupled modules that have “minimal dependencies on other modules as evidenced by simple, well-defined interfaces and by the absence of implicit sharing of data and intellectual property” (U.S. DOD OSA Data Rights Team 2013). Changes to one module shall not necessitate significant changes to another module or zone.

Modules shall be integrated with a high level of cohesion. Highly cohesive modules are characterized by the “singular assignment of identifiable and discrete functionality” (U.S. DOD OSA Data Rights Team 2013). “The purpose is to ensure that any changes to system behavioral requirements can be accomplished by changing a minimum number of modules within a system. In determining the level of both module coupling and cohesion, the approach used to determine design and flexibility tradeoffs shall be clearly described. See Chapter III, Table 5 through Table 8, for a list of considerations that aid in applying these OSA principles.

## **R.     INTERSYSTEM INTEGRATION**

After establishing the top-level system requirements, and interfaces, the attention of the system engineering process is turned towards ensuring that all of the new systems, those related to the autonomous operation and missions, are well integrated with all other LCU systems, and with external systems. At this point, the systems engineering focus is on ensuring the integrations of various system elements into a final system configuration. “Such elements include not only mission-related hardware and software but also people, real estate and facilities, data/information, consumables, and the materials and resources necessary for the operation and sustaining support of the system throughout its planned life cycle” (Blanchard and Fabrycky 2011, 132). See Figure 21 for an example operational view of the LCU USV intersystem integration. Figure 21 shows the operational connection between the LCU USV, air vehicles, shore establishments, warfighters, control systems, data systems, and underwater systems.

There are a few areas of primary concern when integrating new subsystems with the remainder of the LCU systems, external systems, and the operating procedures. For the LCU USV a few key concerns for intersystem integration are the interface of the vessel with its host (e.g., well deck, shore establishment, pier, or port) and the interface between the various payloads and the vessel (e.g., “conex” box and cargo deck, or UUV launch system and LCU machinery controls).

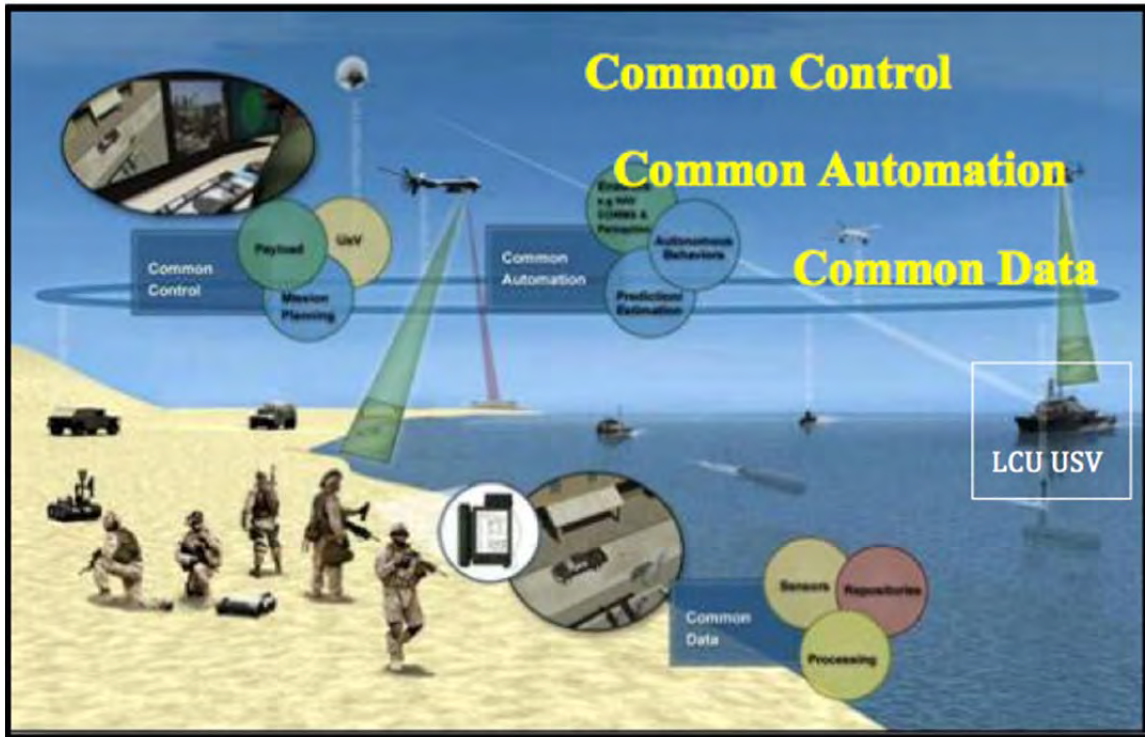


Figure 21. Operational view of LCU USV intersystem integration (after DOD 2011).

## 1. LCU USV Berthing Interface

All naval vessels must be stowed in a secure, monitored space while the vessel is not in operation in the open water. Some refer to this place as the “home port” of the vessel. The current fleet of 32 LCU are home-ported at Assault Craft Unit (ACU) 1 in San Diego, CA; ACU 2 in Norfolk, VA; and a small number are Forward Deployed Naval Forces (FDFN) with detachment West Pacific (WESTPAC) to in Sasebo, Japan. The current Naval plan replaces the existing LCU fleet with exactly the same number of Surface Connector (X) vessels (i.e., LCU replacements) berthed at the existing LCU Shore establishment ACUs. This means that the future LCU USV likely needs to be berthed elsewhere. There are many assumptions, requirements, and considerations that go into determining where the LCU USV is berthed when not in service.

While operational, the LCU USV is likely to be hosted inside the well decks of the amphibious big-deck ships of an ARG/MEU, ESG, or Battle Group. Of course, this assumes that there is space available in a well deck, and that the operational

commander's mission calls for the use of an LCU USV. The LCU USV can also be hosted at a pier almost anywhere in the world. LCU USVs can also be beached. From a river in Europe, to a remote island in the South China Sea, there are many options for berthing the LCU USV when not operational, and not hosted in a well deck of a ship. Thus, berthing requirements are likely not to hinder program success.

## **2. LCU USV Logistics and Consumables Interface**

How the system interfaces with other important systems necessary for its operation is important. Some of these include consumables, repair/maintenance items, and the people who have to perform these duties.

The LCU USV has the option of operating in either a manned or unmanned state. Currently, the LCU receives resupply of consumables like food, water, maintenance provisions and fuel while in home port or in the well deck. The LCU USV is able to receive such consumables in the same manner as the current LCU fleet.

Routine maintenance personnel, materials and tools used for maintenance tasks will need to interface with the LCU. The interface requirements for these items thus also need to be determined. Many of the interface requirements are expected to be the same as for the existing LCU whereas the type of maintenance, logistical footprint, and physical maintenance space requirements are not expected to change from the current LCU.

## **3. LCU USV Payloads Interface**

There are a wide variety of payloads that may be hosted by any given LCU USV vessel. The unique attributes of each specific payload dictates that the detail design requirements of the interface between the payload and the LCU USV vessel must remain flexible. For instance, a simple static "conex" box payload interface may be accommodated sufficiently by the existing pad-eye tie down structure on the existing cargo deck. A payload of autonomously operated UUVs may also require the addition of a cradling system, as well as a launch and recovery mechanism in order to meet interface requirements.

## **S. OSA CONSIDERATIONS FOR INTER-SYSTEM INTEGRATION**

OSA must be implemented in intersystem integration with the objective of minimizing intersystem dependencies. The systems engineering approach shall result in a layered system design, maximizing independence between systems components, hardware, and software (U.S. DOD OSA Data Rights Team 2013). The system shall be able to survive a change to the internal and external infrastructure with minimal to no changes required to the core functionality. Data defining the interfaces must be made available to the program throughout the lifecycle of the system. Data accessibility can promote the decoupling of components and component reuse. See Chapter III, Table 5 through Table 8, for a list of considerations that aid in applying these OSA principles.

## **T. SYSTEM ARCHITECTURE**

“It is the job of the architect to pose the brilliant solution” (Langford, 2012, 275). A good architect poses a solution that is within objectives, resources, limitations, stakeholder sensitivities, constraints, budget, schedule, rules, policy, skills, etc. Architecture is what the system does and how it does it (Langford 2012, 276). Systems architecture includes both system conceptualization and system visualization.

### **1. Conceptualization**

Conceptualization is the beginning of the systems architecting phase where there is still much uncertainty as to how the technical requirements and metrics requirements might manifest in the final system. Conceptualization involves integrating system requirements into a single concept. It requires that the concept make sense in written form before the architect begins forming that concept in to a visual, physical form (i.e., Visualization). At this point, the systems engineer has used notionally selected operational scenarios to help think through the customer needs, requirements, and perform a stakeholder analysis.

User needs and requirements are conceptualized by answering the following example questions (Langford, 2012, 271) (see Table 21):

- What decisions does the user need to make?
- How much information does the user need to make those decisions?
- From where will the information come?
- How should the information be presented to the user?
- What is the timeline for the users decisions?
- What procedures should be built into the product or service that are most natural to assist the user in making decisions?

Table 21. Sample question to guide system conceptualization  
(from Langford 2012, 271)

In the case of the LCU USV it is important to conceptualize first how the craft needs to be rearchitected as an optionally unmanned vessel. Next, it is important to conceptualize how the vessel needs to be rearchitected in order to meet one or more of the various new missions that may need to be accomplished.

As a starting point for conceptualization, this analysis refers back to the four definitions of autonomy derived earlier in this analysis (see Chapter I, Section G). With increasing levels of autonomy comes an increased cost to the Navy. Additionally, increased levels of autonomy also require less bandwidth from communications assets (i.e., lower wireless signal requirements). Therefore, it is best to conceptualize a craft that is a combination of Remote Controlled Operation and Semi-Autonomy. Flexibility makes sense because most unmanned systems are a combination of levels of autonomy and thus cannot be clearly bounded by any one definition of autonomy.

One assumption is that the LCU USV has little value to the Navy unless personnel can be totally removed. Therefore, building the craft with autopilot-type autonomy is not of interest in this analysis. While manning might be reduced because of the elimination of a navigator and/or helmsman, risks associated with manning are present because of the personnel onboard for other reasons such as payload operation and deployment.

***a. LCU USV System Concept, Iteration 1***

The first iteration of design consists simply of reconfigured craft navigation and machinery control systems to include optional, remote-controlled, or preprogrammed semi-autonomous navigation and propulsion. This gives the option of removing



personnel from the vessel if there is no requirement for manned payload operation/deployment while the vessel is underway (i.e., not in port/well-deck). There are no autonomous mission packages, but in turn mission systems and static payload can be preloaded at a pier or well deck according to need. The missions are limited to that possible with a traditional, non-reconfigured LCU (see Table 22).

<p><b>Features of Design Concept, Iteration 1</b></p> <ul style="list-style-type: none"><li>• Semi-Autonomous, preprogrammed navigation and propulsion</li><li>• Remote controlled navigation and propulsion</li></ul>
------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

Table 22. LCU USV design concept features, Iteration 1.

While matching LCU capabilities, this design iteration nevertheless limits the ability to conduct some missions typical of a USV. Thus, the next design/conceptualization iteration needs to address that issue more sufficiently. However, increasing vessel capability also increases cost, and so care needs to be taken not to add cost-prohibitive capability.

***b. LCU USV System Concept, Iteration 2***

This design iteration has the same features as iteration 1 except that added capability can enable remote-controlled payload operation (i.e., towing, launch and recovery, charging, data transfer). This assumes that manned interaction with the payload is still able to happen at both the end and the beginning of an overall mission evolution (i.e., at the pier or in the well deck). This also gives an additional option of removing personnel from the vessel if there is no requirement for manned payload operation/deployment while the vessel is underway (i.e., not in port or well-deck) (see Table 23).

<b>Features of Design Concept, Iteration 2</b>
<ul style="list-style-type: none"> <li>• Fully-Autonomous, preprogrammed navigation and propulsion</li> <li>• Remote controlled navigation and propulsion</li> <li>• Remote controlled payload operation / mission accomplishment</li> <li>• Reduced habitability spaces to create extra room for flexible infrastructure autonomous payloads and payload support spaces</li> <li>• A conex box or cradle type mission module area on the cargo deck for the above-deck systems with connections for data transfer, powering/charging with the payload</li> <li>• A launch and recovery crane and/or tether system</li> </ul>

Table 23. LCU USV design concept features, Iteration 2.

*c. LCU USV System Concept, Iteration 3*

This design iteration is the same as Iteration #2 except that it also provides the additional capability for totally autonomous, preprogrammed payload operation (i.e., not remote controlled) (see Table 24).

<b>Features of Design Concept, Iteration 3</b>
<ul style="list-style-type: none"> <li>• Fully-Autonomous, preprogrammed Navigation and propulsion</li> <li>• Remote controlled navigation and propulsion</li> <li>• Fully Autonomous, preprogrammed payload operation/mission accomplishment</li> <li>• Remote controlled payload operation / mission accomplishment</li> <li>• Reduced habitability spaces to create extra room for flexible infrastructure autonomous payloads and payload support spaces</li> <li>• A conex box or cradle-type mission module area on the cargo deck for the above-deck systems with connections for data transfer, powering/charging with the payload</li> <li>• A launch and recovery crane and/or tether system</li> </ul>

Table 24. LCU USV Design Concept Features, Iteration 3.

Concept formulation is complete when the builder thinks that the system can be built to the client's satisfaction (Maier and Rechtin 2009, 400). At this point, this thesis analysis concludes design iteration and revisits the requirements in order to make decisions as to what requirements can be met, and which requirements may not be able to

be met with this design. At this point, it is easiest to heuristically “down select” to one preferred concept to pursue based on the expected level of autonomy.

Design iteration #2 is chosen because of its ability to meet many more mission requirements of a traditional USV while not being as costly as Design iteration #3. With continued conceptualization and design iterations, the systems engineer must begin to consider tradeoffs between overall user needs, design requirements, cost, and design feasibility. Design Iteration 3 remains viable as a future upgrade option since Design Iteration 2 is a non-conflicting subset of capabilities.

## **2. Visualization**

“Design is the capture of what you want to do (i.e., idea) in physical, functional, and process thinking. Visualizing the idea through sketches, imagery, photos, or drawings conveys design. The appearance of the idea is expressed and refined until the views of the design capture your physical, functional, and process thinking. Once the outward appearance is firmed up, the physical, functional, and process thinking is conveyed through diagrams of how things will work, what will happen if, and what the design means to someone else. (Langford, 2013, 8 March E-mail to Author/M. Smith)”

### ***a. Autonomous Operation of the LCU USV Controls***

The LCU, as traditionally operated, has several manned systems/interfaces. Our chosen design maintains these manned interfaces. Sailors primarily interface with the LCU when controlling craft at the helm console, the navigation station, the conning station, and the cargo deck (see Figure 22).

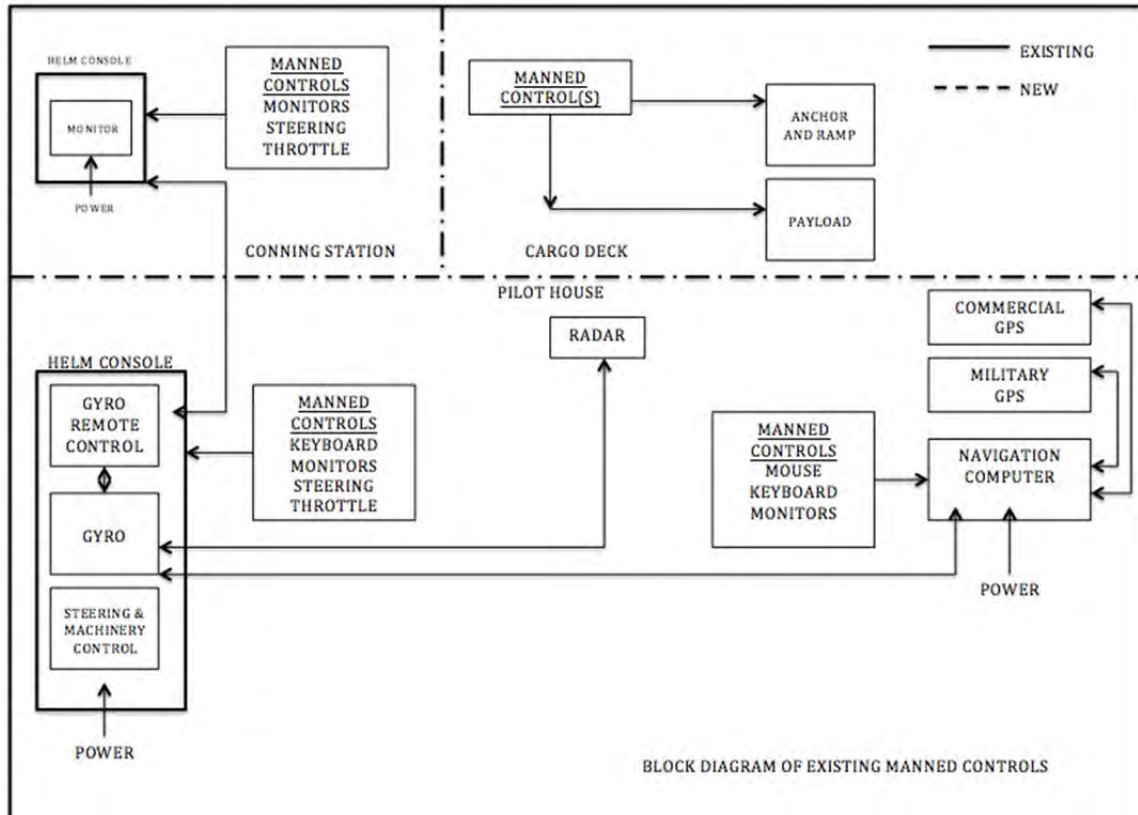


Figure 22. Block diagram of existing LCU 1610 class controls.

The simplest required change for the LCU craft to become an optionally unmanned vessel is the change to the design of the control mechanisms for navigation, and steering and machinery monitoring systems. In order to satisfy the requirements of our chosen design, this analysis also has to address engineering a system for the unmanned control of the cargo deck controls such as the anchor, the ramps, and necessary control of the payload. Development of unmanned controls for the payload is beyond the scope of this thesis analysis (see Figure 23).

