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MONTEREY, CALIFORNIA

SYSTEMS ENGINEERING CAPSTONE REPORT

TORPEDO RECOVERY VEHICLE SUNSET AND REPLACEMENT

by

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June 2019

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TORPEDO RECOVERY VEHICLE SUNSET AND REPLACEMENT

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ABSTRACT

This capstone report presents an analysis of alternatives (AoA) for the sunset and replacement of the TWR-841 (Torpedo Weapon Retriever) currently in service at the Narragansett Bay Test Facility (NBTF) at the Naval Undersea Warfare Center, Division Newport (NUWCDIVNPT). The analysis follows a systems engineering approach to define the problem space, generate requirements, generate alternatives, and analyze the proposed solutions. A Design Reference Mission (DRM) defines the current capabilities and operations of the TWR-841 and similar vessels. Operational and system requirements are then derived from this DRM to describe the capabilities required for a replacement. Three primary categories of alternatives were identified, including procurement of a new vessel, procurement and modification of an operational ship, and contracting of currently fielded vessels for operations. The performance of each alternative was compared against the defined requirements to identify overall performance of each vessel. A life-cycle cost estimate including procurement and operations and sustainment for each alternative is presented. This study found that the contracting-as-a-service option was the most cost-effective alternative. Of the contracting options, the M/V GO America was the most economically viable option for the NBTF, meeting the system requirements for the lowest price.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIS	Automatic Identification System
AoA	analysis of alternatives
ARPA	automatic radar plotting aid
ASW	anti-submarine warfare
AUTEC	Atlantic Undersea Test and Evaluation Center
AUV	autonomous underwater vehicle
CAPE	Cost Assessment and Program Evaluation
CBS	cost breakdown structure
DRM	design reference mission
DRMO	Defense Reutilization and Marketing Office
FMS	foreign military sales
GSA	Government Service Administration
HF	high frequency
INSURV	Board of Inspection and Survey
LCC	life-cycle costs
LCCE	life-cycle cost estimate
MPC	Multi-Purpose Craft
M/V	motor vessel
NAVSEA	Naval Sea Systems Command
NBTF	Narragansett Bay Test Facility
NGWR	Next-Generation Weapons Retriever
NOAA	National Oceanographic and Atmospheric Administration
NSSC	Naval Submarine Support Command
NSTM	Naval Ships Technical Manual
NUWC	Naval Undersea Warfare Center
O&S	operations and sustainment
OSV	off-shore support vessel
PEO	Program Executive Office

PMRF	Pacific Missile Range Facility
PMS	planned maintenance system
PPE	personal protective equipment
RHIB	rigid hull inflatable boat
ROV	remotely operated vehicle
R/V	research vessel
SCN	Shipbuilding and Conversion, Navy
SLEP	service life extension program
SOTDMA	self-organizing time division multiple access
SSB	single sideband
SVTT	surface vessel torpedo tube
SWATS	Shallow Water Acoustic Tracking System
T&E	test and evaluation
TTL	torpedo tube launch
TWR	Torpedo Weapons Retriever
UHF	ultra-high frequency
USNSCS	United States Naval Sea Cadet Ship
UUV	unmanned underwater vehicle
VHF	very high frequency

EXECUTIVE SUMMARY

Ever since the inclusion of the torpedo into its arsenal, the United States Navy has required a means of exercising and recovering torpedoes for fleet training and asset acceptance. The TWR-841 (Torpedo Weapons Retriever) was designed to fill the capability to locate, isolate, and retrieve test torpedoes in an open water environment. The Narragansett Bay Test Facility (NBTF) at the Naval Undersea Warfare Center (NUWC) in Newport, Rhode Island uses the TWR-841 for the launching, testing, and retrieval of underwater systems. TWR-841 has now entered its fourth decade of service and is nearing the end of its useful life. The NBTF is the primary location for in-water testing involving torpedoes for NUWC, and the operational age of TWR-841 is starting to affect the Navy's ability to field test torpedo systems.

A new vessel is required to replace the existing system before it is no longer operational. In May 2016, the Navy's Board of Inspection and Survey released a Structural Inspection Report on USNS TWR-841. The report found 11 of the 14 inspected spaces need repair and eight of the 11 at a critical level (Board of Inspection and Survey 2016). The TWR-841 is reaching mechanical and technological obsolescence. Without substantial maintenance and upgrades to its current systems, the vessel will lose operational suitability.

The operational requirements of the TWR-841 have also changed over time, and a replacement will be required not only to retain its capabilities but also adapt to ever-changing missions and payloads requiring testing. The dramatic rise of autonomous vehicles in the undersea domain requires the testing of new types of payloads in similar environments. Having flexibility in one vessel to conduct multiple types of operational profiles will be critical for the success of the NBTF.

