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Unmanned Low Profile Vessels (ULPVs): "Narco Subs" for Contested Logistics

Capt Sergio A. Sierra, USAF—Student, Naval Postgraduate School. [sergio.sierra@nps.edu]

Abstract

This research explores the potential military application of low-profile vessels (LPVs), also known as semi-submersible vessels (SSVs), commonly referred to as "narco subs," which are extensively used by drug trafficking organizations (DTOs) for transporting illicit goods. LPVs' effectiveness in evading interdiction is attributed to low observable attributes such as their aerodynamic shape, thermal shielding, and ability to ride very low in the water (minimal freeboard). LPVs can be manufactured affordably and quickly thanks to their simple design, easy-to-use building materials, and use of commercial-off-the-shelf (COTS) components. The research explores the concept of unmanned low-profile vessels (ULPVs) as a solution to contested logistics challenges within the U.S. military. This research aims to use modeling and simulation to analyze the idea of ULPVs supporting military logistics, offering insights into design considerations for an affordable, producible, and effective solution to enhance the U.S. military's operational capabilities in a contested environment. In addition, this research intends to create an acquisition strategy for the DoD to leverage the U.S. industrial base, and potentially that of partner nations, to manufacture and field ULPVs affordably and at scale to meet DoD requirements. The final deliverables of this research effort are intended to provide the DoD with a consolidated product to inform decision making on questions regarding the military use of ULPVs.

Keywords: Narco, sub, low profile vessel, vessel, lpv, narco sub, unmanned, ulpv, unmanned low profile vessel, ssv, semi-submersible, ship, boat, design, digital modeling, simulation, contested logistics, logistics, cots, acquisitions, military, attritable, contested environment, usmc, usn, usaf, navy, marine corps, air force, eabo, dmo, ace, materiel, industry, small business, acquisition strategy

Introduction

The prevalent use of low-profile vessels (LPVs), also known as semi-submersible vessels (SSVs), and most referred to as "narco subs," by drug trafficking organizations (DTOs), highlights a potentially advantageous model for a military capability, one largely untapped by the U.S. military. LPVs afford drug traffickers an affordable and effective means to move illicit material around the world, crossing vast distances of open ocean and evading some of the most sophisticated drug interdiction efforts aimed at preventing the successful transit of narco subs. The fundamental nature of LPVs to float minimally above the free surface has contributed to their effectiveness, while the simplicity of their construction and use of commercial off-the-shelf (COTS) technology has contributed to their affordability. Drug traffickers continually fabricate LPVs in the jungles and villages of South America to move their goods affordably and effectively throughout the world. In turn, the DTOs of South America have proven that LPVs are an effective and repeatable model, one that can be adapted to meet U.S. military requirements.

The use cases for LPVs in the U.S. military are likely many; however, an unmanned version of an LPV, an unmanned low-profile vessel (ULPV), may be an ideally suited materiel solution to address contested logistics challenges faced by the Joint force. The simplistic nature of LPV construction means that they can be constructed by a large portion of the U.S. and partner nation industrial bases, as opposed to only large defense industry shipyards. This large pool of potential manufacturers may result in manufacturing innovation and competition, further driving down material costs and introducing the ability to scale said production to high quantities compared to current U.S. shipbuilding capability. In this era of insufficient national shipbuilding capacity (Eckstein, 2024) and naval maintenance and repair backlogs (GAO, 2023), the ability to use alternative industrial sources is an essential requirement for any new approach.

Understanding how ULPVs can support contested logistics will benefit all Department of Defense (DoD) Services as each branch looks for options to maintain a sufficient logistics capability in a contested environment. In addition, understanding the technical and design considerations necessary for a ULPV to meet the requirements of the contested logistics mission, while also remaining affordable and simple enough to support high rates of production, will help inform the design of a desirable ULPV materiel solution to the DoD.

Problem

The problem is that, in the context of a hypothetical conflict with the People's Republic of China (PRC) in the Indo Pacific area of responsibility (AOR), there is a shortfall of logistics vessels to accomplish intra-theater logistics (Martin & Pernin, 2023). In addition, current logistics vessels are vulnerable against projected threats and are likely to be unescorted in a future large conflict (Larter, 2018), thereby negatively impacting projected success rates for vessels to deliver supply at their intended destinations. This capability gap is summarized as a lack of viable intra-theater logistics vessels, assuming an area denial, anti-access (A2AD) threat environment present from various weapon engagement zones (WEZs) from various PRC weapons systems deployed on land, air, and sea.

This matters because the foundation of any military to conduct operations hinges on successful logistics operations that provide the means to conduct military operations. Failure to address the capability gap in survivable intra-theater logistics vessels for military operations in the Indo Pacific will likely lead to a significant decrement in both the capacity and effectiveness of U.S. military operations, resulting in loss to U.S. persons, materiel, and objectives in the AOR.

This also matters because the existence of an intra-theater logistics capability gap undermines U.S. ability to deter military aggression or conflict escalation in the AOR. Rectifying the U.S. military's ability to confidently provide logistical support in a contested environment such as the Indo Pacific is a critical aspect of increasing its capacity for deterrence.

Purpose

The purpose of this research is to inform the design and employment of ULPVs to support military logistics operations in a contested environment like the Indo Pacific. This research also intends to create an acquisition strategy for the DoD to leverage the U.S. industrial base, and potentially that of partner nations, to manufacture and field ULPVs affordably and at scale to meet DoD requirements. The final deliverables of this research effort are intended to provide the DoD with a consolidated product to inform decision making on questions regarding the military use of ULPVs.