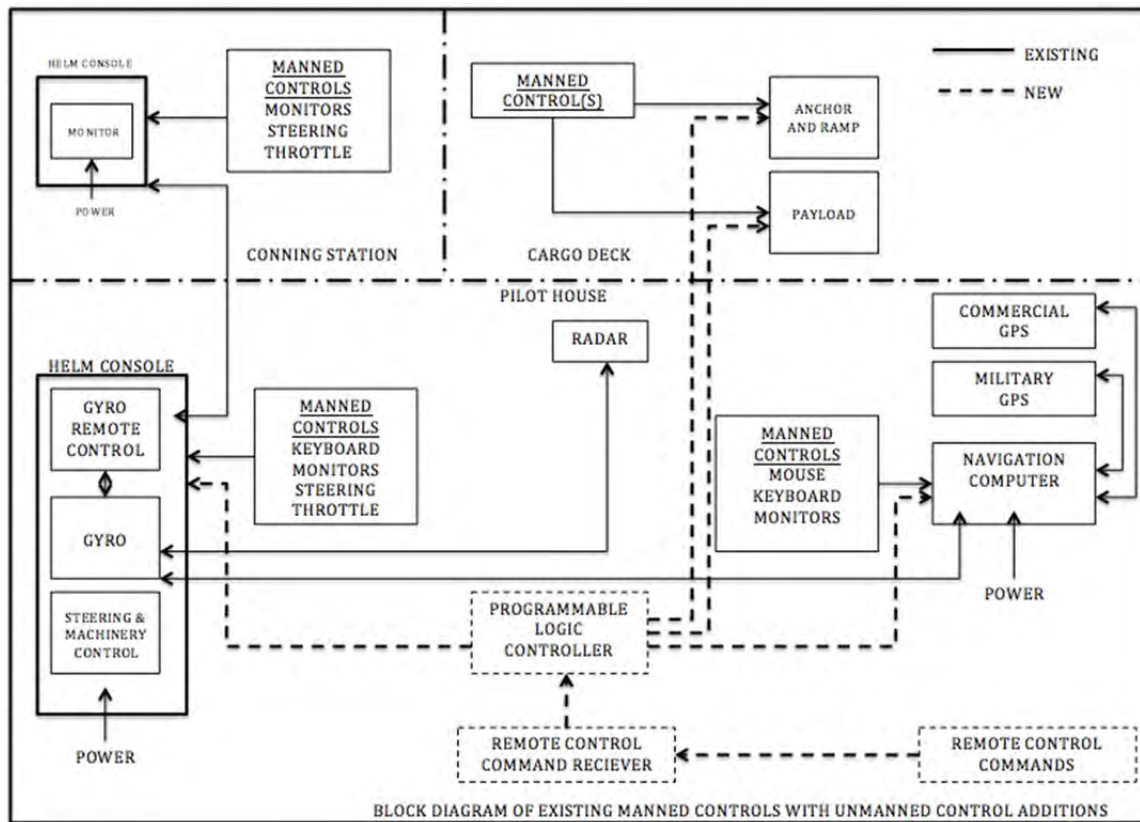


Figure 23. Block diagram of existing manned controls with addition of unmanned control systems indicated by dashed lines.

The key focus of the engineering for the unmanned systems of the LCU USV is replacing the human logic and decision-making ability with a computer-controlled logic capability. For this purpose, this design concept includes a programmable logic controller (PLC). This logic controller/system can allow for preprogrammed navigation and propulsion, or remote controlled navigation and propulsion, and/or remote controlled payload operation/ mission accomplishment. See Appendix D for details and explanation of notional system elements, companies, and other stakeholders that contribute to the conversion of the LCU to the LCU USV for unmanned control and operation.

Further development of the engineering for the unmanned controls is reserved for further study. Keeping with OSA principles, the engineering of the unmanned controls might mandate the use of commercial-off-the-shelf (COTS) components for the PLC and other components of the unmanned system. Identifying and integrating these components



requires close monitoring of industry capabilities in order to get requirements that are executable and competitive over the full system lifecycle in accordance with OSA principles.

***b. Autonomous Area-of-Operation Awareness***

A number of sensor systems need to be integrated into the outside of the structure of the LCU USV for sensory data collection. A number of cameras also need to be installed for 360-degree operational visual awareness by remote operators. Sensors are also needed for other human-like senses such as sound and vibration. Pictured in Figure 24 is the sensor suite for the Control Architecture for Robotic Agent Command and Sensing (CARACaS) autonomous control system. From bottom to top, the components are the stereo electroptic, 360-degree electro-optic, radar, and lidar (Brizzolara 2014).



Figure 24. Sensor suite for the Control Architecture for Robotic Agent Command and Sensing (CARACaS) (from Brizzolara 2014).

*c. Autonomous Operation of LCU USV Payloads and Mission Execution*

The systems that are essential to the reengineering of the LCU USV for unmanned operation are mainly electronic, and mechanical systems that do not make the craft appear drastically different on the exterior. In other words, most of the systems are computer and machinery/mechanical changes that are implemented inside of the LCU hull. Nevertheless, in order to realize the true value of the LCU USV, it helps to visualize several of the reengineered craft configurations for unmanned operation of the various payloads.

Figure 25 shows an LCU USV carrying a payload delivery mission in unmanned remote controlled mission mode. On the deck, there are conex boxes that were loaded by sailors in port or well deck for delivery to the mission area. The LCU USV conducts an unmanned transit and delivery with the crane offloading the boxes at the destination.



Figure 25. Modified image showing visualization of LCU USV with crane, carrying payload delivery mission of conex boxes (after FrenchConnections 2014 and Wikimedia Commons 2014).

For unmanned ISR, MCM, testing, unmanned vehicle support, and environmental collection, the craft needs the ability for fully autonomous payload operation, preprogrammed payload operation/mission accomplishment, or remote controlled payload operation/mission accomplishment. This can be accomplished via a towed sensor, an autonomous crane-like launch and recovery system, and/or a pulley-like, reeled line system. Figure 26 shows an LCU USV with a towed UUV payload system.

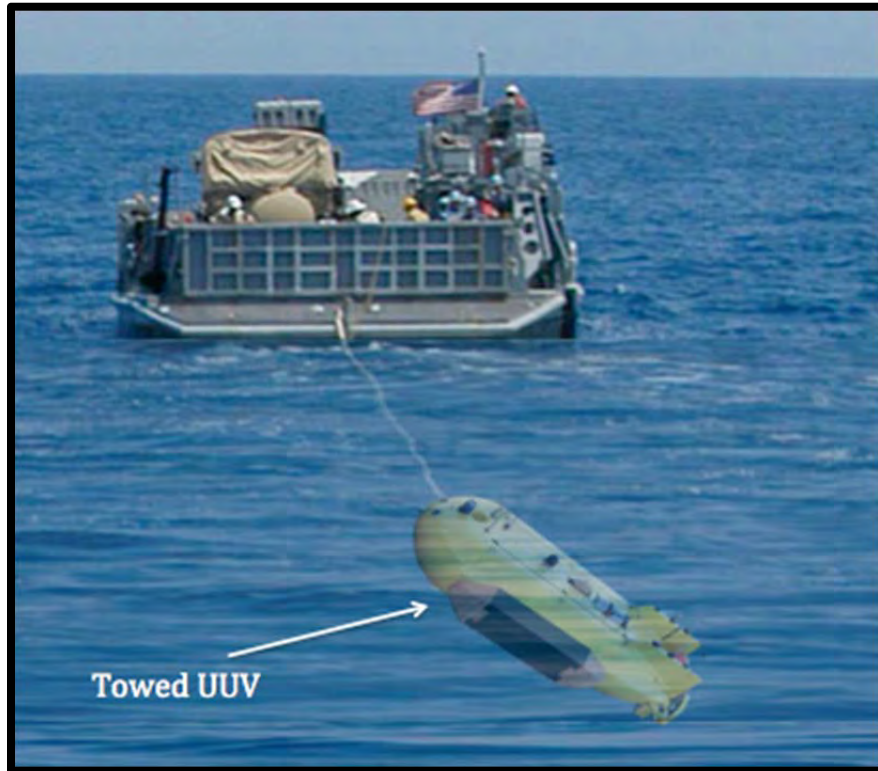


Figure 26. Modified image showing visualization of LCU USV towing a SeaOtter II UUV payload (after Navsource 2014 and Military Technology 2014)

Figure 27 shows a visualization of the LUC USV with a crane handling a UUV payload.



Figure 27. Modified image showing visualization of LCU USV with crane launching/recovering a UUV payload (after Tribune Broadcasting 2014 and NavSource 2014).



Many other considerations must be planned when visualizing and engineering the system. For the LCU USV, these considerations are best saved for further work that may be completed as a part of a requirements-driven operational study on detailed design and construction of the LCU USV system.

## **U. TESTING**

LCU USVs must adhere to the same requirements as any manned craft or boat. Any LCU USV craft test program must address both craft operation, craft system operation, craft safety and craft systems safety. “Testing unmanned systems, in general, is a significant challenge and can be very costly. For example, if it is impossible to put a man aboard a USV, the amount of time and expense increases significantly to verify that the propulsion system is working correctly” (DOD 2013). The Navy has developed a guide for testing USVs and drafted an approach to certifying USVs. This and other USV test guidance documents are listed in Table 25. Testing is typically more effective when performed as early in the design process as possible. Virtual testing using modeling and simulation has further benefits.

<ul style="list-style-type: none"><li>• MIL-STD-882D Standard Practice for System Safety</li><li>• Department of Defense Unmanned Systems Safety Guide for DoD Acquisition</li><li>• PMS406 Guidance for USV Test Safety</li></ul>
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Table 25. USV test guidance references.

Once constructed, the LCU USV must undergo test and evaluation to ensure validation of requirements, and verification of operation. Manned testing is the safest, most reliable manner of initial testing for USVs. Because the LCU USV can accommodate personnel onboard, the crew can ensure proper operation and evaluation of systems and subsystem performance. This may be considered developmental testing. Once the LCU USV is ready for full operational test and evaluation, the craft may be operated at the chosen level of autonomy on a dedicated test range. It may be noted that some craft are too small (jet-ski-sized craft, for example) to accommodate onboard test

personnel and thus require all operation to be performed remotely or autonomously (Naval Surface Warfare Center, Carderock Division, Detachment Norfolk (NSWC-CD-DN) 2012). This is not the case with the LCU USV.

Testing and evaluation is the stage of the systems engineering process where the open architecture standards used in system design are evaluated for compliance. Figure 28 shows the notional challenges of testing the LCU USV for U.S. Coast Guard Collision Regulations (COLREG) compliance. In this test scenario, a traffic vessel is crossing from the right. The unmanned surface vessel (USV) autonomously maneuvers around the traffic vessel in compliance with the collision regulations. The colors around the USV indicate in velocity space: safe velocity vectors (green), potential collisions (red) and violations of collision regulations (purple). The white circle in front of the USV is the desired velocity vector and the blue line is the actual velocity vector (Brizzolara 2014).

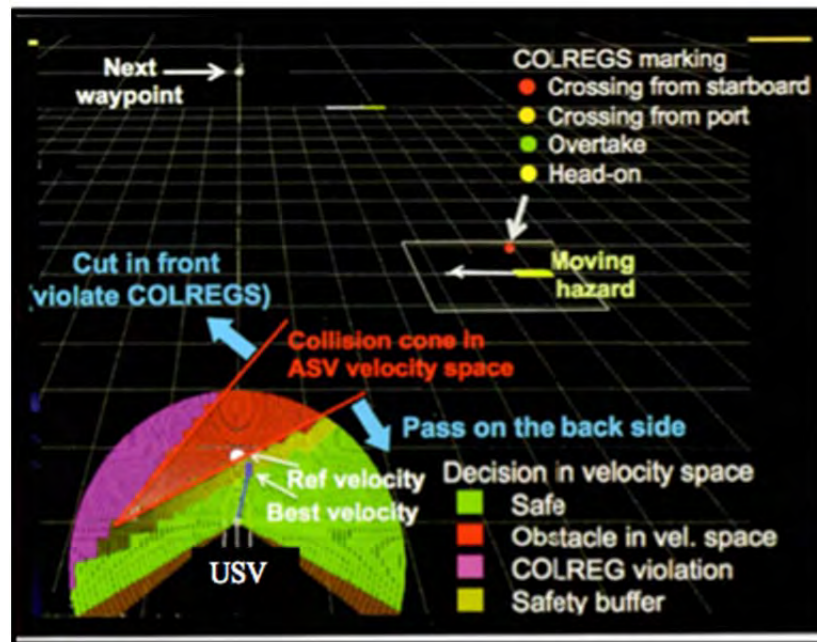


Figure 28. Notional USV challenges when testing for compliance with COLREGS. (after Brizzolara 2014).

The systems engineering process must certify conformance of the LCU USV system. The program needs to prepare validation and verification mechanisms such as

conformance certification and test plans to ensure that the system and its component modules conform to the external and internal open interfaces. Proper test, verification, and validation are also necessary to minimize risk to acquisition and operation of the LCU USV. Verification is conducted to ensure that selected work products meet their specified requirements (DAU 2014). Validation is conducted to demonstrate that a product or product component fulfills its intended use when placed in its intended environment (DAU 2014).

Normally, a USV system design can be verified, at least in-part, by using the system reference model, combined with preliminary market research to compare the system with existing systems. Since there are no existing USVs of comparable size and capability to the LCU USV, this method is not likely to be feasible.

The LCU USV system might follow a similar standard for the USV verification and validation process as in current U.S. Navy USV development. First, the LCU USV software and systems can be simulated in a lab environment. Next, the mechanical and electrical systems (which are mostly legacy components) are tested pierside. Finally, all systems are run in a controlled water environment (Naval Surface Warfare Center, Carderock Division, Detachment Norfolk (NSWC-CD-DN) 2012). A detailed review of the reference models compared to the chosen LCU USV system and subsystem technologies, and compared to the LCU USV functional models allow further verification that of each of the LCU USV subsystems conformed appropriately to the desired technical architecture.

Validation occurs when the LCU USV is put into initial operational use, and the warfighter is given a shakedown period in which to evaluate the performance of the vessel versus the needs in the area of operation.

## **V. IMPLEMENTATION**

After the system is built to the satisfaction of the systems engineer and the stakeholders, the process of preparing it for use in operational circumstances must begin. Implementation includes initial operational capability execution, and reiteration of many

of the previous steps of the process model based on subsequent operational feedback. This period is often referred to as post shakedown availability.

Implementation also includes operator training, deployment planning, maintenance considerations, life cycle management, and logistics planning. Some of these issues are addressed further in the Business Case Analysis chapter.

## **W. TRANSITION**

The systems engineering process must be concerned with the LCU USV system all the way through the full transition of this system into initial operation capability (IOC) with the Navy Fleet. The timing, location(s), and pace of delivery are just a few factors that must be planned by the systems engineering process when deciding how to introduce the system to the Navy fleet. This includes making sure that all aspects of program life cycle are fully addressed outside of the purview of the engineering team that brought the system to fruition.

Although the systems engineer maintains some sort of reach-back policy with the fleet and program managers, they are able to be less involved with system and program development at this point. At this point, resource sponsors, program managers, acquisition managers, in-service engineering agents, and the fleet begin to maintain the program of record. Some of these issues are addressed further in the Business Case Analysis chapter.

## **X. DISPOSAL LIFE CYCLE**

Navy assets must first be stricken from the Naval Vessel Register before they can be disposed. Once stricken, their disposition can occur via several methods: scrapping, transfer to the U.S. Maritime Administration (MARAD), foreign transfer, experimental/target, donation, historic memorial, transfer to other government/non-government agencies or navy sale. (Navy League of the United States 2014)

LCU are not listed as part of the Naval Vessel Register and so there is more flexibility with respect to disposal options. Many traditional LCUs, and similar craft have been located for sale on the open, commercial market in recent years. This becomes a likely method of disposal for deactivated LCU USVs. Other disposal options such as test

targeting, and scrapping are also viable. Some of these issues are addressed further in the Business Case Analysis chapter.

Interestingly, since LCUs are available to foreign military partners, the LCU USV becomes adaptable and holds interest for a wide variety of partnered efforts and vessels o opportunity that are maintained by international Naval partners.

## **Y. SUMMARY**

This chapter demonstrated the application of OSA principles to systems engineering methodology as a management approach for converting a Landing Craft Utility (LCU) to an Unmanned Surface Vehicle (USV). The approaches hold broad generality for the adaptation of other manned Naval vessels into the fleet-compatible unmanned systems. It guided the reader through the SE process of converting an LCU to a USV while asking and answering applicable OSA questions. This process began by identifying stakeholders, and top-level system requirements. Next, this data was used to develop operational concepts, and system constraints. OSA principles were considered and implemented throughout these steps. Subsequently, this chapter considered how to manage system integration efforts by combining SE with OSA. After this, the design of the LCU USV was conceptualized from the data derived. After choosing a final design, testing, implementation, and lifecycle considerations were examined, again by combining OSA with SE. After conduction a thorough SE analysis using OSA, a foundation is set for a business case analysis in the next chapter.

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## **V. BUSINESS CASE ANALYSIS**

This chapter presents a business case analysis (BCA) regarding the LCU USV. In the specific case of system repurposing and reuse, it must be beneficial to the system owner to continue system operation instead of system disposal. In order to accept the feasibility of fielding the LCU USV, the U.S. Navy must decide that such conversion is worth the return on investment. There are several decisions that go into making this approach a reality. These include the decisions not to dispose of the LCU right now although the craft are well beyond the intended service life. First, a decision must be made to maintain the current hulls in an operational state. Second, a decision must be made to install alterations that convert the LCU hull into a USV. Finally, operating an LCU as a USV is likely to require the decision to add additional payload operations so that payloads can be operated remotely or autonomously.

### **A. CASE FOR KEEPING THE LCU BASE PLATFORMS**

In order for the U.S. Navy to consider keeping the LCU active for conversion to the LCU USV, a case must be made that there is value to be gained greater than the value that might be gained from another, more traditional method of vessel disposal. Traditionally, a craft of this type can be disposed of by selling it as scrap metal, putting it up for resale on the open market, or transferring it to another country.

#### **1. Scrap**

The LCU has a lightship displacement (i.e., weight), of 203 tons (200 LT). Thus, the LCU can garner approximately \$95,000 given the current price of steel of approximately \$470 per ton (London Metal Exchange 2014). More detailed calculation of the scrap value of the craft, and the cost of scrapping the craft is beyond the scope of this analysis, and needs to be reserved for separate analysis.

#### **2. Sell on Open Market**

Landing Craft Utility (LCU) are not listed on the Naval Vessel Register, so they are not limited to traditional Naval disposal limitations or processes. In fact, after

individual craft in the LCU fleet reach the end of their service life, and are deactivated from Naval operations, they are sometimes found listed for sale on the open, commercial market.

According to one website, in 2006 a landing craft utility was put on sale in the open market for \$350,000 (Philippine Defense Forum. 2014). More detailed calculation of the resale value of the craft, and the cost of resale of the craft is beyond the scope of this analysis, and needs to be reserved for separate analysis.