TWR-841 and similar vessels currently fielded in other test locations were used to derive mission capability requirements. A Design Reference Mission (DRM) was developed by the Team to refine the system and functional requirements around current capability gaps and mission profiles. Several top-level requirements and their

corresponding derived requirements were generated from this DRM. The Team used these requirements to compare and verify proposed alternatives for the TWR-841 replacement.

Using the overall mission requirements defined in the DRM, this capstone report team proposed a list of alternatives to the current TWR-841 that satisfied the identified requirements for the Next-Generation Weapons Retriever (NGWR). These alternatives included the fabrication of a new vessel, the transfer and modification of an existing vessel already in service, or contracting specific mission sets out to vendors in the local area.

The Team conducted an analysis of alternatives (AoA) on the proposed solutions evaluating each option on the following:

- initial date of operation for the NGWR
- degree to which the NGWR meets flexible payload support requirements
- degree to which the NGWR meets base performance requirements
- degree to which the NGWR meets habitability requirements
- degree to which the NGWR meets operational and environmental requirements
- degree to which the NGWR meets availability requirements

Analysis of each choice was conducted to identify how each system performed based on these metrics. Once the ratings were completed for each measure, we documented and compared against each other using a Pugh Matrix. A life-cycle cost estimate was prepared for each alternative comparing both procurement and operations and sustainment (O&S) costs. The final analysis compared the rated performance of each alternative against its cost to identify the most cost-effective solution.

For procurement alternatives, the R/V Sally Ride was eliminated due to substantial up-front acquisition cost, which exceeded the allowable budget of the NBTF. The Single-Screw Trawler was the cheapest option, but it did not meet many system requirements, even with modification. It was therefore eliminated as a feasible option.

The AoA determined that the contracting-as-a-service option was the most cost-effective solution for the NBTF based on historical utilization rates. For the contracting options, the M/V GO America provided the most value, meeting all system requirements with the exception of an aft ramp and rollers, while being the cheapest option. From research conducted for vessel alternatives, it was discovered that an aft end ramp and rollers is a unique feature, and is not included in the vast majority of similar types of vessels. If an aft ramp with rollers is a required capability for any NGWR alternative, the MPC meets most additional system requirements at a lower price than the other remaining alternatives. Of the procurement alternatives, the Deep Sea Research Vessel provided high performance for a reasonable cost, while lowering the maintenance required due to it being a new vessel.

Reference

Board of Inspection and Survey. 2016. *INSURV Structural Inspection Report Hull/Deck Team: USNS TWR 841*. Virginia Beach, VA. Naval Sea Systems Command.

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I. INTRODUCTION

The United States Navy (USN) maintains a capability to locate, isolate, and retrieve test torpedoes and other equipment such as unmanned underwater vehicles (UUVs) in an open ocean environment. This capability requires in-water testing to determine operational suitability of remote systems. The Narragansett Bay Test Facility's (NBTF) current Torpedo Weapons Retriever (TWR), TWR-841, is the primary vessel used for retrieval of underwater systems and the largest in use designed explicitly for the torpedo recovery mission. TWR-841 has now entered its fourth decade of service and is nearing the end of its useful life. To date, there has been no analysis for an extension or replacement of the TWR-841. Failing to refurbish or replace TWR-841 will affect the U.S. Navy's ability to field test new torpedo and UUV systems.

A. BACKGROUND

TWRs were initially designed to perform launch and recovery missions facilitating in-water test and development of torpedo systems. This requirement has evolved over the past two decades to include UUV operations. The Naval Undersea Warfare Center (NUWC) conducts the development, testing, and evaluation of underwater systems to maintain the superiority of the U.S. Navy. NUWC is broken down into two major commands, NUWC Division Newport and NUWC Division Keyport, with each supporting multiple detachment sites conducting operations in their respective undersea test ranges. The respective NUWC divisions and detachments employ a variety of TWR vessels to support activities.

1. TWR-825 and TWR-841

The Navy commissioned ten hulls of the 120-foot class of TWRs. Under contract, Marinette Marine constructed the vessels at their shipyard in Marinette, WI (Ship Building History [SBH] 2019). Design of the hulls started in the early 1980s with the first deliveries beginning in 1985 (SBH 2019). Of the original 10 hulls, only TWR-825 and TWR-841 are still in service.