Scope

The geographic area of interest for this study begins at mainland China and extends to the expected maximum range of the DF-26B anti-ship ballistic missile WEZ, approximately 4,000km from the coast of mainland China, as depicted in Figure 1. This area contains the places of interest and the relevant distances therein for intra-theater logistics in the Indo Pacific.

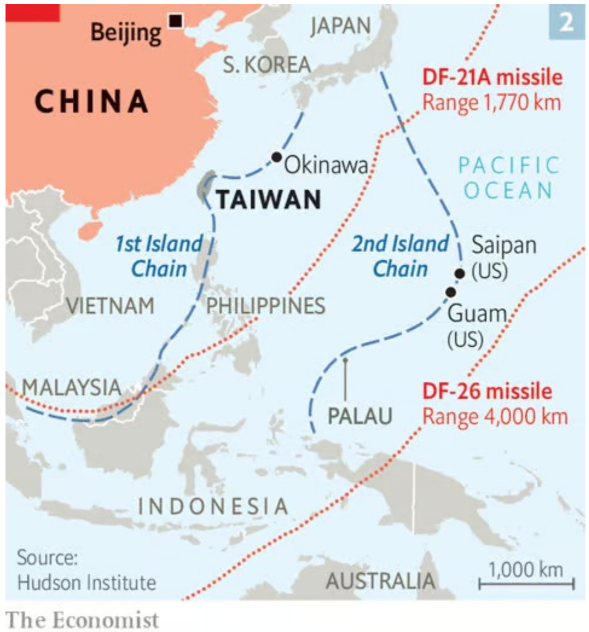

Figure 1. Indo Pacific Area of Interest & PRC Range Rings
("America and China Are Preparing for a War Over Taiwan," 2023)

Each of the services' operational models in the Indo Pacific are expected to be expeditionary in nature, thereby emphasizing forces that are mobile, agile, geographically distributed, and capable of various military operations within contested or potentially contested locations that may be austere or temporary in nature. The expected supply categories and their respective quantities anticipated for U.S. forces to conduct expeditionary operations in the Indo Pacific lay the foundation for the intra-theater logistical requirements. These logistical requirements inform the design of ULPVs intended to fill the AOR's intra-theater logistics capability gap. This study assumes that ULPVs may be designed to move any class of supply except for some specific class VII supply (major end items) that are anticipated to be too large and/or heavy for transport by ULPVs. The ability of a ULPV to carry any type and quantity of supply category is inherently limited by the design and function of the vessel, and as such, this research intends to consider the tradeoffs of notional ULPV designs and the resulting implications on the types and quantities of supply transportable.

This study assumes that ULPVs can complete these logistics functions for any unit of the U.S. military, regardless of service branch affiliation. This study also assumes that supply will need to be moved as break-bulk cargo and possibly include the use of shipping containers (and containers with similar form factors/MHE interfaces as shipping containers; i.e., tank containers) to move supply for military logistics functions.

Narco Subs: A Tool for Drug Trafficking

Drug trafficking organizations (DTOs) use various methods to traffic drugs by air, land, and sea. DTOs have historically innovated new means to traffic drugs as some prove more successful than others and as law enforcement agencies (LEAs) become more aware of and more effective at interdicting trafficking methods. One such innovative method used by DTOs is the use of "narco subs" to traffic drugs by sea. "Narco sub" is a term used to describe the three main categories of narco-vessels: Low Profile Vessels (LPV)/Self-Propelled Semi-Submersibles (SPSS), Submersibles/Fully Submersible Vessels (FSV), and Narco Torpedoes (the towed variety; Ramirez & Bunker, 2015). Most seized drug smuggling vessels to date are LPVs

(Ramirez & Bunker, 2015), and the focus of this research effort is on LPVs. LPVs cost DTOs approximately $1 million to manufacture and are built throughout Colombia and other parts of South America, in makeshift jungle boatyards (Figure 2), and in 30 to 45 days' time (VICE, 2011).

Figure 2. LPV Boatyard in Colombian Jungle
("The Archaeology of 'Narco Subs,'" 2020)

LPVs can carry up to 10 tons of drugs (Ramirez & Bunker, 2015) and can travel between 3,000 to 3,500 NM (VICE, 2011). In 2019, the first known trans-Atlantic crossing of a narco sub occurred when a 70ft LPV, carrying nearly 7,000lb of cocaine, made a 3,500-mile journey from Brazil to Spain (Figure 3) over a 27-day period (Jones, 2022). These vessels usually carry four crew members who make their voyage in very poor conditions, typically in a small aft space of the vessel that is hot, poorly ventilated, without a bathroom, and with makeshift bunking space (such as on top of fuel tanks; VICE, 2011).