### **3. Foreign Transfer**

Many foreign navies have landing craft similar to that of the LCU 1610 Class. The U.S. Navy takes measures to support U.S. Foreign Policy by transferring eligible ships to the navies of allied and friendly nations. Figure 29 shows the high number of activities around the world with interests in boat and craft acquisition. With the increasing importance of littoral, costal, and shallow-water humanitarian operations, the option to transfer the LCU 1610 class to a foreign Navy needs to be considered by the Navy. While there is no financial gain to be realized with this option, there is significant, measurable political benefit to the United States by choosing this option. More detailed calculation of the cost to transfer the craft is beyond the scope of this analysis, and need to be reserved for separate analysis.





Figure 29. NAVSEA international craft/boat cases (from NAVSEA 2013).

#### 4. Other Disposal Options

There are several other options for disposal of the LCU. The Navy sometimes chooses to dispose of its assets by using them for targeting or test-firing platforms. Additionally, the Navy can choose to sink a ship for use as an artificial reef. Yet another option is to donate the ship to an organization within the United States for use as a historical museum or other display function. While all of these options are somewhat viable for disposal of the LCU, their value to the Navy does not deem them competitive to the option of converting an LCU into a USV.

Scrapping, open market sale, and transfer are all viable options for the LCU. However, a case may be made that the use of the principles of unmanned systems, open architecture and flexibility presented in previous chapters show that more useful life can be garnered from the LCU once converted to a USV.

Converting the LCU to a USV and subsequently getting several more years of service life out of the craft does not reduce the viability of the traditional disposal options. Once the service life of the LCU USV is complete, it can still undergo one of the traditional disposal methods bringing yet another opportunity for additional value to the Navy.

Disposal is estimated to cost approximately \$1.4M per hull (Windhalm 2011). Disposal costs were based upon structural material and the labor cost for salvage (Windhalm 2011). Therefore, it may cost the Navy more money than they get in return to dispose of the craft.

## **B. OPTIONS FOR EXTENDING THE LIFE OF THE EXISTING LCU HULL**

The fleet of LCU is 40+ years old on average. Any system of that age has its own unique maintenance and modernization issues that must be addressed to keep the system relevant and viable. Before the hull can be considered for conversion to a USV, the issues of craft maintenance needs to be addressed to extend the useful life of the hull. The LCU program has been undergoing maintenance and modernization for much of its service life. Upkeep of the craft has traditionally been accomplished via routine overhauls, maintenance availabilities, and modernization upgrades. At several times throughout the service life of the LCU, the idea of a Service Life Extension Program (SLEP) has been considered, but never executed. Routine maintenance and SLEP are the two options that need to be considered most suitable for keeping the hull form (i.e., the shell/base of the LCU USV system) fully operational. The option to add the USV capability to the craft without conducting maintenance is not ideal, but is worth examination as an additional option. Additionally, it needs to be noted that the LCU craft can be mothballed or laid up until the Navy chooses an option for extending the life of the hull.

### **1. Routine Maintenance**

The vessels in the LCU fleet are more than 40 years old, and they are highly maintenance intensive. All craft in the fleet have experienced some level of neglect in maintenance, delay or cancellation of much needed repairs. With no formal maintenance program for a large part of its service life, the craft also underwent years of ad hoc maintenance as performed by sailors according to priorities set by individual Assault Craft Unit (ACU) Commanding Officers. The extent of these maintenance efforts is often limited to that which can be afforded by the allocated DOD budget. The maintenance is often limited to addressing the critical safety, hull, mechanical, and electrical repairs

needed to keep the craft operational until the next maintenance period. Craft generally undergo maintenance periods approximately every four years. An LCU maintenance availability for a single craft costs the Navy anywhere from \$200K to \$1M, depending on the needed scope of work, and the available funding. That represents a cost range of \$50K to \$250K per year, per craft, or an overall average of \$150K per year, per craft.

## **2. LCU Service Life Extension Program (SLEP)**

The longer the LCU USV craft stays operationally viable in the fleet, notionally, the more value that can be reaped from the asset. Keeping the craft viable for more than a few years may require a greater effort and investment than the traditional, routine maintenance program. To determine the specifics of the modification needed to keep the craft operational for five or more years, a number of in-depth design and engineering studies must be performed. Modifications proposed by these studies can then be applied to the craft as part of a Service Life Extension Program (SLEP). The addition of unmanned systems capabilities can be completed in conjunction with the SLEP or subsequent to the SLEP.

The maintenance-intensive systems on the craft include the anchor windlass system, steering Hydraulic Power Units (HPUs), corroded bow ramp, bow ramp winch assembly, main engines and generators, corroded skegs and inaccessible voids, poor ventilation in manned spaces, high-heat conditions in magazines and accessible voids, shafts, propellers, and fire protection systems (Program Executive Office Ships (PEO Ships) 2012). It is likely that a SLEP program might best address most of these systems by replacing or repairing them with the least expensive, technically acceptable, commercial off-the-shelf (COTS) system.

In 2002, the costs for a SLEP program were determined to be \$3.2 million in non-recurring engineering design and planning costs, and \$5.4 million per craft in labor and materials. Assuming that the craft can get ten (10) years of additional life, this equates to a cost of approximately \$550K per year, per craft for the 32 craft in the fleet. These costs estimates change from year to year due to the changing material condition of the craft, and also the ongoing maintenance and modernization programs for the current LCU fleet

(CNA 2002). A more thorough, current estimate of a SLEP program is beyond the scope of this thesis, and needs to be performed as part of a separate study.

### **3. Newly Constructed LCU Hullform**

The LCU is recognized as an essential workhorse for the amphibious fleet. As such, efforts to replace the craft over the years have received significant, broad support. The current LCU replacement program, called Surface Connector (X) Recapitalization (SC(X)R), has received tremendous support, and is slated for initial procurement funding in FY2017 for a craft with the same capabilities as the current LCU (Program Executive Office Ships (PEO Ships) 2012). Although the cost, and exact design of this system have not yet been determined, it may be feasible to consider utilizing the new-build design for LCU as the platform for the LCU USV.

Leveraging the SC(X)R program for the LCU USV can still accomplish the notion of strategic reuse or repurposing. In many ways, leveraging the acquisition program for SC(X)R has the potential to save on acquisition costs for the LCU USV. These savings might be realized from leveraging many of the same craft design requirements, acquisition documentation, logistics plans, and non-recurring engineering plans.

The benefit to this approach are expected to be that the LCU USV might be built on the framework of a new, modernized design that can result in increased craft lifespan and lower maintenance requirements. Additionally, if the LCU USV is fielded in conjunction or in close proximity to the SC(X)R, the Navy's knowledge of how to efficiently build such a system can be optimized from a variety of lessons-learned and reduced learning curves.

As seen in the "Related Work" chapter, many commercial companies and industry partners are using small, commercialized designs to derive new concepts for a large-payload USV. This does not have to be the case. The current LCU is a military craft with many commercial-like design qualities. If industry were to utilize the exiting LCU or SC(X)R as a starting point for the detailed design of a USV, then that approach can

allow this concept to come to fruition much more efficiently. Significant cost savings are possible when price/performance is compared to commercial replacements.

#### 4. LCU with No Additional Maintenance (i.e., Do Nothing)

The LCU vessels have been going for 40+ years with only routine maintenance. As with any system, the LCU requires this maintenance to continue operations. Without routine maintenance, it is difficult to predict how long each vessel can continue safe operation. If the Navy decides to no longer fund LCU maintenance and other life-cycle necessities (e.g., logistics and in-service engineering support), the craft is no longer able to continue safe operation. Notionally, a third party might take ownership of the LCU for continued operation in some form. Additionally, a research agency may realize value in taking ownership of an LCU and converting it to a USV to conduct research on large-scale USVs. However, it is likely not viable to add the USV capability to the LCU unless there is at least minimal support for a continued maintenance of the fleet.

### C. CONVERSION COSTS

There are several conversion costs for the LCU USV. These costs include non-recurring engineering (NRE) expenditures as well as material and labor costs. Table 26 shows a rough-order-of-magnitude estimate for the conversion cost going from the existing LCU to the LCU USV.

<b>System</b>	<b>NRE</b>	<b>Per Craft Costs, Material/Labor</b>
<b>General Craft-Level Craft Controls</b>	\$500K-\$1,050K	\$200K
<b>General System-Level Controls</b>	\$500K	\$4-600K
<b>Power Systems</b>	\$150	\$300K
<b>Navigation</b>	\$200K	\$250K
<b>Engines and Generators</b>	\$500K	\$500K-\$2M
<b>TOTALS:</b>	<b>\$1.85M-\$2.4M</b>	<b>\$1.25M-\$3.45M</b>

Table 26. LCU USV conversion costs.

Appendix D provides a detailed explanation of these costs.

#### **D. TOTAL OWNERSHIP COSTS (TOC) OF LCU USV OPERATION**

Beyond the costs to convert the LCU into a USV, the total costs of ownership of the LCU USV throughout its entire lifecycle must also be considered. These costs include several factors such as operations, support, logistics, infrastructure, and training costs.

##### **1. Life-Cycle Costs of the LCU**

For the discussion of life cycle costs, this analysis focuses mainly on the operation and sustainment (O&S) phase of the life cycle of the LCU. The O&S costs are separated into three categories: crew sustainment costs, maintenance costs, and the cost of consumables and technical support. O&S costs do not factor in the procurement and disposal phases of the life cycle. It costs the Navy \$1.2 (in FY02 dollars) to operate and support the LCU (CNA 2002). This study utilizes this number as a basis for estimating the operations and support cost of the LCU USV. It costs \$946K to sustain an LCU crew for one year, \$276K to perform maintenance on one LCU in a year, and \$50K to supply one craft with consumables such as fuel and spare parts. Table 27 shows the annual O&S costs per LCU 1610 vessel.

Cost category	Cost
Crew	946
Maintenance	276
Consumables and technical support	50
Total	<u>\$1,272</u>

Table 27. O&S Costs of an LCU 1610 class vessel in FY02 \$K  
(from CNA 2002).

It is starkly apparent that crew costs compose nearly 75% of the O&S costs (CNA 2002). Undoubtedly, the manning costs are an area of focus for costs reductions when

converting an LCU to a USV. This is also an important consideration when comparing alterations such as manned commercial craft.

## **2. Logistics Impact**

Fifty-thousand dollars (4%) of the O&S cost is for consumables and technical support. Logistics are an important part of any Naval program, and they must be planned at the beginning of a program. Since the LCU were originally designed as a self-sustaining craft, there is space on the craft to store spares and consumables. Alternatively, the consumables and spares can be stored on a host mother ship (see Figure 30).



Figure 30. A landing craft repair ship, USS *Askari* circa 1967 (from NHHC 2014).

Logistics has been a major consideration since before the inception of the LCU 1610 class program. Many of the existing LCU logistics considerations can be duplicated for the LCU USV since the craft have the same physical footprint. Operational differences account for variation in the type and quantity of spare parts. The particular logistics requirements depends upon the exact LCU USV subsystems, configuration, mission requirements, availability of resupply stations, and the proximity of LCU USV

operation to logistics basing. LCU USVs can be hosted on a mother ship or pierside at a shore establishment, both of which offer varying degrees of available logistics support. Beaching ashore is another option. In the Vietnam area, when a requirement arose to implement a surge in riverine boat forces, the Navy chose to reactivate many retired amphibious ships as hosts for riverine forces. These ships provided mobile berthing, supply, maintenance, repair and gunfire support to the riverine boat forces (CNA 2006). Likewise, large-deck amphibious Navy ships might support the LCU USV as flexible, moveable platforms.

### **3. Infrastructure/Docking Facility Impact**

The Current fleet of 32 LCU are home-ported at Assault Craft Unit (ACU) 1 in San Diego, CA; ACU 2 in Norfolk, VA; and a small number are Forward Deployed Naval Forces (FDFNF) with detachment West Pacific (WESTPAC) to in Sasebo, Japan. If the current LCU were allowed to remain at these shore establishments after being converted to LCU USV, then potential changes to the shore infrastructure need to be considered. The shore infrastructure must be refurbished for extended service life, and altered to accommodate USV berthing, operation, and logistical support. However, the Navy currently has plans to replace the current fleet of LCU with no plan of building a new shore infrastructure to accommodate and support the new fleet. Therefore, the repurposed, old fleet assets (i.e., the LCU USV) likely need to be berthed elsewhere. A cost effectiveness study for shore infrastructure options ought to be performed as part of a future study.

### **4. Impact to Force Structure**

Assuming that the planned LCU replacement craft (i.e., the Surface Connector (X)) requires the berthing at all of the existing ACU shore establishments, it follows that they require the same, current space footprint in the well-decks of the amphibious fleet. Therefore, the LCU USV poses a significant stress to the existing well-deck space and infrastructure if they attempt to operate on the same footprint.



Notionally, the LCU USV has unique and different mission sets, and therefore can operate from a varied array of bases. Host ships operating with LCU USV must have the ability to ballast for wet well operations. This may require that the platform secure flight operations and other topside or weatherdeck evolutions while conducting wet well operations. It is likely to be a slower, heavy-lift logistics or amphibious ship. Generally, launching and recovering an existing LCU from a ship requires two hours; 30 minutes to ballast down and receive the LCU, up to 60 minutes to load the LCU, and another 30 minutes to debark the LCU and deballast (Schmitz 1996). The ships that can carry and host and LCU USV are strategic lift assets such as the Lighter Aboard Ship (LASH), Sea Barge Carrier (SEABEE), float-on/float-off (FLO/FLO, and lift-on/lift-off (LO/ LO) vessels may be required (CNA 2002). Figure 31 shows an example of a float-on float-off ship hosting traditional landing craft.



Figure 31. Motor Vessel (MV) American Cormorant float-on float-off ship hosting various landing craft. (after NavSource 2009, Global Security 2011).

## **5. Training and In-Service Engineering**

Continued support and sustainment of both the crew and craft capabilities are essential. To keep the operators of the LCU USV current to the state-of-the-practice, they must undergo continuous training. To keep the craft operational, they must receive continuous engineering support. An in-service agent acting as the authority on technical and training issues of the fleet of LCU USVs can conduct both of these functions.

With the majority of existing LCU craft located in Norfolk/Little Creek, VA and San Diego, CA, the Navy has also built up the necessary training to support craft operations in those locations. Much of the training for crews of existing LCUs takes place at existing amphibious facilities at or near the ACUs.

With a large quantity of LCU USVs being developed and fielded in the near future, attention must be given to effective system sustainment. An organic support infrastructure for configuration control, supply support, maintenance, storage, and transportation is essential to bring efficiencies and cost effectiveness to these critically important systems. An in-service engineering activity (ISEA) and planning yard (PY) needs to be established for the LCU USV. The Naval Surface Warfare Center, Carderock Division at Joint Expeditionary Base in Little Creek (Norfolk), VA is the current ISEA and planning yard for the current LCU. They are also the in-service engineering expertise for unmanned surface vehicles. Having an established ISEA/PY for LCUs in close proximity to the subject matter experts for USVs naturally suggests that the same, existing groups can perform the same functions for the LCU USV. The exact costs to add additional billets, and manhours to the existing groups need to be determined through additional study. However, it may be assumed that this cost might be significantly less than building these capabilities without the foundation of an existing program.

#### **E. OSA CONSIDERATIONS FOR TOTAL OWNERSHIP COSTS AND LIFECYCLE MANAGEMENT OF OPEN SYSTEMS**

There are several OSA considerations to account for when considering the lifecycle of a system such as the LCU USV. The system architecture shall provide for the use of existing commercial supporting infrastructure and COTS technologies for system components. The system must be designed such that COTS and Non-developmental items (NDI) are logistically supported through the systems lifecycle. In implementing OSA for reduced lifecycle costs and total ownership costs, the program shall ensure the availability of commercial repair parts, repair services, facilities, and manpower, and verify that they are maintained and warrantied at sufficient levels for long-term support.

Reuse of preexisting program elements is also important to implementing OSA in a program such as the LCU USV. The systems engineer and program manager shall ensure that the program reuses preexisting designs, materials, items, facilities, supporting assets or components. The general objective of these efforts shall be to reap the greatest technical and cost benefits via the development of common system elements across various DOD or Service platforms and mission requirements (U.S. DOD OSA Data Rights Team 2013). See Chapter III, Table 5 through Table 8, for a list of considerations that aid in applying these OSA principles.

## **F. LCU USV COSTS SAVINGS**

There many potential areas for costs savings when taking an open systems architecture approach to converting an LCU to a USV. Two of the most significant major areas for costs savings in the craft conversion are manning costs, and fuel costs. This analysis shows that manning costs savings are significant, and a direct result of the craft conversion. This analysis shows that the cost savings for fuel is derived from the inherent fuel economy of the existing LCU platform when compared to similar existing high-speed landing craft, and the high speed requirements of existing USVs.

### **1. Manning Costs Savings**

Manning is the predominant cost driver for DOD and Naval missions and systems. This is typically no different for unmanned systems. A significant amount of manpower is spent on directing mission planning, replanning, data collection, data analysis, mission projection, and creating actionable intelligence from the raw data (DOD 2013). Because unmanned systems must match, and sometimes overmatch, the cognitive ability of their manned counterparts, the costs for the additional sensor and computing technology, and high levels of operator manning can be extensive and prohibitive. Therefore, of utmost importance for DOD is reduced manning in unmanned mission performance, and increased system and sensor automation.

One of the largest challenges in making the business case for developing unmanned systems is that unmanned equivalents for current DOD systems often require equal levels of manning as the existing manned counterparts. “Nearly all unmanned systems require active control of basic vehicle operations and behavior that affects communications, manpower, and system effectiveness” (DOD 2013). For example, a small RHIB for sensor deployment may require three personnel onboard to operate; a helmsman, a payload operator, and a mission commander. The remote operation of an equivalent USV requires at least the same number of personnel to be stationed inside of a remote command and control center. Thus, in this particular case, there are no savings on manning costs, and possibly increased manning costs due to the need to account for the increased monitoring of sensors for unmanned operation.

A typical existing LCU crew consists of 11 personnel. The craft crew can surge to 13 for wartime missions, and the craft has accommodations for 14 crewmembers. These numbers can vary depending on the mission requirements with the smallest crew being 8 personnel (CNA 2002). Table 28 details current LCU crew billets.

Crew costs compose approximately 75% of the operations and support costs for the existing LCU (CNA 2002). “As with other facets of unmanned systems, the need for greater autonomy is subject to fiscal pressures, (i.e., operating within budget constraints while reducing manpower needs and U.S. exposure to dangerous risks and increasing operational effectiveness” (DOD 2013). Thus, the business case for the LCU USV examines the feasibility of eliminating a portion of those billets.

Title/rate	Current LCU
Craft master/E-7	1
Chief engineer/E-6	1
Quartermaster/E-6	1
Mess specialist/E-5	1
Electrician's mate/E-5	1
Second engineer/E-5	1
Signalman/E-5	1
Boatswain's mate/E-4	1
Engineman fireman/E-3	1
Fireman/E-3	1
Seaman/E-3	1
Peacetime total	11
Gunner's mate/E-5	1
Information technician/E-4	1
Wartime total	13

Table 28. Historical LCU 1610 crew billets (from CNA 2002).