The USS *Swampfox* (TWR-825) was originally commissioned in 1985 and was assigned to the Atlantic Undersea Test and Evaluation Center (AUTECE) at Andros Islands. (Grayfox Association n.d.). TWR-825 saw diminishing use in its original role due to advances in the testing and design of new torpedo systems. In 1995, according to the Grayfox Association, TWR-825 was sent to Green Cove Springs, Florida, and mothballed. After two years, TWR-825 was refurbished and transferred to the Naval Sea Cadet Corps. The ship was sailed to Port Huron, MI and recommissioned as the United States Naval Sea Cadet Ship (USNSCS) *Grayfox* (TWR-825) (Grayfox Association n.d.). No longer in the torpedo recovery role, TWR-825 plays a vital role in training U.S. and Royal Canadian Naval Sea Cadets (Grayfox Association n.d.). Figure 1 shows the USNSCS *Grayfox* underway out of Port Huron, MI, with Naval Sea Cadets on the rails.



Figure 1. USNSCS *Grayfox*. Source: Beesley (2019).

TWR-841 was constructed following her sister ship in 1988 and served at AUTECE recovering MK48 heavyweight torpedoes and MK30 targets (Grayfox Association n.d.). In 1991, TWR-841 was transferred to NUWC Newport Division from the Atlantic Undersea Test and Evaluation Center (AUTECE) (Rodney Griffith, personal communication, April 2, 2019). At the NBTF, its missions have expanded from torpedo testing to include UUV launch and recovery, underwater sensor and sonar testing, and oceanographic mapping. NUWC Division Newport uses the TWR-841 as its primary

vessel for the testing and recovery of torpedoes in the NBTF ranges (Lawrence Rainey, personal communication, January 10, 2019).

2. TWR-7 and TWR-8

NUWC Division Keyport has two Torpedo Weapons Retrievers, TWR-7 and 8 (NUWC Division Keyport n.d.). These are similar in usage but smaller than the TWR-841. TWR-7 and 8 are the only two of the 80-foot class purchased by the Navy and built by Tacoma Boatbuilding in the mid-1970s (SBH 2014). Like their counterpart, TWR-7 and TWR-8 are used for surface retrieval of torpedoes and UUVs, range security, target and sound support, and MK30 target launch support (NUWC Division Keyport 2015). Figure 2 shows TWR-7 based out of NUWC Keyport transiting through Puget Sound with a test torpedo on the deck.



Figure 2. TWR-7 Transiting through Puget Sound. Source: Royer (2014).

3. Ranger, Range Rover, and Rangemaster

AUTEC no longer operates any designated TWRs. However, they deploy the Ranger, the Range Rover and the Rangemaster for torpedo recovery operations (AUTEC 2014). Of these vessels, the Rangemaster is most similar to the TWR-841. The

Rangemaster is a flexible test platform that conducts MK48 and MK30 launch and recoveries, and Mobile Acoustic Test System (MATS) test support (NUWC Detachment AUTECH 2014). The Ranger and Range Rover are larger boats that provide similar capabilities, as well as test and evaluation, vehicle recovery, and battle simulation replication. In Figure 3, an inflatable watercraft approaches NAWC 38, a Ranger class vessel, to conduct a naval boarding exercise.



Figure 3. Ranger Class Vessel. Source: USN (2012b).

B. PROBLEM STATEMENT

TWR-841 went into service over 30 years ago and is nearing the end of its useful life. In May 2016, the Navy's Board of Inspection and Survey (INSURV) released a Structural Inspection Report on USNS TWR-841. The report found 11 of the 14 inspected spaces need repair and eight of the 11 at a critical level (INSURV 2016).

TWR-841 is reaching mechanical and technological obsolescence. Without substantial maintenance and upgrades to its current systems, the vessel will lose operational suitability. The U.S. Navy requires a testbed with the capability for launching and recovering underwater systems. TWR-841 has served this purpose for the last 30 years. Currently, there are no efforts underway to determine a replacement. To date, there have

been no data compiled to make a decision and no placeholders for funding have been budgeted for service life extension or replacement of the ship.

Without a plan in place for restoration or replacement, the Navy will lose critical infrastructure that it needs to maintain its technological superiority against emerging threats.

1. Project Scope

This report examines the Navy's capabilities currently fulfilled by the TWR-841. The Team used the mission set of the TWR-841 to determine the operational requirements required for future torpedo, UUV, and recovery operations. These operations are documented in the Design Reference Mission (DRM) in Chapter III. From this DRM, the Team developed a set of system requirements to define the characteristics that must be met by the replacement vessel. We used these requirements to generate a list of alternatives for the replacement of the current system. In Chapter VI, an AoA is used to rate each option on qualitative and quantitative metrics. From the AoA, the Team generated recommendations for interested stakeholders on the options available for the next generation of TWR. For this report, the Team utilizes the term Next-Generation Weapons Retriever (NGWR) when referring to the procurement or design of a vessel that would replace the current TWR-841.

2. Limitations, Assumption, Constraints

The scope of the project focused on determining a suitable replacement of the TWR-841 for the NBTF. Only vessels which could be supported by the NBTF were considered.