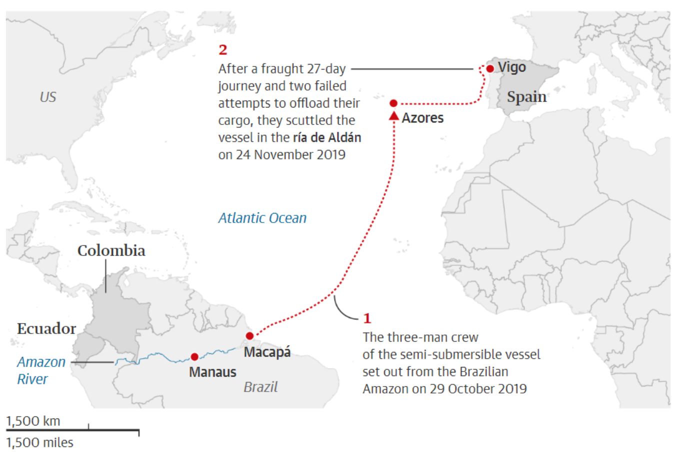

Figure 3. Trans-Atlantic Narco-Sub Journey
(Jones, 2022)

Generally, LPVs are difficult to detect as they are nearly impossible to spot from the horizon and very difficult to detect by radar (VICE, 2011). The low observable attribute of LPVs results from various design features such as the vessel: having minimal features on the deck, being aerodynamic in shape, riding very low in the water (minimal freeboard), using thermal shielding, being built of fiberglass, and being painted in a dark color that blends with the ocean surface (Figure 4; VICE, 2011).

Figure 4. View of Low-Profile Vessel Operating
(Sutton, 2021)

According to the Colombian Navy, however, one method of easily detecting LPVs, despite their lack of visible wake, is by spotting them from the air with an aircraft (VICE, 2011). A 2014 account by U.S. Navy CAPT Mark F. Morris supported the need for aircraft utilization to achieve favorable LPV detection probability, stating:

> American operations analysis shows that given good intelligence of a drug event and a patrol box of a certain length and width, a surface vessel operating alone has only a 5% probability of detecting (PD) that event. A surface vessel with an embarked helicopter increases the PD to 30%, and by adding a Maritime Patrol Aircraft to the mix, the PD goes up to 70%. Analysis by the Colombian Navy shows that adding one of their submarines to the mix raises the PD to 90%. (Ramirez & Bunker, 2015)

The U.S. Drug Enforcement Administration has considered that only about 20% of narco subs are intercepted (Ramirez & Bunker, 2015). In a 2014 testimony to Congress, U.S. Southern Command (SOUTHCOM) reported that low interdiction rates were due to asset shortfalls (Ramirez & Bunker, 2015), presumably resulting in an inadequate number of vessels and aircraft able to conduct maritime interdiction missions against LPVs. Most narco subs have been found in the SOUTHCOM area of responsibility (AOR), with 78% being found in the Pacific (in waters near South and Central America) and 20% being found in the Caribbean (Ramirez & Bunker, 2015). As a result, most LPV interdiction data exists in an environment where LEAs are under-resourced, according to the 2014 SOUTHCOM testimony to Congress, resulting in uncertainty at how effective LPVs are at avoiding detection and interdiction in an environment where they are hunted with more numerous resources.

For DTOs, the business model of LPV fabrication and operation is the result of a cost-benefit analysis where the yielded benefits are far superior to the costs associated with building and operating LPVs (Ramirez & Bunker, 2015). A 10-ton cargo of narcotics may be worth approximately $200 million (Ramirez & Bunker, 2015), minus the $1 million construction cost of the LPV, which leaves a $199 million profit per successful LPV voyage. Factoring in a loss rate of 20%, based on the previously mentioned LPV interdiction rate, results in an average profit per

LPV voyage of approximately $159 million. This calculation assumes a full 10-ton cargo on every LPV voyage as well as a constant interdiction rate of 20%; however, it serves to highlight the superior benefit over the cost of LPV fabrication and operation, resulting in the continued DTO use of LPVs for drug trafficking.

The Appeal of LPVs for Contested Logistics

In a foreword to *Beans, Bullets, and Black Oil*, former Secretary of the Navy Dan A. Kimball highlighted the criticality of logistics to the fight against the Japanese Empire in World War II, saying:

> Victory is won or lost in battle, but all military history shows that adequate logistic support is essential to the winning of battles. In World War II, logistic support of the fleet in the Pacific became a problem of such magnitude and diversity, as well as vital necessity, that all operations against Japan hinged upon it. (Carter, 1998)

Given the success that DTOs experience trafficking drugs with LPVs, it is fair to question if a vessel like an LPV could be used in a military logistics role for the DoD. This question exists at a time when the United States prepares for a possible conflict in the Indo Pacific between China and Taiwan, at a time when the commander of the U.S. Pacific Fleet warned of an insufficient Combat Logistics Force (Katz, 2024). Wargames indicate that U.S. logistics vessels will be sought after by any adversary (Katz, 2024), and past exchanges with Chinese naval leadership indicate that these vessels will be primary targets in a U.S.–China conflict (Suciu, 2020). Joint U.S. forces will require sustainment to effectively fight a war in the Indo Pacific, and that sustainment must ensure support that flows from the United States to the point where U.S. Transportation Command delivers supplies and further to the point where frontline forces receive supplies (Martin & Pernin, 2023). The logistics supply chain in this case spans the geographic distances between factories within the continental United States to military forces staged throughout the Indo Pacific. Martin and Pernin (2022) highlight that the most particularly concerning stretch of the logistics map from the United States to the frontlines of the Indo Pacific is the part known as intra-theater lift, “the portion of the transportation chain that delivers materiel from a port of debarkation to the point of use by an operational unit.”