The average cost for a crewmember was \$86K in FY2002 dollars (see Table 29). In current year dollars (i.e., FY2014), the cost per crewmember can be conservatively estimated to be \$125K per billet. Thus, for each crewmember eliminated from operational requirement from the conversion of the LCU to the LCU USV, the Navy might save \$125K.

Pay grade	Title	Number	Annual cost
E7	Craft master	1	104.1
E6	Chief engineer	1	95.7
E6	Quartermaster	1	95.7
E5	Mess specialist	1	87.4
E5	Electrician's mate	1	87.4
E5	Second engineer	1	87.4
E5	Signalman	1	87.4
E4	Boatswain's mate	1	79.1
E3	Engineman fireman	1	73.8
E3	Fireman	1	73.8
E3	Seaman	1	73.8
Total		11	\$945.6

Table 29. LCU Crew billets and costs (FY02 \$K) (from CNA 2002)

There are six main stations for the core LCU crew: conning (i.e., steering), engineering, deck operations, damage control, weapons, and a miscellaneous station (CNA 2002). There may be multiple billets assigned to each station depending on the needs of the mission. Notionally, for an LCU USV, one person is assigned to the monitoring and control of each one of these stations. Assuming that the LCU USV performs many of the same or similar missions as the existing LCU, this results in a reduction of five (5) billets, going from eleven (11) billets for the current manned craft to six (6) billets for the LCU USV. This equates to \$625K in savings per craft per year in FY 2014 dollars. This is \$20,000,000 saved per year in manning across the entire fleet of 32 LCU USVs.

## 2. FUEL COST SAVINGS

By design, the LCU has inherent fuel efficiency. The traditional LCU has fuel capacity to travel at a sustained speed of 8 knots over a range 1200 nautical miles, without refueling. This is more fuel capacity, by volume, than existing USVs. Not only does this allow for sustained operations with durations comparable to smaller USVs, it

allows for the LCU USV to be able to complete missions using less fuel than comparable manned Naval assets.

The LCU is more fuel efficient, in terms of total fuel cost versus throughput capacity, as compared to the higher, speed craft with similar CONOPS such as the Landing Craft Air Cushion (LCAC)/Ship to Shore Connector (SSC) (Chief of Naval Operations Assessments Directorate (OPNAV N81) 2011). LCU's fuel usage is dramatically less than that of LCAC/SSC (see Figure 32). At lower distance The LCU uses approximately one-third of the fuel required by air-cushioned landing craft, and is even more efficient at higher speeds.

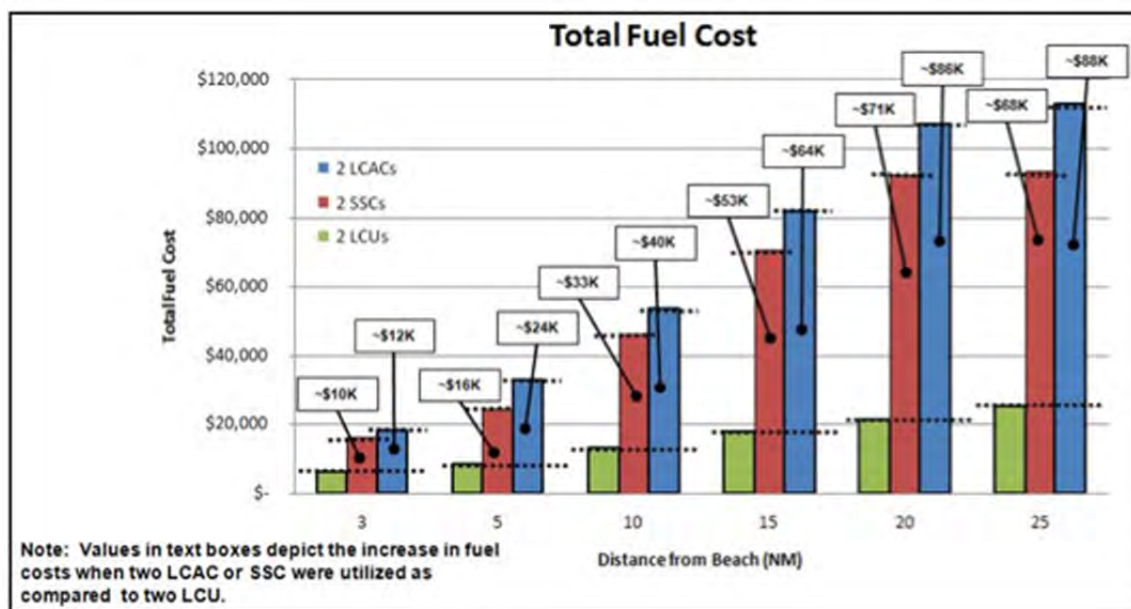


Figure 32. Fuel cost comparison for operation of a single LCU and air-cushioned landing craft (from OPNAV N81 2011).

Though not meant as an indicator to replace the LCAC or SSC with LCU, this does provide further emphasis to the notion that for operations at the lower end of the ROMO, when cycle time is not a factor, the LCU is the craft of choice (Chief of Naval Operations Assessments Directorate (OPNAV N81) 2011). Furthermore, none of the potential missions for the LCU USV require high-speed maneuvers. Where speed is a requirement, a traditional high-speed USV suits the needed capability. For the LCU USV,

it is not cost effective to increase speed. Figure 33 shows that added speed above approximately 11 knots requires drastic increases in horsepower. Increased horsepower in turn mandates increased engine size, higher operational fuel costs, and lowered cargo capacity.

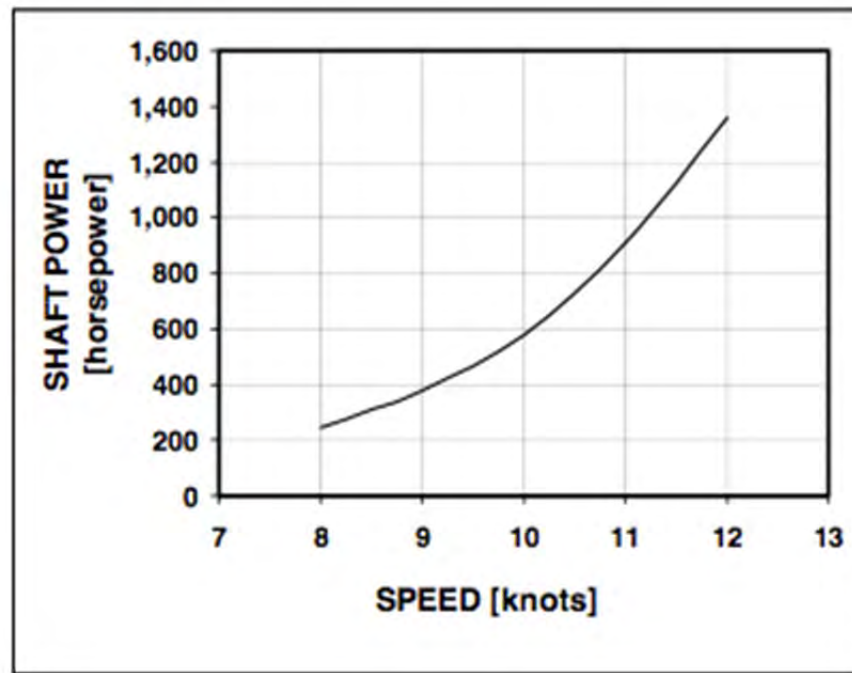


Figure 33. LCU Speed-power curve (at full-load displacement) (from CNA 2002).

One might expect from this data that other USVs of similar size and capability might also become cost-prohibitive at higher speeds.

#### **G. DOD OVERALL BUDGET SUPPORT**

An independent study estimated the global landing craft market at \$10.8 billion by the year 2019. The implications of this are tremendous for the country/organization that achieves and maintains the competitive advantage for such a heavy-lift, open architecture, unmanned landing craft technology (PRWEB 2014). Furthermore, “As unmanned systems have proven their worth on the battlefield, DOD has allocated an increasing percentage of its budget to developing and acquiring [unmanned] systems. With the transition from a handful of innovative experimental systems to normalized



program developments, unmanned systems have received their share of inclusion in Congressional direction and are influenced by many acquisition initiatives and departmental policies” (DOD 2013). While it is difficult to determine the exact return on investment (ROI) of an LCU USV system without further study and analysis, the potential to achieve gains from partnerships with other countries/navies, commercial industry, and academia are unprecedented.

## **H. OTHER BUSINESS CONSIDERATIONS**

This section presents several additional key business considerations that must be considered when converting an LCU to a USV.

### **1. Expanded Opportunities to Leverage this Concept**

The LCU USV reuse concept may be leveraged by multiple industries. These include the commercial maritime transport industry, law enforcement agencies, marine surveyors, weather surveyors, foreign cooperatives, oil platform patrols, and commercial scientific missions. If the Navy chooses not to convert all 32 LCU to USVs, the vessels can still be converted to low-level (i.e., remote-controlled) USVs and sold to other countries through foreign military sales. “Partnering with overseas military defense industries is also essential in the future, looking for those who build most effectively and efficiently” (Greenert 2014). Global Security operations in other countries for Security Force Assistance and Special Operating Force missions can all benefit from the utility of an LCU USV as a base for communications relays, training evolutions, explosive ordnance disposal support, and logistics support.

### **2. Scalability**

There is a wide and varying array of landing craft. Appendix A shows a selection of these. The basic installation of systems for LCU USV operation can be installed on other types of landing craft with minor adjustments to the hardware and software. Furthermore, the size, mission configuration, and cost of the LCU USV are all scalable. The conversion system can range from simple to complex. In a new-construction setting,

the LCU USV design might be used to construct a smaller, simpler version of the craft, or a larger more complex system.

### **3. Modular Production: Kitting**

Kitting is a method used by alteration installation teams for installation of modernizations and alterations on the existing LCU vessels. Just like payloads can be kitted in a modular fashion, installation of new systems can be planned as such. This concept ensures that requirements for parts, processes, and time, and supporting documentation for system installation are consistent across all installations. This method was recently used, for example, for the installation of a new steering and navigation system on the existing LCU craft in FDNF Sasebo, Japan. Likewise, the LCU USV systems can be kitted for installation on the wide and varying array of civilian and military platforms worldwide.

### **4. Leadership Support and Key Strategic Enablers**

As of 2014, modernizing and replacing the existing LCU craft is a top priority of Naval and Marine amphibious forces. Extending that same notion, the LCU USV concept can expect to have considerable support from DOD leadership. The program deserves justifiable leadership support for each of the key enablers for flexible program structures (see Table 30).

<ul style="list-style-type: none"><li>• Ensure strong central leadership, form a powerful coalition, and communicate the vision.</li><li>• Provide war-fighting requirements that will drive flexible, common, and open architecture into our ship designs and acquisitions.</li><li>• Establish a business model that supports flexible warships.</li><li>• Define, standardize, and manage modular interfaces and technical architectures.</li><li>• Invest in technology advancements that support flexibility.</li><li>• Conduct design and production risk reduction prototyping, at-sea tests, and demos.</li></ul>
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Table 30. Key strategic enablers for flexible ship programs (from Program Executive Office Ships [PEO Ships] 2014).

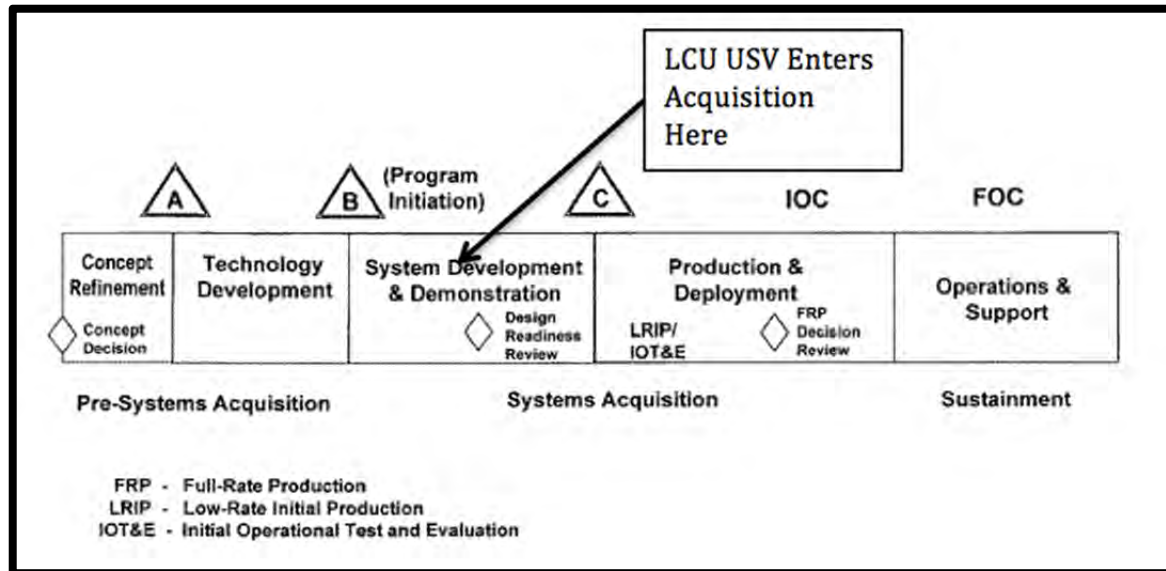
## **5. Flexible Payload Acquisition Strategies (PEO Ships Flex Ships Roadmap)**

If the Navy decides to continue to use the existing 32 (or fewer) LCUs for LCU USV unmanned missions (or other missions), then the Navy must decide on the best strategy to maintain or modernize them for use in the new, varying missions areas. Each LCU USV can be configured for a particular, fixed mission. However, an analysis of alternatives for the LCU USV may reveal that it is better to construct a flexible, modular payload structure for varying missions. In either case, it requires a careful examination of the cost effectiveness for varying missions for the Navy.

The LCU USV program might take advantage of several strategies for payload acquisition. These include “Just-in-time Payload Installation, After-Delivery Payload Installation, Modular Design and Construction, and Family of Ships/Shared Payloads” (Program Executive Office Ships (PEO Ships) 2014). The LCU USV is most likely to take advantage of a family of varying payloads that can be shared by the fleet of LCU USV. The Navy must be careful, however, to not add so much flexibility that the program expenses reach cost prohibitive levels.

## **6. Flexible Craft Acquisition Strategies and Contracting Strategies**

Because the LCU USV is built on the foundation of an existing platform, the program does not have to undergo the full-scale procurement steps required by the DOD 5000.01 Integrated Defense, Acquisition, Technology, and Logistics Life cycle Management System. It is likely that the LCU USV requires a significant level of concept refinement and technology development. However, because the system reuses an existing hull, and adds proven technologies to it, it may be able to skip some of early requirements typical of a new program. If, for instance, a simple remote control autonomy was added to the craft, the LCU USV program may primarily forgo the Pre-Systems Acquisition phases and start in the early stages of System Acquisition (see Figure 34). Thus further savings are realized in comparison to a new-start program.



For simple addition of systems and sensors for basic automation and remote operation, the work might be considered a boat alteration. This boat alteration can be a collection of systems installed, via Alteration Installation Team, on the boats pier side. Although simple, there are several options for the Government to compete this work. A build-to-print approach can be taken in which the contractors compete for a construction contract to produce an exact government design. Alternatively, the government can competitively offer to share the design responsibilities with the contractor, still allowing them the full construction task. The last possibility is for the government to fully compete all design and construction efforts.

The LCU USV program can also exercise flexibility in the contracting approach. The program might choose to execute under the traditional FAR15 negotiated contract approach for non-commercial Items. However, because the LCU USV may have similarities to commercial assets in the near future, and the system can contain extensive use of COTS subsystems, the program can also execute under the FAR 12 commercial item procurement approach.

Different contracting and acquisition strategies yield different results with respect to program timelines for establishing full operational capability. Assuming that it takes

five years after the existing LCU replacement program receives construction funding, the first LCU USV vessel might finish construction in fiscal year 2022. See Table 31 for a notional LCU USV construction profile.

<b>Fiscal Year</b>	<b>FY 22</b>	<b>FY 23</b>	<b>FY 24</b>	<b>FY 25</b>	<b>FY 26</b>	<b>FY 27</b>
<b>LCU USV Construction Quantity</b>	1	3	7	7	7	7

Table 31. LCU USV notional construction fielding profile by fiscal year.

## 7. Incentives: Getting Industry On-Board with this Concept

When engaging industry, flexibility must be created and maintained from the program conception. It is imperative that the OSA management strategy used in the LCU USV program includes provisions for incentives and/or award fees for the contracted industry stakeholders. Contractors must be incentivized to adopt the “reuse” approach to system acquisition versus the traditional “start over” approach. When the Government contracts work with industry, the program must be structured such that contractors are incentivized to deliver the best quality product or service to the Government at the best possible cost.

For the LCU USV program this can be accomplished in a number of ways. Initially, the wide field of competitors in the marketplace is likely to incentivize contractors to develop a cost effective solution. Whether contracting an industry partner to install alterations via AIT, or contracting a shipyard to conduct full-scale LCU USV conversion program, incentives need to be built into the contract structure to produce continued savings. The contract ought to include cost plus incentive fee or fixed price incentive fee structures depending on the level of risk sharing between the contractor and the Government. These incentives can lead to improved supportability, improved interoperability, increased use of open systems, and optimization of unmanned system components.

Beyond contract structure, another huge incentive for industry is the ability to continue to profit from work originally performed under government contract. In order to incentivize industry, the government must create contractual provisions for contractors to use their intellectual property and data to profit in other markets. This must be accomplished without limiting the government's ability to access the same data for future program development.

## **8. Legal Considerations**

The legal considerations for the operation of unmanned systems are still in their infancy and are changing with time. Preparing for current and projected capabilities is a matter of updating the literature to reflect current operational concepts, threat projects, and technology improvements (CNA 2006). Doctrine, instructions and guidance for the operation of unmanned systems must be well maintained to the current legal environment. Maintaining this doctrine requires a continuous feedback loop from unmanned systems managers, developers, testers, and users.

## **I. OVERARCHING OSA BUSINESS PRACTICES**

Implementing OSA in the business practices of the systems engineering process means ensuring that there are multiple sources capable of meeting the requirements at any given point in time. In the case of a system such as the LCU USV, the modularity of the system design must promote the deification of multiple sources of design, supply, repair, and support. Furthermore, all of these sources must support flexible business strategies that enhance, not hinder, competition. If appropriately implemented, OSA considerations sufficiently address a wide range of factors from system power and cooling design, to legal rights for intellectual property to quality assurance, to market acceptability, to total program cost. See Chapter III, Table 5 through Table 8, for a list of considerations that aid in applying these OSA principles.