A Service Life Extension Program (SLEP) was initially considered to modernize TWR-841. However, the Team assessed that a SLEP is not a viable option due to the age of the current ship and the material condition of the vessel outlined in Chapter II.

Regardless of being classified as a naval vessel, the ship will only be employed for test and evaluation support and requires no offensive or defensive capabilities.

C. STAKEHOLDER REVIEW

In the generation of this report, the Team utilized information provided from interested stakeholders to identify capability and operational constraints on the TWR-841. Working with the stakeholders allowed the creation of requirements for the replacement of the TWR.

The Team has identified the following entities as having an interest in the results of this research. A brief description of stakeholders and their expected interests are as follows:

1. NUWC Division Newport

NUWC Division Newport is a branch of the Naval Sea Systems Command based in Newport, Rhode Island. They provide research, development, and test and evaluation (T&E) support for submarines, AUVs, and offensive and defensive undersea weapons. NUWC Division Newport relies heavily on the NBTF to support their research and development of marine weapon systems. The NBTF offers shallow water ranges which allow for testing in real operational environments. NUWC Division Newport utilizes the TWR-841 for its current torpedo recovery and AUV support operations. It will be the primary benefactor for the replacement or refurbishment of the TWR-841.

2. NUWC Division Keyport

NUWC Division Keyport is based in Keyport, WA and utilizes the Pacific Undersea Warfare Test & Evaluation Range for operations. NUWC Division Keyport's primary mission is to provide advanced technical capabilities for test and evaluation for undersea warfare. They provide services such as fleet materiel readiness, logistical support and obsolescence management. Similar to NUWC Division Newport, they provide testing on torpedo and UUV systems that require the use of TWRs and other support ships. An NGWR would offer enhanced capabilities to their currently aging fleet.

3. Program Executive Office Ships

Program Executive Office (PEO) Ships is the Defense Department's ship acquisition office. They oversee the design, construction, and procurement of the majority of the DoD's surface vessels (NAVSEA n.d.).

Within PEO Ships, the Support Ships, Boats, and Craft Program Office (PMS 325) manages the procurement of auxiliary and special mission ships, Navy standard boats, service craft, seaborne targets, and Foreign Military Sales (FMS). PMS-325's Special Mission Ships division would manage the construction or procurement of an NGWR and ensure affordability, cost savings, and efficiencies in the process.

D. SYSTEMS ENGINEERING PROCESS

The Team utilized a tailored systems engineering approach to present strategies to interested stakeholders on the replacement of the Torpedo Recovery Vessel. The Team went through a four-step process to: define the problem space, generate requirements, propose solutions, and analyze the metrics of the proposed options. Figure 4 shows the four-step process used by the Team.