Although individual services have capabilities to meet a portion of their intra-theater transportation demands, when combined, they do not meet all needs of the joint force (Martin & Pernin, 2023). In addition to the sheer quantity of supply that would need to be transported across large distances over water, a fight in the Indo Pacific would leave U.S. logistics vessels to contend with growing anti-access/area denial (A2/AD) capabilities of the PRC. These PRC capabilities span air, land, and sea, and leverage various missiles of growing quantity and capability intended to impose maximum attrition to slow and impede any adversarial military operations (Joshi, 2019). PRC A2/AD capabilities would envelop the entirety of what will be the intra-theater logistics operating area for a U.S. military operation in the Indo Pacific (Joshi, 2019). Because logistics operations are expected to take place in contested environments, and because the DoD lacks the logistics forces to support a large military campaign in the Indo Pacific, the need for new materiel solutions to accomplish contested logistics missions has arisen (Mills & Limpaecher, 2020).

One thought to help address the capability gap in intra-theater contested logistics is to apply the DTO model of LPVs to U.S. military logistics, perhaps even in an unmanned capacity (Mills & Limpaecher, 2020). Narco-sub–like vessels such as LPVs are thought of as a prospective materiel solution to provide logistics support to the USMC’s expeditionary advanced base operations (EABO; Mills et al., 2020) or to Taiwan in the event of a Taiwan conflict (Griffin, 2024). A U.S. unmanned low-profile vessel (ULPV) may be able to leverage the low observable benefits that make DTO-operated LPVs difficult to detect and interdict but without the need of a crew and subjecting that crew to the conditions and risks associated with an LPV operating in the waters of the Indo Pacific under the PRC's A2/AD threat bubble.

DTO LPV Design Themes

There are a few key design themes that arise from DTO LPVs that are foundational to the success of the drug trafficking LPV model. These design themes are design simplicity, design for mission needs, and design for asset attritability. Narco subs evolved over decades, beginning in the early 1990s with experimentation, through the early 2000s with prototyping, and continuing from 2007 to the present with design standardization and maturation (Ramirez & Bunker, 2015). One similarity among photos of all captured or interdicted narco subs is the simplicity of design that they all share (Ramirez & Bunker, 2015). Shaping wood and fiberglass into a functional LPV within 30 to 45 days, using local unskilled labor (VICE, 2011), in the jungles of Colombia is possible because of simple vessel design. Perhaps assisting the rapid LPV manufacture timeline is what Ramirez & Bunker (2015) indicate, that DTOs use readily available commercial off-the-shelf (COTS) components for the engines, navigation systems, and communications systems for their LPVs. The interiors of these LPVs further highlight their design simplicity, with little to no accommodations made for the crew and the sole focus on mission needs like cargo carrying capacity (large cargo holds) and vessel range (large fuel tanks), with neither compromised to carve out space for the crew (Figure 5). In a sense, DTOs have created a minimal viable product (MVP) to accomplish maritime drug trafficking at the lowest possible cost and highest possible benefit.

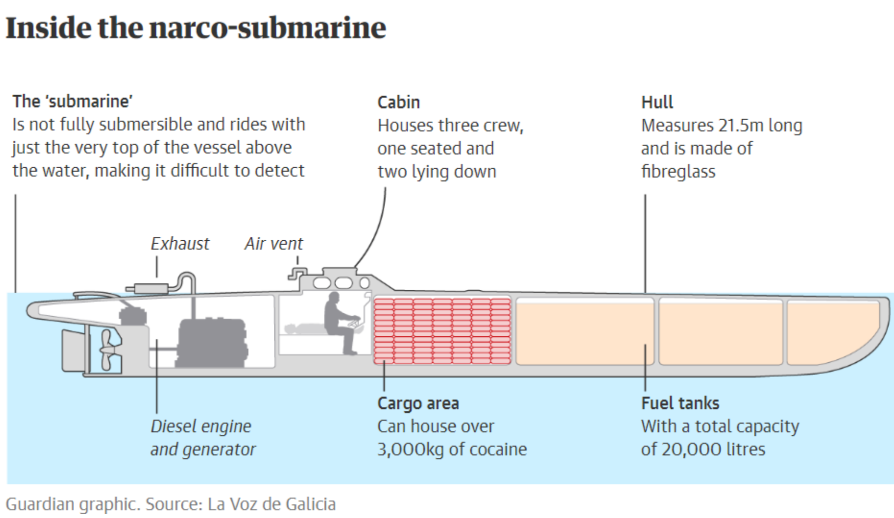

Figure 5. Cutaway of LPV Highlighting Crew, Cargo, Engine, and Fuel Spaces
(Jones, 2022)

In addition to design simplicity, LPVs appear tailor-designed for their mission needs. As LPVs have evolved over time, their design has become more aerodynamic, they have less piping on the hull, they run awash or with less freeboard, they incorporate lead shielding, and they use seawater to cool exhaust gases, all to decrease the probability of detection by counter-drug operation by LEAs (VICE, 2011). While the hulls have become more aerodynamic and larger in size, their shapes continue to remain like a sealed 'go-fast' boat with a deep V-shaped hull, sufficient for the sea states they operate in (Ramirez & Bunker, 2015). Within the confines of this hull design, maximum space is afforded for cargo and fuel capacity. Loading and unloading the LPVs is accomplished through a simple single hatch on the vessel, by hand, and either at dock or at sea (VICE, 2011).