## **J. SAVINGS THROUGH SELECTION OF BUSINESS AND SYSTEMS ENGINEERING PROCESS MODELS**

Systems engineering is essential to realizing a product that meets the needs of the stakeholders. However, simply performing good systems engineering alone does not guarantee production of the desired product. The management approach to how you procure the system matters tremendously too. This is particularly important with the strategic reuse of an existing asset such as in the LCU USV program.

DOD systems in general, and unmanned systems in particular are hardware, software, middleware, and data intensive. When working with industry, DOD must be sure to protect the software, data rights, and intellectual property developed with program funding. Standards such as ASTM F2541-06, “Functional Allocation of Major UUV Autonomy and Control Components” must be used to protect the data rights of the Government in working with industry to create an unmanned system. This standard details the functional allocation of major unmanned system (specifically UUV) autonomy and control components.

The current state-of-the practice for unmanned systems in DOD details several areas for improvement with the current systems and engineering process models (see Table 32).

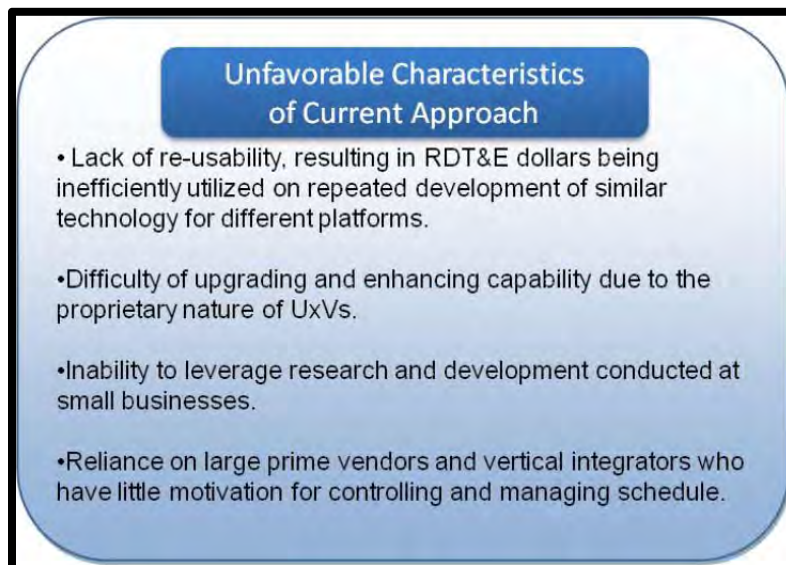


Table 32. Unfavorable characteristics of the current business and SE approach to DOD unmanned systems (from DOD 2011).



By applying the OSA principles from Chapter III (see Tables 5–8) with an existing SE model, this study shows that the LCU USV program sufficiently addresses the unfavorable characteristics of the current approach to USV acquisition (see Figure 35).

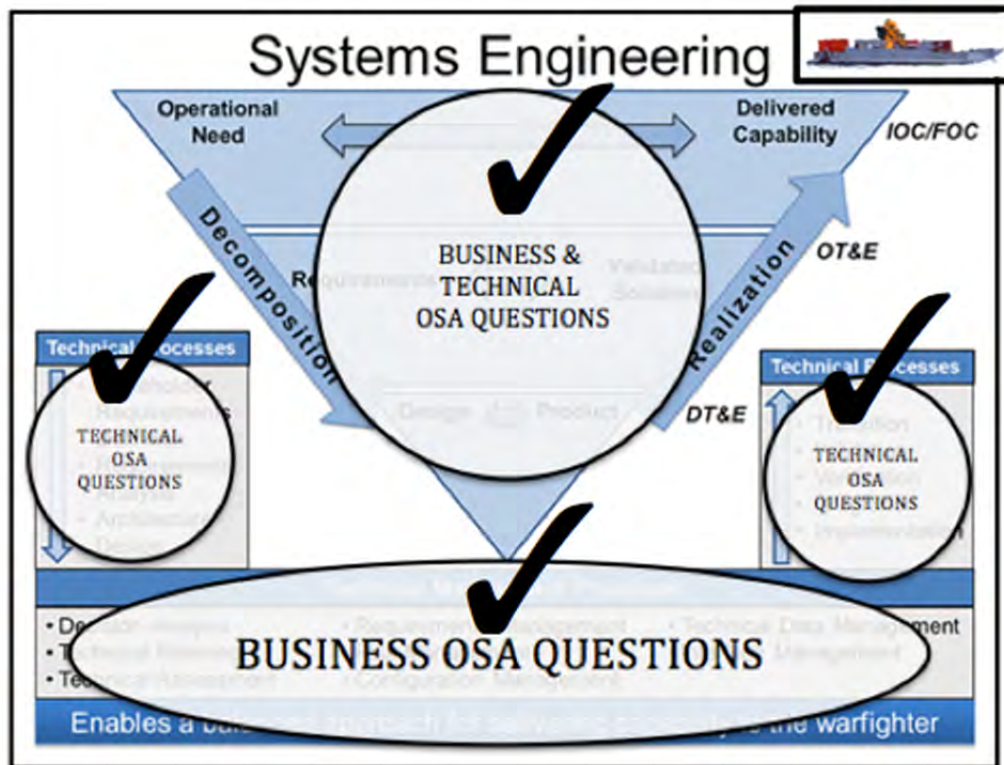


Figure 35. OSA-based systems engineering management model for LCU USV development (after DoD 2014).

## K. SUMMARY

The section presented a business case analysis (BCA) regarding the conversion of the LCU to the LCU USV. Central to the discussion of the business case were the considerations to keep the LCU craft, then extend the life of craft. After these decisions were proved feasible and viable, the chapter then presented several areas for TOC and lifecycle cost savings when using OSA to convert the LCU to a USV. The chapter then presents and resolves several other business considerations including system and program scalability, industry incentives, leadership support, and legal issues. Finally, the chapter presents potential savings through the use of OSA business practices and process models.



## **VI. CONCLUSIONS AND RECOMMENDATIONS**

To help explain the value of reuse and repurposing, this thesis details a case study utilizing a Landing Craft Utility (LCU). The Landing Craft Utility (LCU), 1610 class, was built in the 1970s as an update of the landing craft made famous during the island-hopping amphibious campaign of World War II. The LCU is 135 feet long and can carry 180 tons of equipment or 400 combat equipped Marines at 12 Knots. These vessels are normally transported into theater in the well decks of L-Class amphibious ships; however, organic messing and berthing facilities for its crew of 13 (including 2 Officers) enable self-sustained at sea operations in excess of seven days.

The LCU affords heavy-lift, endurance and independent operations when speed is not the driving requirement. The LCU remains a valuable and complementary platform in the context of expeditionary operations and surface logistics support of forces ashore. The current U.S Navy Landing Craft Utility (LCU) 1610 Class is planned for replacement between 2017–2023. Upon deactivation, conceivably, these assets can be repurposed as controllable USVs and used for many more years.

This thesis demonstrated how the concepts of open systems architecture (OSA) must be applied within the context of an existing, traditional systems engineering methodology to result in the production of a flexible system that supports the Defense enterprise in maintaining the competitive advantage.

This was accomplished by leveraging an existing systems engineering process model in conjunction with the use of the OSA management and business practices. Particularly, the OSA practices were illustrated by deriving several questions that must be appropriately answered in the effective implementation of the SE process.

To prove utility of this systems engineering management approach, this thesis demonstrated an atypical asset-repurposing program. The Landing Craft Utility (LCU) was not intentionally, originally designed as a highly reusable truck with an inherent ability to be repurposed for future, yet-to-be-determined missions. However, this thesis

has proven, via converting an LCU to a USV, that there is value in design for reusability and repurposing of exiting assets.

This thesis showed that OSA technical architecture is best implemented by defining high-level flexibility requirements. This not only leaves more trade space for the designers and engineers, but it also helps keep system costs low by loosely defining the interfaces. It also allows the system to be upgraded at a later time. Extending this notion, this thesis shows that proper up front architecting can balance non-recurring acquisition costs with future recurring life cycle and modernization costs.

A reference model and open standards are used to show the value of interface flexibility. This study also showed that, when working with open systems, the systems engineering team can avoid major system changes, even if the system is already rigidly/maturely designed, by developing an open technical architecture within existing design constraints. By defining key interfaces, modules, stations, and zones, the impact of alterations might be less costly. This type of design methodology is especially effective for highly technical systems such as the LCU USV where technology advances may occur rapidly.

Often, in traditional DOD acquisition programs, acquisition authorities choose the lowest cost, most technically acceptable choice from amongst feasible, new design alternatives. Strategic reuse or repurposing of assets represents a break from the traditional sense of new-product acquisition, new-construction, or product upgrade/modernization decisions. The idea of design for reusability is something that has been applied within software and computer science applications for some time, but it has not been a primary consideration in DOD systems engineering practices. In the case of the LCU USV, this analysis made the decision to continue the use of a Naval asset via repurposing it instead of traditionally disposing of the asset.

## **A. RECOMMENDATIONS**

Future work may include an assessment of whether a deeper business case analysis is needed. It is now time for the second, more detailed iteration of the LCU USV SE and OSA process. The second iteration may be very short, and may simply be a

leadership decision to proceed to detailed design or analysis of a certain needed capability. It may include the decision to perform an in-depth Capabilities Based Assessment, Mission Needs Analysis, sensitivity analysis, measure of effectiveness analysis, or Cost Benefit Analysis to assess the most suitable mission areas, or vessel designs. This pilot study is sufficient to initiate an in-depth business case analysis by an forum such as the Defense Acquisition Research Symposium (DARS).

The LCU USV can be used for a plethora of missions if redesigned for flexibility. Although this thesis focuses mostly on the simple addition of unmanned navigation and maneuvering capability, a few simple architectural modifications can greatly increase the utility of this craft. The required mission of the LCU USV is likely to be dynamic and changing according to mission needs at any given point in time in the future. A detailed study of this includes a detailed analysis of alternatives, and conduct of a more granular level of concepts of operations. This work can be an exemplar for other conversions of manned craft into USVs. That knowledge alone may be sufficient justification to proceed since it is an enabler for rapid force reconstitution.

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## APPENDIX A. DISPLACEMENT LANDING CRAFT

See chapter I, Section C for the characteristics of the U.S. Navy LCU 1610.

This Appendix is from (Bottelson 2001). It presents a selection of displacement landing craft for comparison to the LCU 1610 Class vessels.

### **Landing Craft, Vehicle, Personnel (LCVP) aka: “Higgins Boat”**

This craft was designed specifically to meet the needs of the amphibious fleet during WW II. It was the predecessor of the LCM (Bottelson 2001).

Hull:	Originally wood (oak, pine and mahogany), later Steel
Displacement:	18,000 lbs. (light)
Length:	36'3"
Beam:	10'10"
Draft:	3' aft, 2'2" forward
Speed:	9 knots
Armament:	Two .30-cal MGs
Complement:	3 enlisted
Capacity:	36 troops or 6,000 lb. vehicle or 8,100 lb. general cargo
Propulsion:	225 hp Diesel or 250 hp gasoline engine
Notes:	This craft was designed specifically to meet the needs of the amphibious fleet during WW II. It was the predecessor of the LCM.

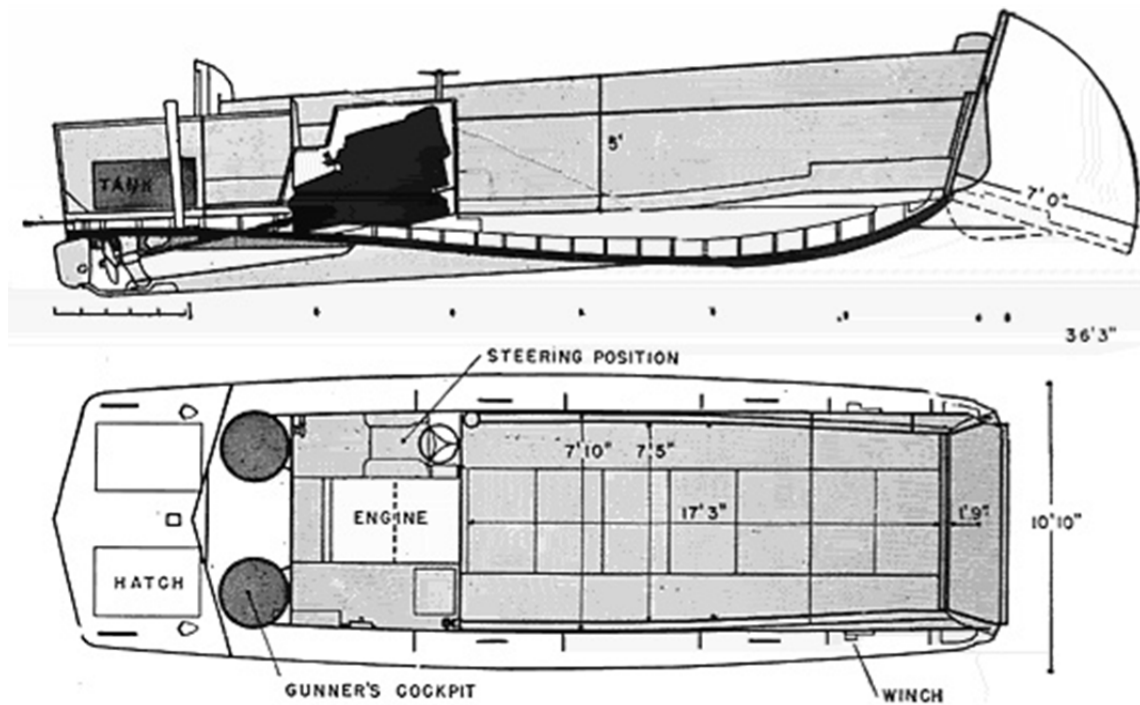


Figure 36. Landing Craft, Vehicle, Personnel (from Bottelson 2001).

### **Landing Craft, Tank (LCT) - Mark 5 Type**

The Mark 5 Type Landing Craft was eventually developed into the LCU. The LCT Mark 6 version was developed in mid-1944 and made use of lessons learned from D-Day. It was built with a stern gate that allowed for “drive-through” of vehicles. The LCT Mark 6 very much resembles the modern LCU (Bottelson 2001).

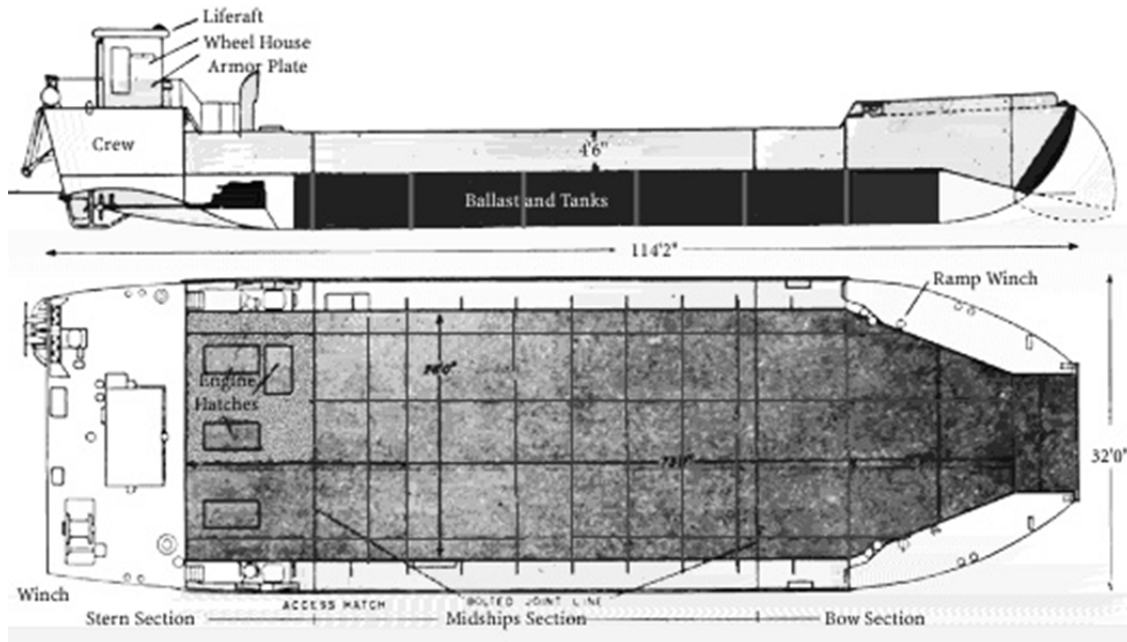


Figure 37. Landing Craft, Tank (from Bottelson 2001).

#### **Landing Craft, Mechanized (LCM) Mark 6 (LCM-6)**

Hull:	Steel
Displacement:	64 tons full load
Length:	56'2"
Beam:	14'
Speed:	9 kts (10.3 mph)
Crew:	5 enlisted
Capacity:	34 tons or 80 troops
Propulsion:	Two marine diesel engines, twin screw
Range:	130 miles at 9 kts

### **Landing Craft, Mechanized (LCM) Mark 8 (LCM-8)**

This Craft is currently in use for training and MPF support (Bottelson 2001)

Hull:	Steel
Displacement:	75 tons full load
Length:	73' 8"
Beam:	21'
Speed:	12 kts (13.8 mph)
Crew:	5 enlisted
Capacity:	60 tons
Military lift:	One M60 tank or 200 troops
Propulsion:	Two Detroit 12V-71 Diesel engines; 680hp sustained; twin shafts
Range:	190 miles at 9kts full load
Notes:	This craft is currently in use for training and MPF support.

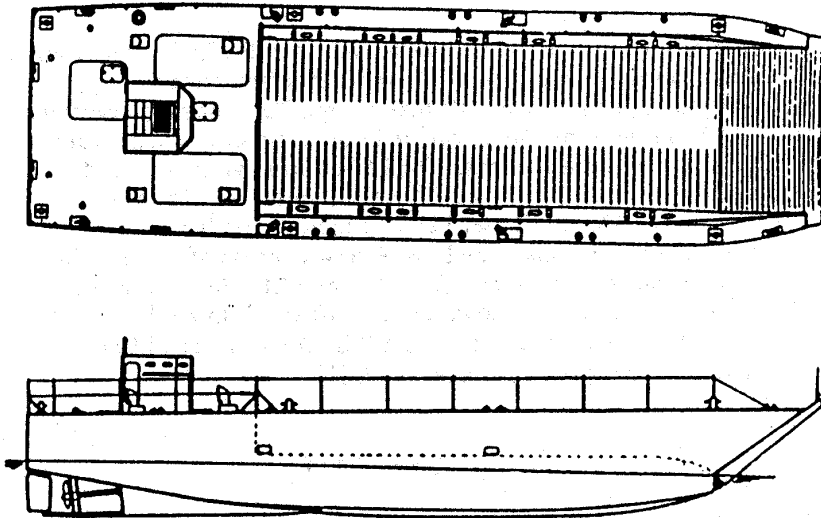


Figure 38. Landing Craft Mechanized-8 (from Bottelson 2001).