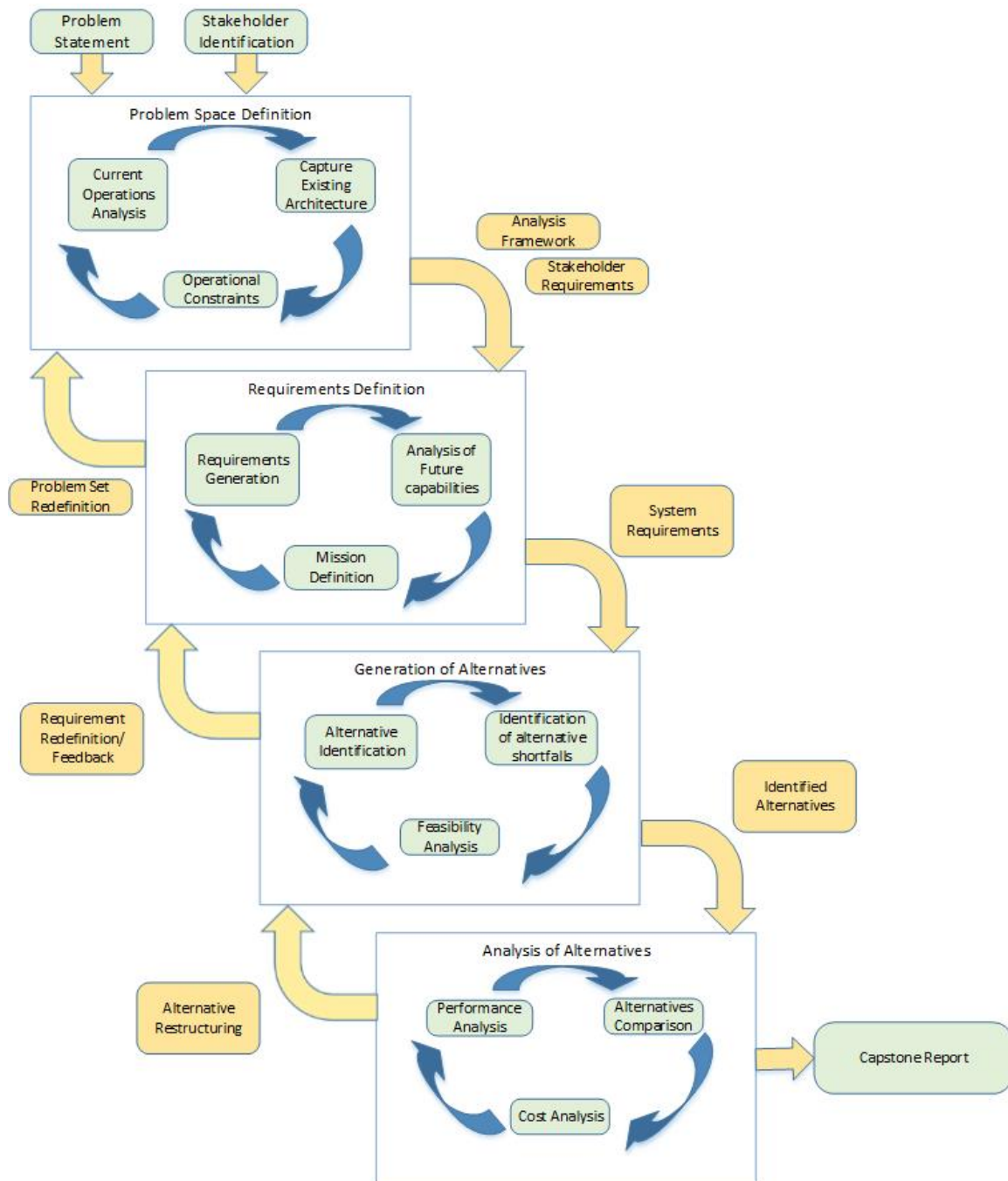


Figure 4. Systems Engineering Approach to Project Generation

1. Problem Space Definition

The Team defined the problem space by taking the original problem statement and identifying the stakeholders. The Team used the existing architecture to analyze the current operations and constraints of the TWR-841 system. With a baseline established, the Team refined the problem space and generated requirements to guide the development of the NGWR solution. A clearer understanding of the problem space set the foundation for requirements definition.

2. Requirements Definition

The requirements are defined using the system architecture from the problem space definition. The Team utilized stakeholder inputs and determined the current and future needs for the NGWR. In the requirements definition phase, the problem space is evaluated to determine if the original assumptions require refinement. The mission subsets for the NGWR were used to refine the system requirements. The output from this phase is a list of system requirements.

3. Generation of Alternatives

With the requirements defined, the Team generated a list of suitable alternatives that meet the system requirements. Alternative constraints were evaluated throughout the generation of alternatives to determine the overall viability of the proposed vessels. Once a list of alternatives was determined, the Team generated quantitative metrics to rank the options.

4. Analysis of Alternatives

The Team took a holistic approach during the analysis of alternatives (AoA) to conduct a performance and cost analysis on the list of proposed alternatives. The Team compared the options against each other concerning the initial date of operation and performance against the documented requirements. These metrics allowed the Team to rank each proposed alternative.

Using a Pugh matrix, the Team documented the performance of alternatives against each other. A cost estimate was completed for the procurement, operation, and sustainment (O&S) costs for each alternative. By using the Pugh matrix and cost estimates, the Team created a hierarchy within the solution set to determine the best course of action for the replacement of the TWR-841.

II. SYSTEM DESCRIPTION

The TWR-841 is a very versatile test vessel. The ship can be modified to support a variety of torpedoes, UUVs, and sensor tests. Because of its adaptability, TWR-841 is a valuable asset to the NBTF having the ability to perform a variety of launch and recovery missions of undersea naval systems.

A. TWR-841 CHARACTERISTICS

The Naval Sea Systems Command provided the characteristics presented in this section for the TWR-841 (NAVSEA n.d.-e). The TWR-841 has a length of 120 feet, a 25-foot beam, and a draft of 12 feet, which allows the ship to navigate in deep and shallow water. The maximum height of the vessel is approximately 42 feet and has a gross regulatory tonnage of 248 tons. Powering the vessel are twin Caterpillar diesel engines, each delivering 2350 BHP. The maximum speed the TWR-841 can reach is 12 knots. The TWR-841 has a fuel oil capacity of approximately 8,000 gallons and consumes around 50 GPH when traveling at a rate of 10 knots. The vessel has berthing for 18 personnel. For single-day missions, the TWR-841 requires four crew for safe operation. Multi-day missions require nine individuals, two sets of four for navigation and operation plus a cook. Figure 5 depicts TWR-841 pulling into port at Newport, RI, with test equipment strapped on its open deck.