One additional theme to highlight is the inherent attritable nature of LPVs manufactured and operated by DTOs. These LPVs include a scuttle valve that floods the hull if activated by the crew (VICE, 2011), and it is used often in LPV interdictions to prevent LEAs from obtaining criminal evidence (Ramirez & Bunker, 2015). Even if the LPV reaches its destination and successfully unloads its cargo, LPVs are typically scuttled rather than reused (VICE, 2011). Since LPVs are typically only valued at 2–3% the value of the cargo they carry, they are viewed as expendable (VICE, 2011).

It is also worth noting that DTO LPV designs are unbounded by regulations on maritime transport, such as those governed by the International Maritime Organization (IMO; n.d.). The IMO sets standards for the safety, security, and environmental performance of international shipping (IMO, n.d.), and it is likely that the acquisition process for any sort of LPV or ULPV by the DoD would need to comply with maritime specifications, standards, and laws for vessel design, construction, and operation, all factors that are not concerning to DTOs.

Considerations for ULPVs in the DoD

The question at hand is how the DoD could best adopt the DTO LPV model and evolve it to an unmanned asset that can accomplish logistics operations for the joint force in a contested environment. Helpful to addressing this question is framing it within the context of an operational area where ULPVs may be utilized, such as the Indo Pacific in a notional conflict with the PRC. The following subject areas are an overview of several key considerations that the DoD should consider for the design and operation of ULPVs in the Indo Pacific.

Initial Thoughts: Vessel Design

LPVs are immersed more than standard surface vessels; however, maintaining a minimal freeboard and proximity to the free-surface allows LPVs to use low-cost combustion engines while also negating the need for costly pressure vessels, submarine control surfaces, and other mechanisms necessary for a vessel that operates fully submerged (Sung et al., 2022). Initial analysis indicates that LPVs have increased stability with more slender hull shapes (Sung et al., 2022), and a review of DTO LPVs shows a trend toward increasingly slender vessels over time (Sutton, 2020).

It is important to consider the differences in sea conditions, or sea states, that exist between the waters where DTOs operate versus the waters of the Indo Pacific. As there is little to no data on how LPVs would perform in the sea states of the Indo Pacific, some initial research has been done on semi-submersible vessels (SSVs) which can be applied to LPVs. Initial research at the U.S. Naval Academy indicates that LPV hydrodynamic performance would be very sensitive to the forces of surface waves and that more extensive testing is needed (Sung et al., 2023). Further findings include increased resistance, due to increased hydrodynamic drag, experienced with a hull operating more immersed (Sung et al., 2023), likely equating to a need for greater power requirements than traditional surface vessels to attain a similar operating speed.

In addition to hydrodynamic considerations, most of which require further research for DoD adoption of SSVs (and LPVs; Sung et al., 2023), LPV design should also consider the material choice for fabrication as well as the complexity of the vessel design. As previously discussed, drug trafficking LPVs are typically made of wood and fiberglass. These materials are more affordable and easier to build with compared to metal, requiring less skilled labor or specialized machinery. In addition, these materials are harder to detect with radar than metal is. In the context of military conflict, these materials may be advantageous to help defeat threats that ULPVs encounter in the waters of the Indo-Pacific. Maintaining a vessel design that is simple and with as few extra features or building steps as possible will allow the DoD to follow the DTO LPV model of minimal cost, thereby driving towards a design that is both affordable and able to be rapidly built, increasing the chance of the ULPV being considered attritable.

Finally, it should be kept in mind how the vessel is intended to be loaded, unloaded, and interfaced with by people and other vessels or equipment. For a vessel with the primary mission of transporting supply for logistics, it is paramount that the vessel be designed with the operational environment in mind. For example, if the ULPV needs to resupply Marines operating on expeditionary advanced bases (EABs) in the Indo Pacific and the island EAB location does not have a pier, then it should be considered if the ULPV needs to be able to beach or if the Marines will have to retrieve the supply by other means. If the ULPV needs to be able to beach, it must be able to make its way through the shallow, and often reef- and rock-strewn, water of islands in the Indo Pacific. This requires a vessel with a shallow draft, a hull attribute poorly suited for transiting rough sea states over large distances. DTO LPVs do not have a shallow draft hull; then again, DTO LPVs typically load and unload at sea or pier side. It should also be considered how supply will be loaded onto and off the ULPV, either by crane, roll-on/roll-off, by hand, or otherwise.

Other Considerations Being Researched

This research effort is exploring various other considerations for ULPVs in the DoD in addition to the few mentioned above. The final report on this effort will include greater detail on all of the aforementioned areas. Other considerations that will be included in the final report include but are not limited to vessel performance, autonomy, supply types, vessel loading, vessel unloading, vessel interdiction and tampering, external communications, positioning, navigation, and timing (PNT), and command and control (C2).

Possible ULPV Designs

This research is aware of multiple designs for ULPVs that will be analyzed. One such design, from CDR Todd Greene at the U.S. Naval Academy, is called the NightTrain (Greene, 2023). NightTrain is an innovative ULPV concept with a unique design to ferry shipping containers across large distances, proposing to move supply from the factory to the frontlines (Greene, 2023). Other ULPV designs resemble DTO LPVs, only without the need for a crew. Estimated performance parameters of these designs will be utilized in this research's modeling and simulation efforts to provide expected performance parameters, such as a design's probability of detection.