### **Patrol Boat, River – Mark I (PBR-I)**

Hull:	Lightweight fiberglass
Weight:	18,000 lbs (without crew and ammo)
Length:	31'
Beam:	11' 7"
Draft:	9" underway
Speed:	28 knots
Armament:	Twin .50 caliber Machine Gun turret in the bow, Single .50 caliber Machine Gun in the stern, M-60 Machine Gun, M-18 40mm Grenade Launcher, Crew's Small Arms (4 M-16s and Captain's .45 M1911A1) Additional Armor: 90mm Recoilless Rifles, 60mm Mortars, flamethrowers, 20mm Cannons
Crew:	4 enlisted
Propulsion:	Two 250 HP diesels each connected to a 6" diameter Jacuzzi water jet, capable of 6000 gallons per minute discharge.
Notes:	Boats patrol in pairs, with additional Chief Petty Officer as Patrol Officer

### **Armored Troop Carrier (ATC)**

Hull:	Steel
Displacement:	61 tons
Length:	56'
Beam:	17' 6"
Draft:	4 to 4 ½'
Speed:	9 kts
Armament:	Two .50 caliber MG, one 20mm cannon, two M-60 MGs, two MK 18 grenade launchers, various small arms
Complement:	5 enlisted
Capacity:	
Propulsion:	Two marine diesel engines, twin screw
Notes:	Converted LCM-6 landing craft. Some were fitted with helicopter pads above the troop area to allow for medevac.

### Assault Support Patrol Boat (ASPB)

Hull: Steel  
Displacement:  
Length: 50'  
Beam: 16'  
Draft:  
Speed: 15 kts  
Armament: Two 30 caliber MGs, grenade launcher, one 20mm cannon forward,  
one 81mm mortar aft, various small arms  
Complement: 5 enlisted  
Propulsion: Two marine diesel engines, twin screw

### Command and Communications Boat (CCB)

Hull: Steel  
Displacement: 72 tons light  
Length: 60' 6"  
Beam: 17' 6"  
Draft: approx. 3 ½'  
Speed: 9 kts  
Armament: One 40mm cannon, one 20mm cannon, two .50 caliber MG, two M-60 MGs, various small arms  
Complement: 11 enlisted plus Division Commander and staff  
Propulsion: Two marine diesel engines, twin screw  
Notes: Much like the Monitor except the mortar pit was replaced with a communications module.

### Monitor

Hull: Steel  
Displacement: 82 tons light  
Length: 60' 6"  
Beam: 17' 6"  
Draft: approx. 3 ½'  
Speed: 9 kts  
Armament: One 40mm cannon, one 20mm cannon, three .50 caliber MGs, two MK 18 grenade launchers, one 81mm mortar, various small arms  
Complement: 11 enlisted  
Propulsion: Two marine diesel engines, twin screws  
Notes: Converted LCM-6. Later models were fitted with guns of up to 105mm.



Figure 39. Landing and Combat Craft (from Bottelson 2001).

## APPENDIX B. TECHNOLOGY READINESS LEVELS

Conceptual systems for each of the mission capabilities identified are assessed from a technology readiness perspective using Technology Readiness Levels (TRLs) (DOD 2007).

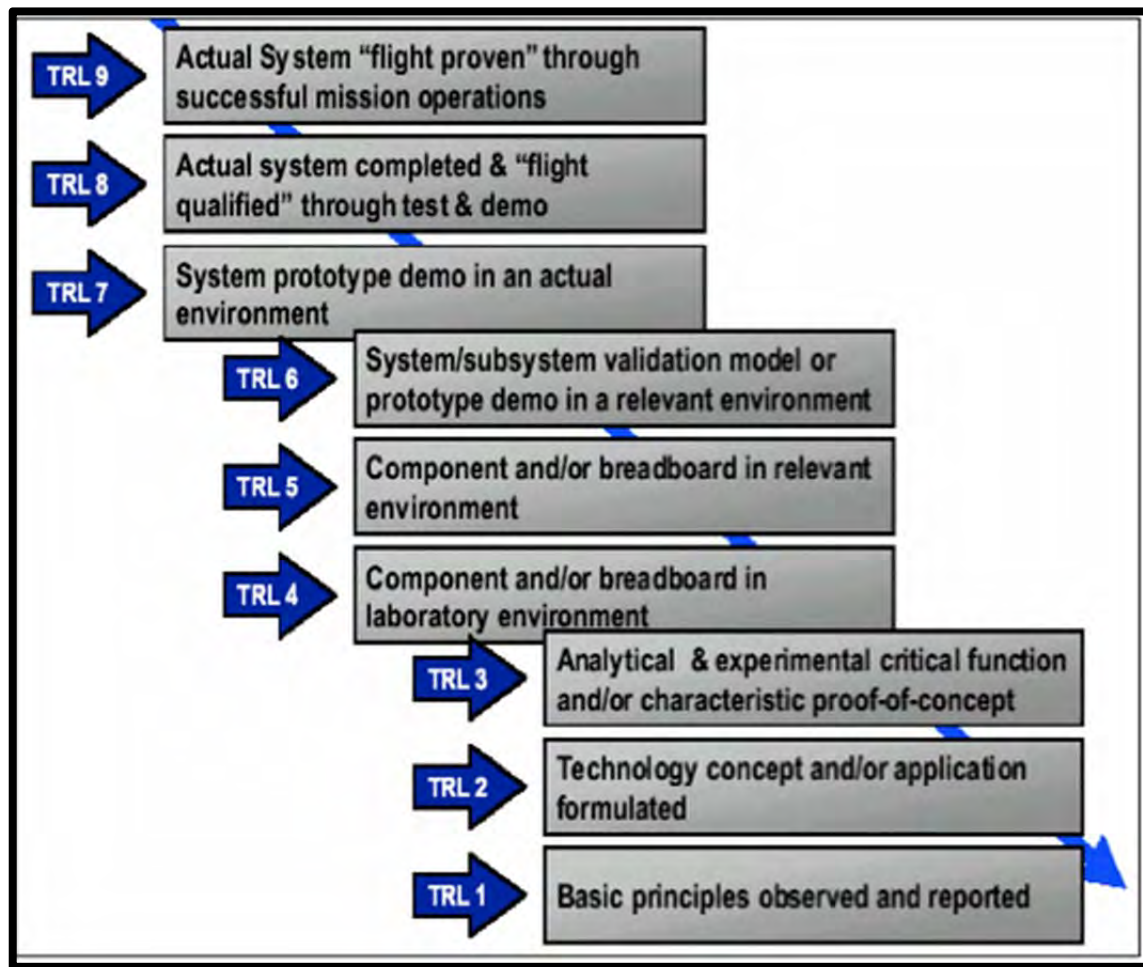


Figure 40. Technology Readiness Levels (from DOD 2007).

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## APPENDIX C. LCU-USV 4-LEVEL FUNCTIONAL DECOMPOSITION

This thesis presents an overarching functional analysis that covers the scope of the potential mission set. This functional decomposition is partially adapted from the *Required Operational Capabilities And Projected Operational Environment For Navy Expeditionary Intelligence Command Forces* (OPNAV N85 2010) and from *NPS-SE-11-006 Capstone Project/Thesis* (Calvert 2011). Note that functions 1, 2, 3, 5, and 6 may also be represented as subordinate functions to each of functions “4.X.” However, it is presented in this manner to facilitate comprehension.

1. Load/Recover/Retrieve/Receive Payload
  - 1.1. Load/Receive/Recover/Retrieve USV/UUV/UAV for MIW, ISR, or support missions while underway
2. Transit/Operate/Maintain LCU USV Platform
  - 2.1. Employ safety countermeasures
    - 2.1.1. Control LCU USV during all conditions of active jamming
    - 2.1.2. Prevent and control damage
    - 2.1.3. Control fire, flooding, electrical, structural, propulsion, and hull casualties
    - 2.1.4. Carry out emergency destruction of classified matter and equipment rapidly and efficiently.
    - 2.1.5. Provide ability for personnel to abandon/scuttle ship rapidly.
    - 2.1.6. Provide Self-destruct capability for LCU USV
    - 2.1.7. Maintain security against unfriendly acts
    - 2.1.8. Provide damage control security and surveillance
  - 2.2. Perform seamanship, airmanship and navigation tasks
    - 2.2.1. Operate day and night, and under all weather conditions
    - 2.2.2. Navigate under all conditions of geographic location, weather, and visibility
      - 2.2.2.1. Transit autonomously via GPS waypoints to area of responsibility
      - 2.2.2.2. Transit or semi-autonomously via remote commands from shore, commands from an on-board pilot, and/or GPS waypoints.
      - 2.2.2.3. Conduct manned transit with traditional LCU craftmaster
    - 2.2.3. Operate from a well-deck equipped amphibious ship
    - 2.2.4. Operate from a pier
    - 2.2.5. Get underway, moor, anchor, and sortie with duty section in a safe manner
    - 2.2.6. Utilize programmed evasive steering
    - 2.2.7. Employ evasion techniques
    - 2.2.8. Tow or be towed
    - 2.2.9. Provide capability to collect, store, retrieve, and process obstacle contact information.

3. Unload/Deploy/Launch Payload including MIW, ISR, and Functional mission equipment.
  - 3.1. Deploy/Launch/Load USV/UUV/UAV for MIW, ISR, or support missions while underway, or while anchored.
4. Execute Missions
  - 4.1. Execute environmental collection in permissive environments
    - 4.1.1. Host/maintain environmental collection payload(s) and supporting equipment on LCU USV platform to execute environmental collection in permissive environments
    - 4.1.2. Provide all necessary systems, services, programs, and facilities to safeguard classified payload systems, material, and information.
    - 4.1.3. Provide all necessary systems, services, programs, and facilities to remotely monitor the embarked payload.
    - 4.1.4. Activate/deploy/launch/unload payload(s) and mission equipment for while underway, or while anchored.
      - 4.1.4.1. Tow sensor packages
    - 4.1.5. Deactivate/load/recover/retrieve/receive payload(s) while underway, or while anchored.
    - 4.1.6. Replenish the payload
      - 4.1.6.1. Secure payload
      - 4.1.6.2. Establish connection with payload
      - 4.1.6.3. Repower payload
      - 4.1.6.4. Transfer/receive, process, and analyze data from payload
  - 4.2. Execute Persistent ISR in permissive environments
    - 4.2.1. Host/maintain persistent ISR payload(s) and supporting equipment on LCU USV platform to collect, process, and evaluate information to determine location, identity, and capability of hostile forces through ISR means.

[All other Persistent ISR mission functional activities are the same as activities 4.1.2 through 4.1.5]

  - 4.3. Execute Processing, Exploitation, and Dissemination
    - 4.3.1. Host/maintain communications payload(s) and supporting equipment on LCU USV platform for coordination and control of external organizations or forces and control of unit's facilities
    - 4.3.2. Host/maintain communications payload(s) and supporting equipment on LCU USV platform to relay visual and electronic Naval communications
    - 4.3.3. Host/maintain payload(s) and supporting equipment on LCU USV platform to effectively use the electromagnetic spectrum for detection and targeting while deterring, exploiting, reducing or denying its use by the enemy.

- 4.3.4. Host/maintain communications payload(s) and supporting equipment on LCU USV platform to act as an information processing and intermediary decision point for command and control of downstream mission needs.

[All other Processing, Exploitation, and Dissemination mission functional activities are the same as activities 4.1.2 through 4.1.5]

4.4. Execute Payload Delivery, Autonomous ship-to-shore, or shore-to-shore connector payload Delivery

- 4.4.1. Transfer/receive cargo and personnel from ship to shore
- 4.4.2. Host/maintain payload(s) and supporting equipment on LCU USV platform for resupply of combat consumables to combat forces in the theater of operation, noncombat general payload transfer/receive operations ,and other supply support missions
- 4.4.3. Provide support facilities for material and passenger handling and securing

[All other Payload Delivery mission functional activities are the same as activities 4.1.2 through 4.1.5]

4.5. Execute Unmanned Vehicle Support

- 4.5.1. Host/maintain environmental collection payload(s) and supporting equipment on LCU USV platform to execute unmanned vehicle support in permissive environments

[All other Unmanned Vehicle Support mission functional activities are the same as activities 4.1.2 through 4.1.5]

4.6. Execute Search and rescue (SAR) of conscious victims

- 4.6.1. Function as on-scene commander or relay station for Search and Rescue (SAR) operation
- 4.6.2. Host/maintain payload(s) and supporting equipment on LCU USV platform to execute SAR

[All other SAR mission functional activities are the same as activities 4.1.2 through 4.1.5]

4.7. Execute Training Support

- 4.7.1. Host/maintain payload(s) and supporting equipment on LCU USV platform to execute VBSS, antipiracy, targeting, electronic countermeasures training and other training support.

[All other Training Support mission functional activities are the same as activities 4.1.2 through 4.1.5]

4.8. Execute Test platform missions

- 4.8.1. Host/maintain Test Mission payload(s) and supporting equipment on LCU USV platform to execute unmanned vehicle support in permissive environments.
- 4.8.2. Receive direct commands from a shore facility during the test.

[All other Test mission functional activities are the same as activities 4.1.2 through 4.1.5]

4.9. Execute MCM intelligence preparation of the battlespace (IPB)

- 4.9.1. Host/maintain MCM IPB payload(s) and supporting equipment on LCU USV platform to execute unmanned vehicle support in permissive environments.

[All other MCM IPB mission functional activities are the same as activities 4.1.2 through 4.1.5]

4.10. Minefield proofing

- 4.10.1. Host/maintain Minefield proofing payload(s) and supporting equipment on LCU USV platform to execute unmanned vehicle support in permissive environments.

[All other MCM IPB mission functional activities are the same as activities 4.1.2 through 4.1.5]

5. Host/Maintain Payload on Platform

- 5.1. Receive fuel while underway or docked
- 5.2. Provide all necessary systems, services, programs, and facilities to safeguard classified material and information.

6. Maintain LCU USV Platform

- 6.1. Provide upkeep and maintenance of LCU USV
- 6.2. Provide organizational level maintenance
- 6.3. Repair own unit's equipment
- 6.4. Receive fuel while underway or docked
- 6.5. Provide all necessary systems, services, programs, and facilities to remotely monitor the LCU USV system condition.



## **APPENDIX D. EXEMPLAR COMPANIES, PARTS AND COSTS**

There are several technologies that exist to help alter the navigation, steering, and control systems of the LCU to repurpose it as a USV. This appendix shows a number of common candidate exemplar systems. Lessons learned by other OSA programs can likewise provide even better possibilities.

### **B. NAVIGATION SYSTEM**

There are several technologies that are key to converting the LCU into a USV. One of the primary systems that needs conversion is the navigation system. Technologies that may be altered or installed to convert the navigation system are as follows:

#### **1. Radar**

The LCU is likely able to keep the existing Furuno radar, but add a Simrad 4G Frequency Modulated Continuous Wave (FMCW) radar for close up detection. The initial signal transmission of the Furuno most likely does not allow for close object detection and avoidance. However, the FMCW Simrad 4G might complement the Furuno by detecting objects that are relatively close to the LCU USV.



Figure 41. 4G Frequency Modulated Continuous Wave (FMCW) radar (from Simrad Yachting 2014).

## 2. Light Detection and Ranging (LiDAR)

LiDAR is a technology that aids the USV in close-up object detection and avoidance. The word is short for Light Detection and Ranging. “This 360-degree rotating device incorporates 64 laser beams to produce colorful 3–D data images on a computer screen and is being used by leading map content providers for creating the maps now seen on mobile devices and GPS systems. While the LiDAR sensors are used in unmanned cars, mining trucks and military patrol boats, Hall believes LiDAR [is] helpful for docking to show obstacles in day” (DeMartini 2013).

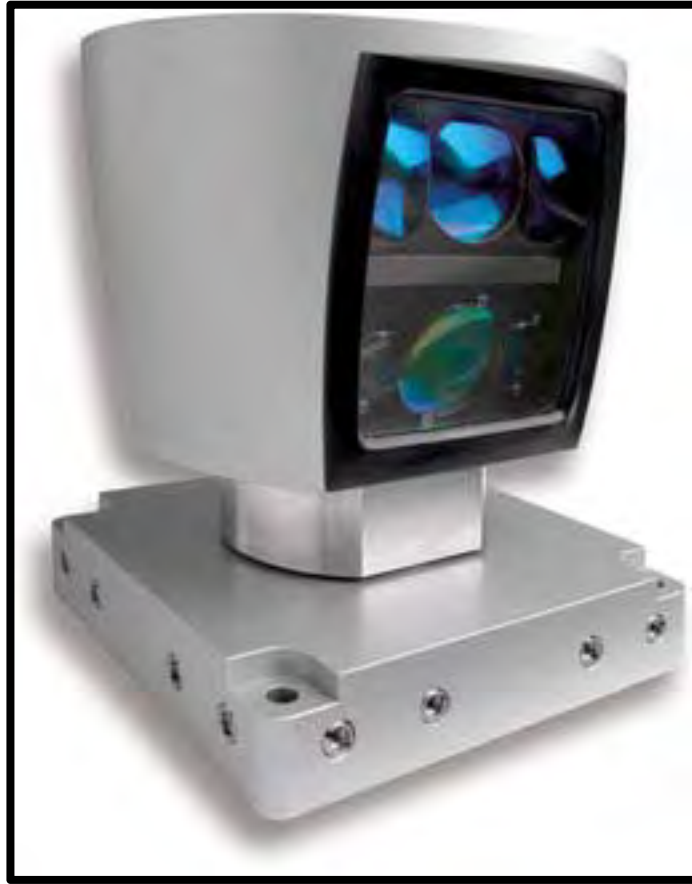


Figure 42. Light Detection and Ranging (LiDAR) system (from DeMartini 2013).

### **3. Global Positioning Satellite (GPS)**

The existing LCU global positioning satellite (GPS) system has both commercial GPS and Military GPS components. The LCU USV GPS system keeps the two GPS signals, but changes the commercial GPS to one that talks NMEA 2000, a plug-and-play communications standard used for connecting marine sensors and display units within ships and boats, vice NMEA 0183, the combined electrical and data specification for communication between marine electronics. Alternatively, the design can utilize a converter for both commercial and DAGR GPS's that can convert the serial NMEA 0183 to NMEA 2000 Controller Area Network (CAN) bus that makes it easier to transmit/receive from the craft level systems. The same is true for the Gyrocompass.

#### **4. Speed and Depth Sensors**

The LCU USV can utilize a Maretron Depth/Speed/Temperature (DST) 110 triducer, transmitter so that the true speed/depth through water can be recorded and analyzed.