Figure 5. TWR-841 in Transit. Source: NAVSEA (n.d.-e).

A defining characteristic of the TWR is an open deck that can accommodate large torpedoes and support equipment. The deck is highly configurable and has dimensions of 51 feet x 25 feet. The standard deck configuration employs torpedo rollers that can be replaced with fiberglass grating if required. The ample deck space allows for the carriage of up to 12 heavyweight or 18 lightweight torpedoes. The deck also has the unique capability to lower its aft end allowing for easier retrieval of torpedoes from the water. Figure 6 shows TWR-841's deck in the lowered position with rollers installed and a full complement of test torpedoes stored. Depending on mission requirements, accommodations are made to support portable science vans of up to 20 feet in length.



Figure 6. TWR-841 Torpedo Deck Configuration. Source: NAVSEA (n.d.-f).

1. TWR-841 Deck and Load Handling Equipment

Figure 7 shows one of the many alternate configurations of TWR-841's deck. In this picture, the torpedo rollers are removed to support the fiberglass deck. A 16-foot-high x 7-foot-wide stern U-frame with a 5,000-pound capacity is mounted on the stern of the ship. The U-frame will coordinate with a SEA-MAC winch that is used to haul and pull torpedoes out of the water. The ship's drum has a capacity of 5,000 feet of ½-inch wire with a full drum line pull of up to 5,000 pounds. The deck of the vessel contains an Appleton knuckle-boom self-contained 25 HP crane. This crane, shown in the foreground of Figure 7, has a 24-foot reach and can hold 4,000 pounds at all angles. The torpedo recovery winch and transfer carriage can pull up to 3,000 pounds. A portable workstation for housing equipment and personnel during test missions is shown in the foreground on the port side in Figure 7 (NAVSEA n.d.-e).



Figure 7. TWR-841 Alternate Deck Configuration. Source: NAVSEA (n.d.-f).

The TWR-841 has an Ideal Windlass capstan on the starboard stern and can haul 3,800 pounds and pull at 30 feet per minute. The last major piece of operational equipment is a Pinger Pole that allows deployment of transducers over the side of the ship (NAVSEA n.d.-e).

2. TWR-841 Communication and Electronics

The TWR-841 has multiple forms of communication used to support their missions. Table 1 shows a list of the communication systems available onboard the vessel. The TWR-841 has two very high frequency (VHF) marine two-way communication radios that have a line of sight range up to 30 miles. The primary function of these radios is ship-to-ship and ship-to-shore voice communication. These radios assist in safe navigation and allow the TWR-841 to communicate with land-based teams during testing and missions.

Along with the VHF, the TWR-841 also uses ICOM high frequency (HF) Single Sideband (SSB) radios that feature full transmit and receive coverage of all marine bands from 2.0 through 26.5MHz (ICOM Canada n.d.). The ultra-high frequency (UHF) RT-980A/GRC-171(V) radio can provide useful reception range approximately up to 250

nautical miles and has a frequency range of 225–400 MHz (Pike 1999). The WQC-2/C-7440A provides the TWR-841 the ability to communicate with a vessel while submerged at frequencies compatible with all other existing underwater telephone units (Department of the Navy 1976). The various navigation, station keeping, and diagnostic equipment conforms with the NMEA 2000 communication standard, which allows the transfer of communications and commands between devices on a secure network (Fullilove 2014).

Table 1. TWR-841 Communication Equipment. Adapted from NAVSEA (n.d.-e).

Communication Equipment	Equipment Description
2 VHF Marine	Analog voice radio for ship-to-ship communication with up to a 30-mile range.
VHF NUWCNET	Analog voice radio used for Naval Undersea Warfare Center communication
UHF RT – 980A/GRC-171(V)	Long range UHF radio for ship-to-shore and ship-to-air communications. Operates from 225 to 400 MHz and can employ basic electronic communication countermeasures.
HF SSB, ICOM IC-M810	Radiotelephone with full transmit and receive of marine bands.
WQC-2/C-7440A	Underwater Telephone utilized on manned submersibles and surface ships to allow voice and audio tone transmission through water.
MARINESAT	Satellite telephone
Cellular Phone	Commercial cellular network telephone

To aid and support the crewmembers throughout their mission, the TWR-841 employs various types of electronic equipment. Table 2 shows a list of the electronic equipment available aboard the vessel. The TWR-841 uses a Furuno FAR2127 BB, which is a multi-color high-performance black box radar used to display ARPA and AIS target information (Furuno n.d.). The Furuno FCV1150 Depth Sounder provides the TWR-841 the ability to monitor water depth and uses a 12.1-inch LCD. The Magnavox MX 4200 DGPS is a single frequency receiver designed for real-time navigation. Automatic Identification System (AIS) is a shipboard broadcast system that replicates a transponder, operates in VHF maritime band, and uses Self-Organizing Time Division Multiple Access

(SOTDMA) technology to ensure reliable ship-to-ship operations (U.S. Department of Homeland Security 2018). The TWR-841 also uses the Furuno 7403 Sirius WX Receiver which provides up-to-date, detailed weather forecast, weather radar, lighting, and marine warnings (SiriusXM n.d.).