Modeling & Simulation

Part of this research aims to use modeling and simulation to help inform relatively unknown aspects concerning the idea of ULPVs for military contested logistics. One aspect of analysis seeks to understand the probability of detection and susceptibility of ULPVs operating in the Indo Pacific against threats from the PRC. Another aspect of analysis seeks to understand the impact of ULPVs on maintaining a steady level of supply for expeditionary units, such as Marines operating on EABs during a conflict with the PRC. Yet another aspect of analysis will incorporate virtual sandboxing via a virtual sand table (VST) to visually depict ULPV employment and collect data to inform potentially new considerations for ULPVs.

Next Generation Threat System (NGTS)

"NGTS is a military simulation environment produced by the Naval Air Warfare Center Aircraft Division (NAWCAD) that provides real-time military scenario simulations. NGTS models threat and friendly aircraft, ground, surface, subsurface platforms, corresponding weapons and subsystems, and interactions in a theater environment" (Tryhorn et al., 2023). NGTS modeling and simulation work in this research is a collaborative effort between the Naval Postgraduate School and the Naval Information Warfare Center Pacific (NIWC Pacific).

NGTS will be used to simulate the performance of ULPVs in a contested environment, specifically, the ability of ULPVs to transit a body of water shared by various types and quantities of PRC surface and airborne assets without being detected or destroyed. NGTS will be used to simulate two types of environments in the contested space making up intra-theater lift, open water ("blue" water) transit and littoral transit, as the type and quantity of PRC assets encountered in each environment are likely to be different. Many cycles of NGTS simulations will run to output data on a ULPV's probability of detection in an Indo Pacific conflict. As ULPVs are assumed to be unarmed in this research, their greatest chance of successfully completing logistics missions in a contested battlespace may rely on remaining undetected.

NGTS Assumptions & Limitations

Some assumptions and limitations are made in the NGTS simulation. First, the data used to create the performance parameters for all red team (PRC) assets is based on unclassified, open-source information. Second, the performance parameters of blue force (U.S.) logistics vessels are either based on open-source information or estimated based on similar existing vessel parameters (such as parameters of DTO LPVs to inform some ULPV parameters). Third, the type and kind of red force assets present in each of the operational environments (blue water and littoral) are best estimates based on open-source information of PLA order of battle data. Other NGTS assumptions and limitations will be documented as this research's modeling and simulation effort progresses.

Causal Loop Diagram

The NGTS modeling and simulation work will inform ULPV probability of detection given specific red force (PRC) capabilities based on various asset types and quantities. The probability of detection data output from the NGTS simulation runs will then be input into a causal loop diagram (CLD) to simulate the larger interaction of variables concerning ULPVs maintaining a level of supply at an expeditionary base location. "Causal loops diagrams (also known as system thinking diagrams) are used to display the behavior of cause and effect from a system's standpoint. A CLD is a causal diagram that aids in visualizing how different variables in a system are interrelated" (Barbrook-Johnson & Penn, 2022). According to Barbrook-Johnson and Penn (2022),

> CLD are made up of connections, or edges, which represent causal influence from one node to the other; either positive (i.e. they increase or decrease together) or negative (i.e. they change in opposite directions, if one goes up, the other goes down, and vice versa). The maps always show and focus on feedback loops, both in the construction of the map and in its visualization. Loops are made conspicuous by the use of curved arrows to create circles.

This research effort will use the following CLD (Figure 6) or a version of it (as this research is still ongoing and the following CLD is still a work in-progress) to analyze the impact of ULPVs on maintaining a steady level of supply for expeditionary units. The following CLD is a draft, working product.

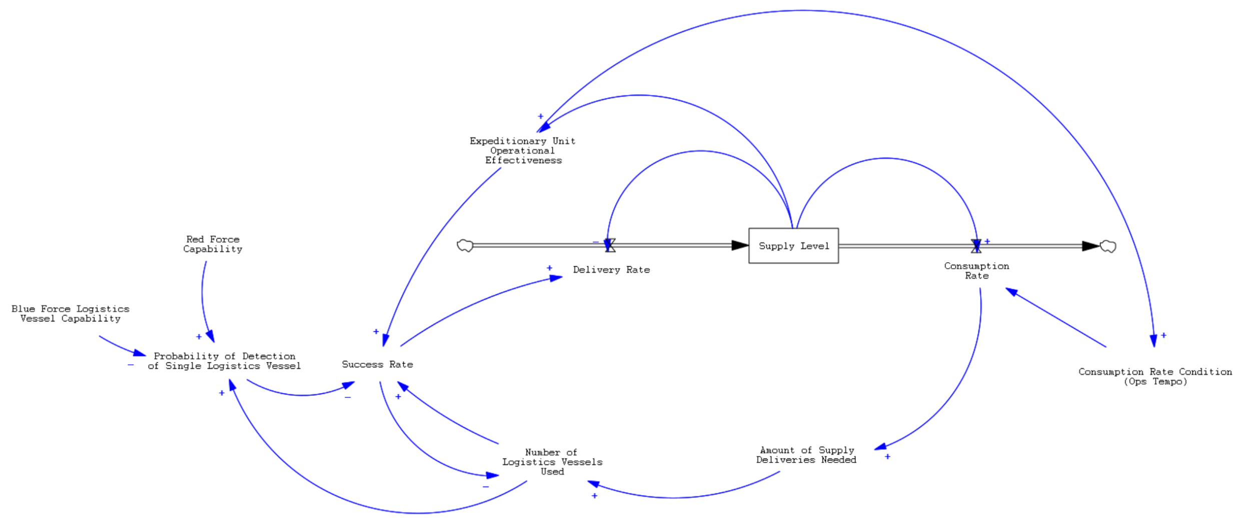

Figure 6. Causal Loop Diagram for Contested Logistics and Expeditionary Unit Resupply