#### **5. Inertial Navigation**

In addition to altering the traditional navigation systems, the LCU USV design likely needs to add an inertial Navigation System. In case of failure of gyrocompass and/or GPS, the vessel can maintain position and heading accuracy for a period of time.

#### **6. Cameras**

The existing LCU do not have situational awareness or sensory cameras. This is an added system for conversion to the LCU USV. The design requires 360-degree view cameras as well as stereo optics for gauging craft heading. The FLIR company makes a camera that is essentially just a software upgrade to their control system for 360 view. There are several others cameras in the marketplace from L-3, General Dynamics, and other companies that were tested and utilized on other Navy USV programs at NSWCCD.



Figure 43. FLIR Systems 360 degree camera (from OpticsPlanet 2014).

### **C. STEERING SYSTEM**

The existing LCU fleet recently received installs of an upgraded central machinery monitoring and control system (CMMCS). The CMMCS can last for many years to come, and works well as a basis for the LCU USV steering system.

The feedback sensor for the rudder positions likely needs to be changed to a Linear Voltage Differential Transmitter. Doing this reduces the system's susceptibility to noise, and vibration that has plagued the ones currently in use.

The IQAN<sup>TM</sup> electronic control system for mobile machinery that was used for the new CMMCS system is the exact same system as that used for the Navy's USV programs for the LCS UISS Unmanned Influence Sweep System (UISS) steering control module. There are several other USV's that are being tested such as the Autonomous Maritime Navigation (AMN) boat. An added benefit of using the existing IQAN system is that it is already J1939 compliant and can be modified relatively cheaply to suit the needs of the "master control system" i.e., the brain. This is in line with open systems architecture principles.

There are several companies, including WR Systems company and Spatial Integrated Systems (SIS), that both have fantastic experience in developing steering control systems for the USVs. After conversion and alteration for use with the LCU USV, the system may no longer be considered COTS as such alterations are customized for the platform in use. However, the software for the CMMCS can be easily modified to meet the messaging standards for all USVs. For example, the standard might say that PGN 65280 is for steering and the first two bytes are for main rudder and the second two bytes are for the flanking rudder position.

Because the LCU USV design builds off of existing, newly installed systems, the cost is minimal to get the "steering system" in line to be USV capable. This also helps meet objectives for cost, schedule, and government data ownership, and intellectual property ownership. This also helps ensure that the messages are controlled and defined so any third party control system can integrate easily with it. If the LCU USV steering system design went with a pure COTS system, there is a high likelihood that the

messages are proprietary and likely requires a memorandum of agreement (MOA) or other contractual agreement with the steering company to release them to the government, if in fact they are known.

#### **D. CONTROL SYSTEM**

The LCU USV control system is split into a “Craft Level” and overall “System Level” components. The Craft Level consists of the controls, monitoring, and automation of the systems required to run the boat manned or unmanned. This consists of the engines, generators, power distribution/control, steering, throttle control, ancillary machinery monitoring and control, and navigation.

The “System Level” consists of the “brain” of the LCU USV control system. This consists of the cameras, network communications (such as PRC-117G VHF/UHF/SATCOM), ground control station, and other systems.

##### **1. Craft Level**

Because the LCU vessels have a new CMMCS, the craft level controls do not need extensive alteration. Ideally, the engines are upgraded to an engine controller unit (ECU) controlled engine such as MTU, Caterpillar, and even new Detroit Diesels. This gives the added benefit of emission controls as well as simplified fly-by-wire control. However, it may not be necessary if it is cost prohibitive.

New generators also need to be acquired that are ECU controlled as well as automated switchgear with smart relays/breakers. The existing LCU have two generators on board so redundancy is covered as one can supply the required loads. Essentially, the new CMMCS created a generic ECU that really monitored the engine, but might not control emissions. With an ECU controlled engine, the fly-by-wire is not necessary.

The switchgear needs to be monitored by a programmable logic controller (PLC). The IQAN system can perform this function, but it is limited in its inputs and some converters to convert IP to CAN/J1939 or Profibus/Modbus to J1939 as most relays don't talk J1939 since that is a mobile communication protocol. There is ability for improvement in these OSA standards. Many switchgears come with automatic paralleling

capabilities. This is not present on the existing LCU as it can only manually parallel with governor controls that can help keep them in parallel, control the reactive droop, load balancing, etc.

The power distribution panels needs to be changed out to something that is automated. The Octoplex makes a suitable AC power distribution system that is NMEA 2000 compliant and has automatic breakers that can be reset if tripped by sending a message via the CAN bus.

The DC distribution also needs to be upgraded for the same reason. The E-T-A Company makes several modules that were used for Navy USV projects including the Sea Lion. The E-T-A modules are easy to program and the government can control that as well.



Figure 44. The Honorable Dr. Donald C. Winter uses a remote device to bring the SEAL Insertion, Observation\_and Neutralization (SEALION) craft into port at Naval Amphibious Base Little Creek (from Wikimedia Commons 2014).

The ancillary machinery required such as pumps, bow ramp motor, etc., can all be monitored and controlled via the IQAN<sup>TM</sup> electronic control system for mobile machinery. For safety and condition monitoring, Locked rotor conditions are detected from the Octoplex system and messages indicating conditions are sent to IQAN.

The upgrades for this level of control system upgrades costs approximately \$500K with the engines/generator upgrades. An additional \$350K costs are accrued if the panel, switchgear, and other ancillary upgrades are installed. These costs account for the detailed design costs, and some non-recurring engineering (NRE).



## **2. System Level**

The System Level control system is the “brain” of the system. It is the master controller of the system. WR Systems and SIS are two companies that were responsible for helping develop the network link, selecting radios, designing the ground control station, cameras, on existing U.S. Navy USV programs. One example of the ground control station is called Mobile Operation and Control Unit (MOCU).

Another important system is the radios that must be network radios for passing data over the air. The Sea Lancet is an example of these radios. There are other models by Cobham that are sufficient for high data rates. If it needed to be over-the-horizon capable, then the system needs to utilize satellite communications (SATCOM) from the PRC-117G radio system. The L-3 also makes data radios with paralleled antennas. These were tested by the Navy on the Stiletto USV with transmission of HD video from many miles away. The current LCU fleet has the PRC-117G upgrade.

Both the WR company and SIS company have been involved with the cameras for U.S. Navy USVs. There are several 360 degree cameras out there that are marine capable. Gyrocam by General Dynamics is one example, FLIR is another. As stated above, FLIR’s is just a software upgrade so costs are minimal for the upgrade. L-3 also made a suitable high definition 360 degree camera.

A rough order of magnitude estimate for developing a new systems level control for the LCU USV is on the order of \$400–600K depending on the mission requirements of the LCU USV. If it is to operate over the horizon for long durations that requires redundancy and a larger quantity smart technology.

## **E. COMPANIES FOR LCU USV SYSTEM DESIGN AND INSTALLATION**

For the master control system, ground control system, communications, etc. (i.e., the “System Level”) the following companies are likely be interested parties:

- Spatial Integrated Systems (SIS)
- WR Systems
- Textron Marine and Land Systems (TMLS): Experienced with the CUSV system and Trident Warrior exercises.
- NASA Jet Propulsion Laboratory (JPL): They developed the brains for the Mars Rover and completed work with USVs with the Autonomous Maritime Navigation test craft.
- Maritime Applied Physics Corporation (MAPC): They helped develop the USV High Tow Force.
- SAIC Corp.

Table 33. Companies for LCU USV System Level Control design and installation.

For the “Craft Level” systems, the following companies are likely be interested parties:

- NSWCCD: They are the most familiar with the existing craft being the ISEA as well as being the ISEA for USVs. The LCU USV would also be “government owned” therefore mitigating risks associated with proprietary information between parties.
- Spatial Integrated Systems (SIS): they could potentially do both the craft level and system level.
- WR Systems: They could potentially do both the craft level and system level.
- Oregon Iron Works: They built the current UISS prototype and Sea Lion upgrades, and are very familiar with IQAN and the E-T-A company power products.
- CDI Marine: They have been the contracting support doing the drawings, installation, and maintenance for several existing LCU systems for a number of years. They are very familiar with designing systems for IQAN and E-T-A power products having developed drawings for some USVs and the existing LCU CMMCS.

Table 34. Companies for LCU USV System Level Control design and installation.

## F. NON-RECURRING ENGINEERING (NRE) COSTS

The non-recurring engineering (NRE) costs for the LCU USV varies with the level of alterations that are required by the final design. Engines, Navigation, AC/DC

power distribution and control, Craft Level Controls, System Level Controls (including communications) might all require separate NRE efforts.

### **1. Engine/Generator Upgrade**

This upgrade effort costs roughly \$200K for just the generators and another \$300K for the main engines. If all new, high technology engines and generators are purchased, they might cost \$2M or more per vessel set. The NRE for a system of this nature, to include drawings, electrical/mechanical/naval architecture calculations, etc., is approximately \$400K.

### **2. Navigation**

There is a need for a study to determine the required equipment. A rough estimate for the NRE is approximately \$200K for design and drawings.

### **3. AC/DC Power Distribution and Control**

This effort includes the NRE for the switchgear. Since this power system needs to be automated, require integration into the craft level control system, automated parallel capability, and monitoring, the design NRE costs are approximately \$150K.

The distribution system for AC costs approximately \$150K and the design of the DC distribution system is about the same.

### **4. Craft Level Control Systems**

Keeping the existing CMMCS and adding automation capabilities to it is likely to minimize the costs. With the engines being ECU controlled and fly-by-wire, the master controllers (MC2s) in the engine rooms can be repurposed to ancillary machinery monitoring and control and have one of their CAN busses talking to each engine/generator.

It is an additional \$200K to change the software, add modules, and re-design the CAN bus system to create a redundant bus from the master modules as well as add the ETA (DC Distribution), AC Distribution, monitoring, and control, etc.

## **5. System Level Control Systems**

Depending on the mission requirements, if it is necessary for over the horizon operations, and the level of required autonomy the system level control costs might vary. Designing for semi-autonomy and/or remote control autonomy with the human in the loop, the design of such a system leveraging previous designs costs approximately \$500K.

## **6. Summary**

In summary, the total for NRE is likely to be on the order of \$1.85M. This may be rounded up to \$2.50M for contingency, scope creep, etc.

## **APPENDIX E. ACTION PLANS FROM THE BII MMOWGLI**

The Business Innovation Initiative (Bii) Massive Multiplayer Online Wargame Leveraging the Internet (MMOWGLI) game explores how to achieve business goals of the Navy's Open Systems Architecture (OSA) Strategy. The motivating theme is exploring the contracting trade space for Intellectual Property (IP) and Data Rights. The game explores what IP and data rights are worth to systems stakeholders. Professional feedback is essential to exploration of all possible ideas in the game (Naval Postgraduate School (NPS) 2014).

The game was based on the fact that large and small industry players each want to compete and profit effectively, now and in the future. Meanwhile, the Navy needs technical data rights for long-term system interoperability, maintainability, and competition. Together, the professional players of the Bii MMOWGLI game derived Idea Card Chains and Action Plans, working together to effectively solve problems associated with OSA (Naval Postgraduate School (NPS) 2014).

The following are excerpts from the Bii MMOWGLI Action Plans as derived by the players that participated in a recent Bii game conducted over the course of two weeks during July 2014. The first Action Plan is centered on the issue of platform rights. The second Action Plan is associated with payload rights. Table 35 shows Bii MMOWGLI URLs. Figures 45 through 52 show applicable excerpts and results from the Bii MMOWGLI.

Page Title	Uniform Resource Locator (URL)
Business Innovation Initiative Homepage	<a href="https://mmowgli.nps.edu/bii">https://mmowgli.nps.edu/bii</a>
Action Plan 43 PLATFORM RIGHTS: What are best license and data rights for the Platform PM to add OSA capabilities to unmanned-system controllers for LCU-USV platform itself?	<a href="https://mmowgli.nps.edu/bii#69_43">https://mmowgli.nps.edu/bii#69_43</a>
Action Plan 44 PAYLOAD RIGHTS: What are best license and data rights for OSA-capable payloads (UAVs, other systems) needing connectivity when deployed on LCU-USV platform?	<a href="https://mmowgli.nps.edu/bii#69_44">https://mmowgli.nps.edu/bii#69_44</a>
Idea cards exploring technical data policies for the following issue corresponding to Action Plans 43 and 44: “A long-term Navy utility platform (LCU) is near end-of-life milestone. Program is considering renewal by conversion into an unmanned system.”	<a href="https://mmowgli.nps.edu/bii#65_374">https://mmowgli.nps.edu/bii#65_374</a> 1

Table 35. Bii MMOWGLI URLs

Round 3

Action Plan 43

**ID** [Action Plan 43](#) for Business Innovation Initiative (bii), Round 3.

**Title** **PLATFORM RIGHTS: What are best license and data rights for the Platform PM to add OSA capabilities to unmanned-system controllers for LCU-USV platform itself?**

**Rating** 1.7 "thumbs up" score (range from 1 to 3) with 12 player votes received, ranking 14 out of 17 plans in Round 3.

**Idea Card Chain Providing Original Motivation**  
[Idea Card Chain 3745](#) started by player [F. Sharp](#): What are right license & data rights for OSA-capable payloads (UAVs, other systems) needing connectivity when deployed on LCU-USV platform?

**Co-Authors** [AllAboutTheData](#), [ABWIS](#), [F. Sharp](#), [Spud](#), [Paste](#)

**Who Is Involved?** NAVSEA, program office, industry proposers for USVs and UAVs. Also, payload managers and operators who might be "passenger" systems riding on this (future concept) OSA-capable platform.

**What Is It?** Long life-cycle program with data rights wants to convert into an unmanned system. What OSA rights are needed to keep this new proposed LCU-USV system flexible and unlocked for another 40 years? This exemplar program has the potential to show productive paths for industry providing upgrades to numerous legacy and commercial systems for Navy benefit.

**What Will It Take?** Exemplars and guidance. Can anyone provide some? No current LCU systems are locked under proprietary data rights, this can be a clean restart using a proven platform.

**How Will It Work?** Proper license and data rights package might renew a decades-old platform for several more decades. Inoculating against known problems can ensure long-term future progress.

**How Will It Change the Situation?** Navy gets to re-use legacy equipment by upgrading with new OSA capabilities. Industry gets some big new market opportunities - if a U.S. Navy LCU might be converted to an LCU-USV satisfactorily, then existing LCUs in allied Navies might also be upgraded. Perhaps an "OSA unmanned-system upgrade package" might be applied to a variety of different legacy ships out there.

Images



**Two Landing Craft Utilities (LCU) assigned to Amphibious Craft Unit Two**  
[http://en.wikipedia.org/wiki/Landing\\_Craft\\_Utility#mediaviewer/File:US\\_Navy\\_060606-N-8154G-115\\_Two\\_Landing\\_Craft\\_Uilities\\_\(LCU\)\\_assigned\\_to\\_Amphibious\\_Craft\\_Unit\\_Two\\_\(ACU-2\)\\_rehearse\\_storming\\_the\\_beach\\_in\\_Curacao,\\_Netherlands\\_Antilles.jpg](http://en.wikipedia.org/wiki/Landing_Craft_Utility#mediaviewer/File:US_Navy_060606-N-8154G-115_Two_Landing_Craft_Uilities_(LCU)_assigned_to_Amphibious_Craft_Unit_Two_(ACU-2)_rehearse_storming_the_beach_in_Curacao,_Netherlands_Antilles.jpg)  
[https://mmowgli.nps.edu/bii/images/43/US\\_Navy\\_060606-N-8154G-115\\_Two\\_Landing\\_Craft\\_Uilities\\_\(LCU\)\\_assigned\\_to\\_Amphibious\\_Craft\\_Unit\\_Two\\_\(ACU-2\)\\_rehearse\\_storming\\_the\\_beach\\_in\\_Curacao,\\_Netherlands\\_.jpg](https://mmowgli.nps.edu/bii/images/43/US_Navy_060606-N-8154G-115_Two_Landing_Craft_Uilities_(LCU)_assigned_to_Amphibious_Craft_Unit_Two_(ACU-2)_rehearse_storming_the_beach_in_Curacao,_Netherlands_.jpg)

LCU Mk10 EDA-R COUGAR12


Figure 45. Excerpt (Page 1 of 4) from Bii MMOWGLI Action Plan for Platform Rights (from Naval Postgraduate School (NPS) 2014).



Figure 46. Excerpt (Page 2 of 4) from Bii MMOWGLI Action Plan for Platform Rights  
(from Naval Postgraduate School (NPS) 2014).

[http://en.wikipedia.org/wiki/Landing\\_Craft\\_Utility#mediaviewer/File:LCU\\_Mk10\\_EDA-R\\_COUGAR12\\_45154571.jpg](http://en.wikipedia.org/wiki/Landing_Craft_Utility#mediaviewer/File:LCU_Mk10_EDA-R_COUGAR12_45154571.jpg)

[https://mmowgli.nps.edu/bii/images/43/1280px-LCU\\_Mk10\\_EDA-R\\_COUGAR12\\_451545710.jpg](https://mmowgli.nps.edu/bii/images/43/1280px-LCU_Mk10_EDA-R_COUGAR12_451545710.jpg)



Videos

1 U.S. Marines and Sailors Onboard Landing Craft Utility | AirSource

U.S. Marines and Sailors Onboard Landing Craft Utility. Published on Jun 21, 2013. U.S. Marines and Sailors assigned to the 26th Marine Expeditionary Unit (MEU), are transported from the USS San Antonio (LPD 17), to Port Aqaba, Jordan, via a landing craft utility while offloading for Exercise Eager Lion 2013, June 7, 2013. Exercise Eager Lion 2013 is an annual, multinational exercise designed to strengthen military-to-military relationships and enhance security and stability in the region by responding to realistic, modern-day security scenario. (U.S. Marine Corps motion media by Lance Cpl. Juanenrique Owings, 26th MEU Combat Camera/Released)

U.S. Marines and Sailors assigned to the 26th Marine Expeditionary Unit (MEU), are transported from the USS San Antonio (LPD 17), to Port Aqaba, Jordan, via a landing craft utility while offloading for Exercise Eager Lion 2013, June 7, 2013. Exercise Eager Lion 2013 is an annual, multinational exercise designed to strengthen military-to-military relationships and enhance security and stability in the region by responding to realistic, modern-day security scenario. (U.S. Marine Corps motion media by Lance Cpl. Juanenrique Owings, 26th MEU Combat Camera/Released) — AirSource — Give us your thumbs up for the troops! Source for interesting current- and archival military videos. Favorite this video and subscribe to AirSource for future video updates. subscribe: <http://youtube.com/AirSource> facebook: <http://facebook.com/AirSource> g+: <http://plus.google.com/110286844006311983475> twitter: <http://twitter.com/AirSource> on the web: <http://www.AirSource.com>

<https://www.youtube.com/watch?v=jcB--d2Drso>


2 Refueling Landing Craft Utility (LCU) 2032

Army Mariners of LCU 2032 "Palo Alto" refuel at the Port of Tacoma. The LCU is returning to Port Huene, Ventura, Calif., from Innovative Readiness Training (IRT)-Mertarvik. The crew completes a four-month deployment providing the Navy and Marines logistical support for the relocation and construction of Newtok Village in Alaska. Video by Sgt. 1st Class Walter Talens | 311th Sustainment Command (Expeditionary)

Army Mariners of LCU 2032 "Palo Alto" refuel at the Port of Tacoma. The LCU is returning to Port Huene, Ventura,




Figure 47. Excerpt (Page 3 of 4) from Bii MMOWGLI Action Plan for Platform Rights (from Naval Postgraduate School (NPS) 2014).