Table 2. TWR-841 Electronic Equipment. Adapted from NAVSEA (n.d.-e).

Electronic Equipment	Equipment Description
Furuno FAR2127 BB	Radar for tracking surface vessels with automatic radar plotting aid (ARPA) and Automatic Identification System (AIS). – 25 kW Power, Frequency range 9410+/- 30 MHz
Furuno FCU1150 Depth Sounder	Water depth sounder used for navigation and safe passage.
Furuno DRS12A Digital Radar	Surface ship tracking radar – 12kW Power, Range scale 0.0625 to 72 nm
2 Northstar LORAN	Long Distance Radio Navigation
Leica MX 400 DGPS	GPS enabled marine navigation system– Frequency range 283.5 to 325.0 KHz
Magnavox MX 4200 DGPS	Differential GPS receiver used to analyze and remove the error resident in the civilian GPS signal.
Magnavox MX-50R DGPS	Differential GPS receiver
Visual Navigation Suite	Computer based navigation system
Furuno 7403 Sirius WX Receiver	Satellite weather receiver station
Automatic Identification System (AIS)	Automatic shipboard tracking system used to identify other surface vessels with VHF line of site.
GYRO MK 27 MOD 1 with NEMA 0183 output	Heading, pitch, and roll indicating system used for navigation and sensors.

B. CURRENT MAINTENANCE STATUS

Over time, exposure to harsh environmental conditions causes significant depreciation of the material and mechanical components of marine vessels. In 2016 TWR-841 underwent a major maintenance cycle for extensive hull and stringer repairs (Rodney Griffith, personal communication, February 22, 2019). After the completion of this

maintenance, structural engineers from Norfolk Naval Shipyard conducted an INSURV structural inspection on TWR-841. Out of 14 total spaces, 11 were identified as requiring structural repair with eight spaces at the critical level (INSURV 2016).

Repairs to the issues documented in INSURV inspection require shipyard level repair to correct corrosion and structural problems. These issues were not fixed during the maintenance before the INSURV inspection due to budget and scheduling constraints (Rodney Griffith, personal communication, February 22, 2019). TWR-841 has not undergone a shipyard level maintenance cycle since the INSURV inspection, and the critical issues remain.

After serving the Navy for over 30 years, TWR-841 has significant corrosion and structural issues that will require continuous maintenance and repairs. As repairs become more frequent and costly, the reduced availability and increased maintenance costs will strain the ability of TWR-841 to provide a cost-effective service to the NBTF customers.

C. LIMITATIONS OF CURRENT SYSTEM

TWR-841 was explicitly designed for the torpedo recovery mission. In the years since its inception, it has been adapted to a multitude of other tasks referenced in Chapter III. Despite its flexibility, there are mission sets requested of the NBTF that their current TWR is incapable of performing.

1. Operational

TWR-841 is classified as a near-coastal vessel and thus restricted to operations within 200 nautical miles offshore of the U.S. or its possessions (Merchant Mariner Credential, 46 C.F.R. § 10 (2013)). This classification places limitations on operations that require testing outside of coastal waters. Specifically, some UUV operations have been turned down by the NBTF due to this limitation (Rodney Griffith, personal communication, February 22, 2019).

2. Functional

Due to the TWR-841's age and material condition, the NBTF team has been unwilling to send the vessel on missions outside of New England, whereas the ship previously would support operations along the Eastern Seaboard (Lawrence Rainey, personal communication, January 24, 2019). This factor has restricted activities even further and limits its ability to provide support for heavy and lightweight torpedo missions that are conducted too far from shore (Lawrence Rainey, personal communication, January 10, 2019).

The TWR-841's size has limited its ability to perform missions requested of the NBTF. Specifically, vessel boarding training to support Maritime Interdiction Operations (Rodney Griffith, personal communication, February 22, 2019). This limitation is not to drive the requirement of procuring a larger vessel, but to state that a replacement vessel with greater size and classification may expand the mission set of the ship while in service at the NBTF.