Model Variable Definitions Listed below are definitions of the variables being utilized in this research effort's modeling and simulation:

- Blue Force Logistics Vessel Capability: The collective attributes of the blue force (U.S.) logistics vessel in question contributing to its detectable signature.
- Red Force Capability: The collective attributes of the red force (PRC) assets (surface vessels and airborne craft) resulting from the type and quantity of red force assets attempting to detect and destroy blue force logistics vessels.
- Probability of Detection of Single Logistics Vessel: Probability that the logistics vessel in question will be detected by red force assets.
- Success Rate: Probability that the logistics vessel in question will not be detected, interdicted, or destroyed by the red force and will therefore reach its delivery destination.
- Delivery Rate: The number of deliveries per measure of time.
- Expeditionary Unit Operational Effectiveness: The ability of an expeditionary unit to support its own needs to maintain unit health, readiness, and the ability to successfully complete any tasked mission.
- Supply Level: The amount of various supply classes that must be maintained at an operational unit to support that unit's health, readiness, and ability to successfully complete any tasked mission.
- Consumption Rate: The amount of supply consumed per measure of time.
- Consumption Rate Condition (Ops Tempo): The influence exerted on the consumption rate given the level of operational activity intensity at a point in time.
- Amount of Supply Deliveries Needed: Quantity of resupply missions required (based on supply capacity of logistics vessel in question) to replenish supply level at expeditionary unit.
- Number of Logistics Vessels Used: Quantity of logistics vessels utilized to resupply expeditionary unit.

CLD Assumptions & Limitations Some assumptions and limitations are made in this CLD. First, the logistics vessels in question will be unarmed and defenseless. Second, logistics vessels will carry supplies that are of equal type and proportional quantity necessary to maintain the total supply level stock at the expeditionary unit. Other CLD assumptions and limitations will be documented as this research's modeling and simulation effort progresses.

ULPV Specific CLD: ULPV System Performance & Expeditionary Unit Resupply
The previous CLD illustrates the conceptual interactions between a logistics vessel, the red forces, and the expeditionary unit supply level. However, in the case of a fully unmanned system such as a ULPV, additional factors would play into the CLD to illustrate the need for the ULPV as a series of systems to perform as desired. The resulting desired system performance would then be a variable, in addition to the probability of detection, impacting the success rate of the vessel. In addition, a presumed reliance on external connectivity between the ULPV and any logistics command and control structure would introduce another series of variables that contribute to the desired system performance as well as the vessel's RF signature.

This research effort may/may not pursue simulation of a CLD specific to a ULPV. However, it is useful to see the possible interactions between CLD variables specific to a ULPV. Below (Figure 7) is a draft, working version of a possible ULPV CLD.

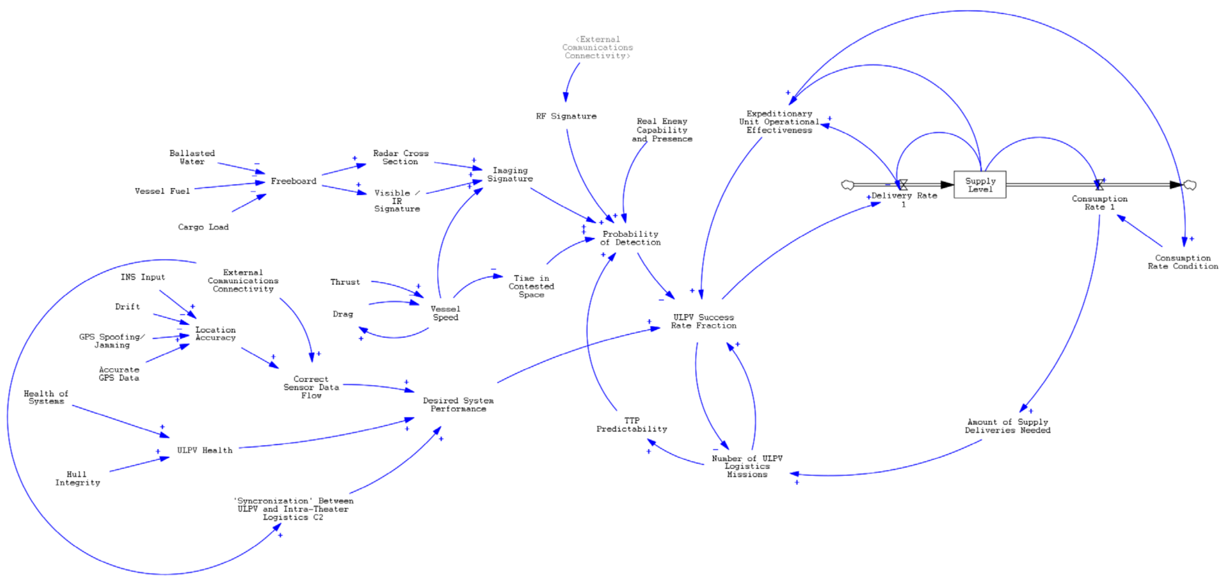

Figure 7. ULPV Specific Causal Loop Diagram for Contested Logistics and Expeditionary Unit Resupply