Refueling Landing Craft Utility (LCU) 2032

Calif., from Innovative Readiness Training (IRT)-Mertarvik. The crew completes a four-month deployment providing the Navy and Marines logistical support for the relocation and construction of Newtok Village in Alaska. Video by Sgt. 1st Class Walter Talens | 311th Sustainment Command (Expeditionary) - AirSource - Thumbs up for the troops! Source for interesting current- and archival military/aviation videos. Favorite this video and subscribe to AirSource for future video updates. subscribe: <http://youtube.com/AirSource> facebook: <http://facebook.com/AirSource> g+: <http://plus.google.com/110286844006311983475> twitter: <http://twitter.com/AirSource> on the web: <http://www.AirSource.com>

<https://www.youtube.com/watch?v=RTuAglDRbYo>



Refueling Landing Craft Utility (LCU) 2033 - Port of Tacoma. Part 2/2

Army Mariners of LCU 2033 "Paulus Hook" refuel at the Port of Tacoma. The LCU is returning to Port Hueneme, Ventura, Calif., from Innovative Readiness Training (IRT)-Mertarvik. The crew completes a four-month deployment providing the Navy and Marines logistical support for the relocation and construction of Newtok Village in Alaska. Video by Sgt. 1st Class Walter Talens | 311th Sustainment Command (Expeditionary) - AirSource - Thumbs up for the troops! Source for interesting current- and archival military/aviation videos. Favorite this video and subscribe to AirSource for future video updates. subscribe: <http://youtube.com/AirSource> facebook: <http://facebook.com/AirSource> g+: <http://plus.google.com/110286844006311983475> twitter: <http://twitter.com/AirSource> on the web: <http://www.AirSource.com>

<https://www.youtube.com/watch?v=ZTN2mCKo5w0>

Player Comments

1 Thursday, 24 July 2014 11:05:59-PDT, Round 3 [gm\\_domb](#): [Author motivation #1] I have an existing legacy Navy boat system that I want to repurpose to be an unmanned boat. In essence I want to install an Open Systems Architecture (OSA) kit/box of systems and components that adds unmanned boat control and another box that adds unmanned payload control. The existing, manned control system is essentially split into a Craft Level and an overall System Level. The Craft Level consists of the controls, monitoring, automation, etc. of the systems required to run the boat manned/unmanned. This would consist of the engines, generators, power distribution/control, steering (already discussed), throttle control, ancillary machinery monitoring and control, navigation (already discussed), etc. The System Level consists of the brain, cameras, network communications, ground control station, etc. Most of the craft-level systems are government-owned, and most systems-level systems are not government owned. For instance, the existing boat steering and machinery control system is government designed and owned. Building on the existing system is the right way to go in terms of cost, schedule, and government ownership perspective. This can also help ensure that the messages are controlled and defined so any third party control system can integrate easily with it. However, some of the added craft-level and system-level components will need to be COTS. If we went with a COTS system chances are the messages are proprietary and would require a Memorandum of Agreement (MOA) with the company (i.e. the steering system company) to release them to the government, if in fact they are known. For example, In the current design of some systems, the engineers had to reverse engineer a control system as the company would not release the messages. This was mainly because they didn't know what they were, but the Government was told that if they knew them they still would not release it as it was proprietary to their system.

2 Thursday, 24 July 2014 11:06:24-PDT, Round 3 [gm\\_domb](#): [Author motivation #2] How do I determine what licenses are needed in order to protect the Government's access to data rights for future craft maintenance, modernization, and design? How do I estimate the reuse feasibility with respect to the level of access to the data rights?

3 Thursday, 24 July 2014 11:37:23-PDT, Round 3 [ABWIS](#): Amazing that any vendor would refuse to release supporting information on any of their products already sold to the government. Perhaps there should be a time limit similar to patent expirations in the purchase agreement. Or would a request for technical data suffice?

4 Thursday, 24 July 2014 [Paste](#): Depending on the initial contract the USG PO signed, USG may have only bought use rights. Supporting info the contractor can require more compensation for especially if the USG wants

Figure 48. Excerpt (Page 4 of 4) from Bi MMOWGLI Action Plan for Platform Rights  
(from Naval Postgraduate School (NPS) 2014).

- 11:42:14-PDT, Round 3 to use it to rebid.
- 5 Thursday, 24 July 2014 11:44:01-PDT, Round 3 *gm donb*: Also see the corresponding [Action Plan 44](#).
- 6 Thursday, 24 July 2014 11:49:41-PDT, Round 3 *Spud*: I think what would need to happen in this case is two things: 1. The old architecture and control systems for the LCU will require an emulator to connect it to a new digital, remotely operated control system. This will then enable it to be connected to an OSA. 2. The OSA needs to be developed. The government could define and design the OSA; therefore, the government owns the IP rights to the OSA and can re-compete it as necessary. Or, the government can contract out both the OSA and the emulator to a contractor but specify in the contract that the government will own the IP rights. The contractor will still make money with the emulator and the use of the OSA.
- 7 Saturday, 26 July 2014 11:54:30-PDT, Round 3 *Jacko*: Suggest looking into MOSA related efforts in other service, MOSA Back End of AFRL as example, that developed an open back end processor system, that supports multiple payload front ends.
-

## Action Plan 44

**ID** [Action Plan 44](#) for Business Innovation Initiative (bii), Round 3

**Title** PAYLOAD RIGHTS: What are best license and data rights for OSA-capable payloads (UAVs, other systems) needing connectivity when deployed on LCU-US

**Rating** 1.4 "thumbs up" score (range from 1 to 3) with 11 player votes received, ranking 15 out of 17 plans in Round 3.

**Idea Card Chain Providing Original Motivation** [Idea Card Chain 3745](#) started by player [F. Sharp](#): What are right license & data rights for OSA-capable payloads (UAVs, other systems) needing connectivity when depl USV platform?

**Co-Authors** [p3c me](#), [Spud](#), [Paste](#), [ABWIS](#), [F. Sharp](#), [AllAboutTheData](#)

**Who Is Involved?** NAVSEA, program office, industry proposers for USVs and UAVs. Payload managers and operators.


**What Is It?** What OSA rights are needed for new payloads and unmanned systems that directly interact with OSA platforms?

**What Will It Take?** Exemplars and guidance. Can anyone provide some?

**How Will It Work?** Proper license and data rights package let new OSA payload systems be compatible and competitive. This might be considered "forward compatibility."

**How Will It Change the Situation?** Faster improvements spirals for Navy that can be used by the fleet. Industry has new market opportunities.


**Images** [1](#)



**LCU USV Concept with payload of UU**

Figure 26. Conceptual Depiction of LCU launching/recovering a UUV payload (aft Broadcasting 2014 and NavSource 2014)


<https://mmowgli.nps.edu/bii/images/44/L>



**LCU USV Carrying a Payload of Ship and a Crane**

Conceptual Depiction of of LCU USV wi payload delivery mission of metal shippir FrenchConnections 2014 and Wikimedia

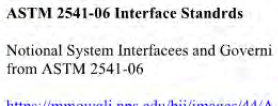
<https://mmowgli.nps.edu/bii/images/44/L>



**Conceptual Depiction of LCU USV tow UU payload**

Conceptual Depiction of LCU USV tow UU payload (after Navsource 2014 and Technology 2014)

<https://mmowgli.nps.edu/bii/images/44/L>



**ASTM 2541-06 Interface Standrds**

Notional System Interfaces and Governi from ASTM 2541-06

<https://mmowgli.nps.edu/bii/images/44/A>

Figure 49. Excerpt (Page 1 of 4) from Bii MMOWGLI Action Plan for Payload Rights (from Naval Postgraduate School (NPS) 2014).

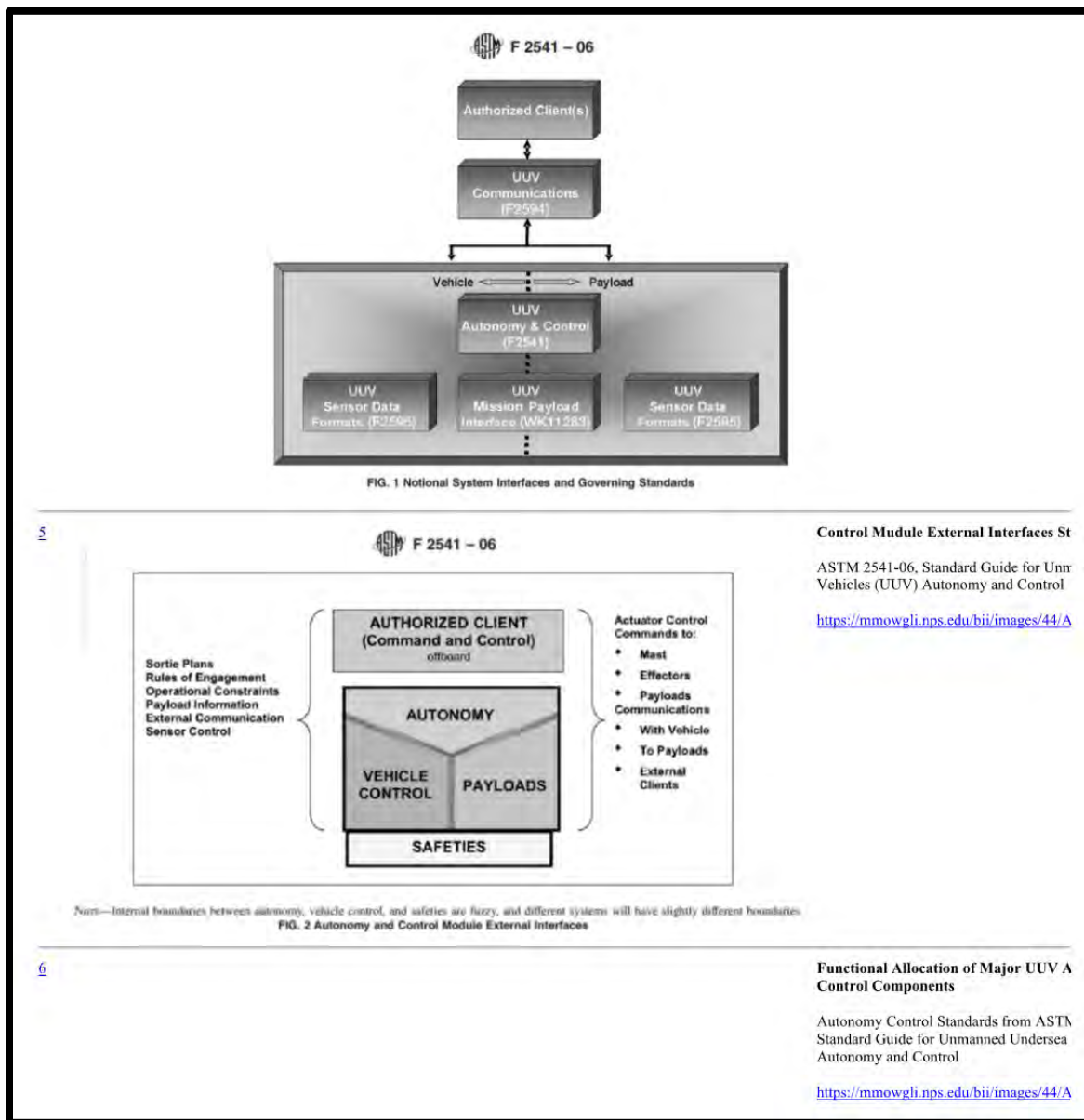


Figure 50. Excerpt (Page 2 of 4) from Bii MMOWGLI Action Plan for Payload Rights (from Naval Postgraduate School (NPS) 2014 and ASTM 2014).



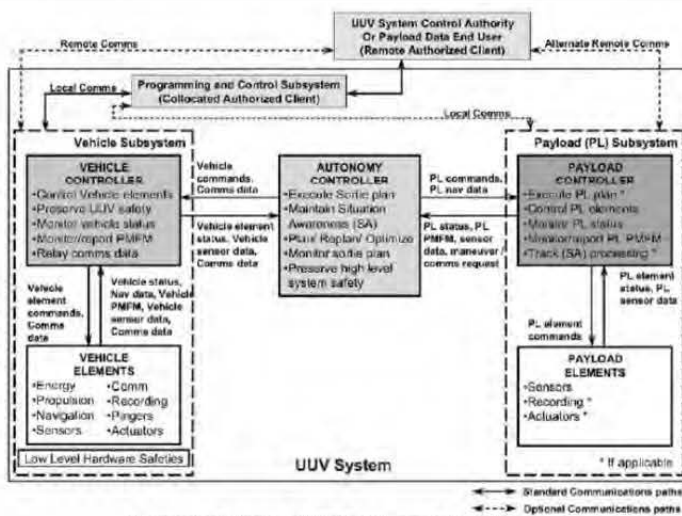


FIG. 3 Functional Allocation of Major UAV Autonomy and Control Components

#### Video



#### US Navy SEALs and Landing Craft Utility Vehicles at White Beach, Okinawa, Japan...HD Stock Footage

US Navy SEALs and Landing Craft Utility Vehicles at White Beach, Japan. The United States Navy Sea, Air and Land forces (Navy SEALs) in Okinawa, Japan. A beach marker yellow and black flag on White Beach 1627 (Landing Craft Utility) Vehicle. Vehicles off load heavy equipment on beachhead. A tank lays a mat on the beach from water edge. Marines walk behind the tank. A mobile crane works on the beach. A heavy duty forklift in the background. Location: Okinawa Ryukyu Islands. Date: June 5, 1970.

Link to order this clip: <http://www.criticalpast.com/video/656750/States-Navy-SEALs-White-Beach-flags-on-the-beach-tank-lays-mat-on-the-beach-Marines-walk-behind-the-tank-A-mobile-crane-works-on-the-beach-A-heavy-duty-forklift-in-the-background-Location-Okinawa-Ryukyu-Islands-Date-June-5-1970>. Visit us at [www.CriticalPast.com](http://www.CriticalPast.com) for broadcast-quality historic clips for immediate download. Fully searchable, the CriticalPast collection is one of the largest archival collections in the world. All clips are licensed royalty-free, world-perpetuity. CriticalPast offers immediate downloads of full-resolution masters and full-resolution time-coded screeners, 24 hours a day, of broadcast news, TV, film, and publishing professionals worldwide images extracted from the vintage footage are also available for immediate download. CriticalPast is your source for imagery of worldwide events spanning the 20th century.

<https://www.youtube.com/watch?v=6Yp5c9y2c6c>

#### Player Comments

- Thursday, 24 July 2014 11:26:41-PDT, Round 3 [gm\\_donb](#): [Author motivation #1] I have an existing legacy Navy boat system that I want to repurpose to be an unmanned boat. In essence install an Open Systems Architecture (OSA) kit/box of systems and components that adds unmanned boat control and another box that adds payload control. The existing, manned control system is essentially split into a Craft Level and an overall System Level. The Craft Level controls, monitoring, automation, etc. of the systems required to run the boat manned/unmanned. This would consist of the engines, generator distribution/control, steering (already discussed), throttle control, ancillary machinery monitoring and control, navigation (already discussed). System Level consists of the brain, cameras, network communications, ground control station, etc. Most of the craft-level systems are government owned. Building on the existing system is the right way to go in terms of cost, schedule, and government ownership perspective. This ensures that the messages are controlled and defined so any third party control system can integrate easily with it. However, some of the system-level components will need to be COTS. If we went with a COTS system chances are the messages are proprietary and would require a Memorandum of Agreement (MOA) with the company (i.e. the steering system company) to release them to the government, if in fact they are. For example, in the current design of some systems, the engineers had to reverse engineer a control system as the company would not release messages. This was mainly because they didn't know what they were, but the Government was told that if they knew them they still would as it was proprietary to their system.
- Thursday, 24 July 2014 11:27:09-PDT, Round 3 [gm\\_donb](#): [Author motivation #2] How do I determine what licenses are needed in order to protect the Government's access to data rights? maintenance, modernization, and design? How do I estimate the reuse feasibility with respect to the level of access to the data rights?

Figure 51. Excerpt (Page 3 of 4) from Bii MMOWGLI Action Plan for Payload Rights (from Naval Postgraduate School (NPS) 2014 and ASTM 2014).

- [3](#) Thursday, 24 July 2014 11:43:23-PDT, Round 3 [gm donb](#): Also see the corresponding [Action Plan 43](#) .
- [4](#) Thursday, 24 July 2014 12:31:36-PDT, Round 3 [ABWIS](#): If the USG negotiates shared IP and data rights upon purchase, it would seem to me that all documentation and technical data would be that package as long as the license payments sustain the life-cycle. Perhaps estimate reuse feasibility against the cost of maintaining the data over the number of years against the cost of replacement or new development in a manner similar to revenue/profit/break-even analyses and lifecycle analyses. It would be interesting to see the results.
- [5](#) Friday, 25 July 2014 11:31:41-PDT, Round 3 [p3c mc](#): Right now, the contractor can retain all rights to proprietary rights to information produced through a program USG paid for. What if the rights are still granted, but only for a fixed time period, as we do with patents? Co A retains rights to all info they produced through the contract, but after the assigned time period, it becomes public domain, allowing others to build from there, and USG can re-compete the program, expand it, re-classify. Classifications would have to be considered, of course.
- [6](#) Saturday, 26 July 2014 11:57:06-PDT, Round 3 [Jacko](#): Suggest looking into data rights structure of MOSA related efforts in other services, MOSA Back End of AFRL as example, that is a back end processor system, that supports multiple payload front ends.
- [7](#) Monday, 28 July 2014 05:41:17-PDT, Round 3 [CynicFan](#): Separating innovation and money is the biggest problem. Contractor/Innovator paid for with Government funds. Comes up with an idea, withholds until intellectual property settled or litigates afterward that it was an independent idea, both of which cost time and funds. Why not a joint license for all items created using Government funds. Government purpose rights to the Government and private sector rights to the contractor for working on the program. Requires upfront listing of all known IP, then everything thereafter is joint licensed. If after 2 years contractor does not develop license development, entire IP goes to Government purpose. If after 2 more years Government doesn't do anything with it, it becomes public domain regardless of security clearance.

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