Virtual Sandboxing

The Modeling Virtual Environments and Simulation (MOVES) Institute at the Naval Postgraduate School has a virtual sand table (VST; Figure 8) that will be utilized with 3D printed models of notional ULPVs to visually depict ULPV employment on real-world projected locations. This process will enable data collection to inform potentially new considerations for ULPV design and employment. 3D models used in SPIDERS3D are produced from a variety of sources, then converted (if necessary) to X3D for mashup composition and Web-based collaborative visualization. Extensible 3D (X3D) Graphics is the international standard for publishing interactive 3D models on the Web (Brutzman & Daly, 2007). More information is available at https://www.web3d.org/x3d/what-x3d.

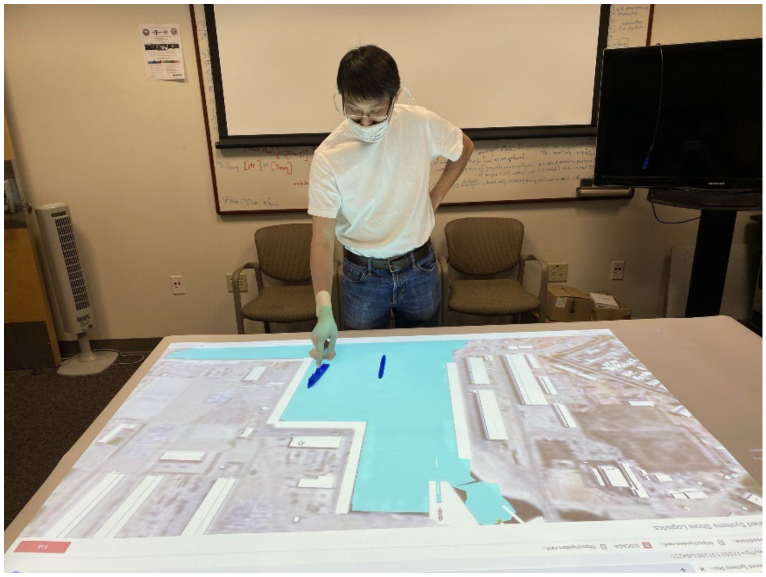

Figure 8. Demonstration of Virtual Sand Table at NPS
(EXWC SPIDERS3D, 2021)

ULPV Acquisition

In addition to the documenting design and employment considerations of ULPVs to support military logistics operations in a contested environment, this research also intends to create an acquisition strategy for the DoD to leverage the U.S. industrial base, and potentially that of partner nations, to manufacture and field ULPVs affordably and at scale to meet DoD requirements. This acquisition strategy will consider all LPV design considerations and lessons learned from DTO LPV operations as well as findings from this research's modeling and simulation efforts.

Considerations for ULPV Production

This research also intends to analyze various considerations to producing ULPVs, especially those expected to impact vessel cost and vessel production time, as part of an overarching intent to analyze the ULPV's ability to be used as a surgable, sustainable, and attritable materiel solution in support of national defense responsibilities to deter, de-escalate, and defeat. One interesting consideration for ULPV production is the prospect of leveraging small businesses and boatyards throughout the United States, vice shipyards, given the insufficient national shipyard capacity (Eckstein, 2024) that may be unlikely to meet production demands of a new line of vessels such as ULPVs. There may exist a relationship between ship design simplicity, COTS component utilization, and material choices that result in a level of production complexity not outside the capability of many small businesses and boatyards throughout the United States. Further, ULPV designs and their respective production complexities may or may not easily support production of ULPVs in host or partner nations throughout the Indo Pacific. The ability to produce ULPVs within the theater of conflict would save the use of copious resources needed to transport these vessels into theater. The analysis of this research intends to inform the ease with which ULPVs may be produced in the Indo Pacific.

Closing Thoughts

ULPVs may provide the DoD long-term stabilization value during an era of grey-zone competition and military conflict. Having a contested logistics capacity to provide indefinite logistics resupply across first and second island chains in the Indo Pacific provides paths for de-escalation back to deterrence, rather than unchecked escalation to conflict. The Liberty Ship program of World War II proved critical to the war's outcome (Herman, 2012). Liberty Ships overcame attrition by German U-Boats in the contested waters of the Atlantic. Many lessons learned from the design and production of Liberty Ships can similarly inform the design and production of ULPVs to overcome threats in the contested waters of the Indo Pacific. Some applicable lessons learned include utilizing principles of standardization and methods of mass production (Lane, 1951, pp. 31, 72) as well as the use of machine tools and prefabrication (Herman, 2012). These same lessons were applied with great success by Andrew Higgins in 1942 (Lane, 1951, p. 185), resulting in the design and mass production of "Higgins boats," tens of thousands of which were shallow-draft landing craft made of wood and steel for amphibious assaults in the Indo Pacific (Strahan, 1994). The geography of the Indo Pacific since World War II remains very similar today, and applying lessons learned from vessels designed, produced, and employed during World War II may prove beneficial to inform ULPV design, production, and employment for the DoD today.

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Department of Defense Management
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