III. DESIGN REFERENCE MISSION

The Team generated a Design Reference Mission to outline the operation context and system requirements for the Torpedo Weapons Retriever (TWR). The DRM is used as a structured scenario-based methodology to identify and document the operational needs of the system in its intended environment. The operation scenarios defined in the DRM allow for the extraction of requirements to ensure operational validity through traceability.

The NBTF conducts a variety of missions in support of the NUWC Division Newport T&E efforts. This DRM outlines a notional operational context for various tasks undertaken by a TWR to define a single functional baseline for the future system. This project used the DRM to answer the following questions.

- What mission capabilities are critical to the deployment of the TWR?
- What are the current and anticipated system requirements for a replacement vessel?

The DRM outlines multiple examples of TWR missions to analyze the capabilities required for the replacement of TWR-841. Figure 8 shows the TWR operational concept. The TWR-841 deploys various payloads or equipment, and communicates with them remotely via several different methods. Once deployed, the payloads and TWR-841 can also use GPS communications for navigation and identifying payload location. The vessel also uses radios to communicate with the NBTF as necessary.

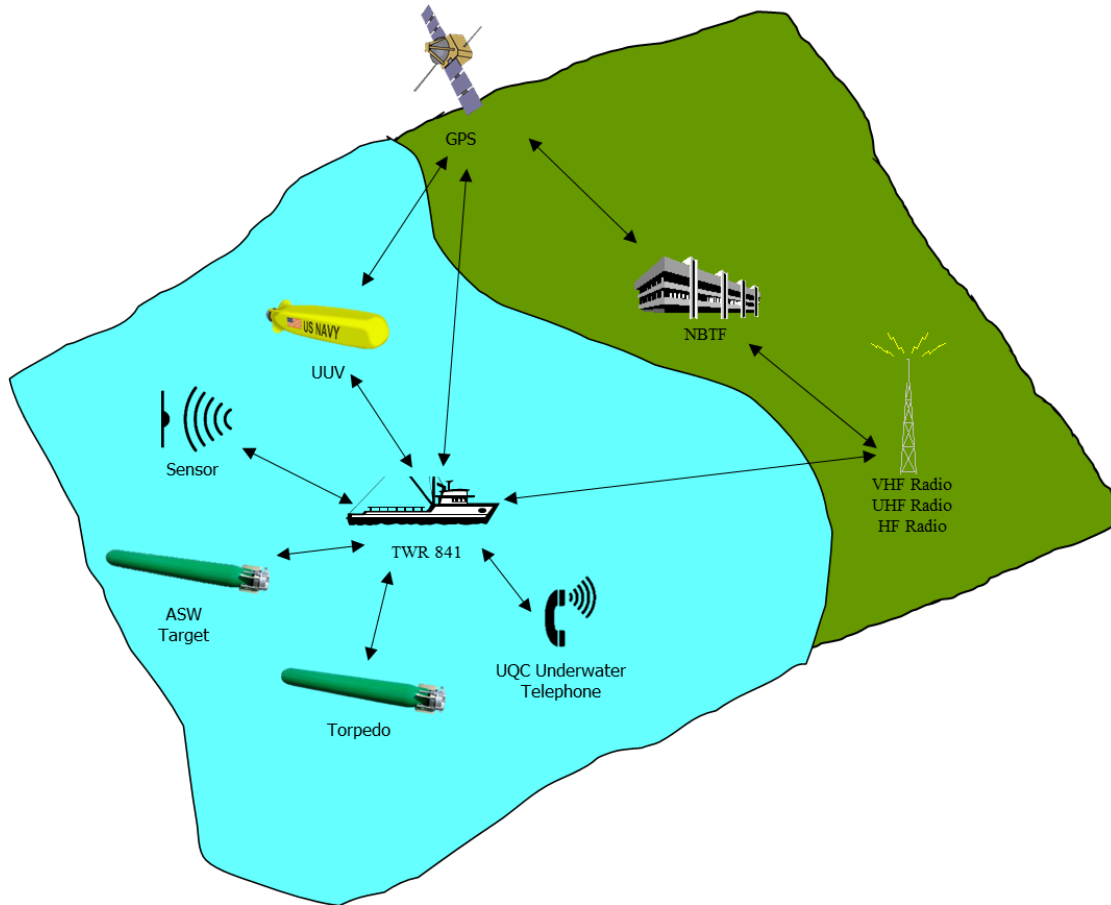


Figure 8. TWR Operational Diagram

The Narragansett Bay Test Facility provides a maritime environment for the TWR to conduct operations. The transmission of information and data within the test facility and with systems under test come from several modes of communication employed by the TWR and test facility. These modes of transmission include VHF, UHF and HF communications equipment defined in Chapter II.

A. PROJECTED OPERATING ENVIRONMENT

This DRM uses the NBTF as the primary operating location to constrain system requirements. NBTF is a subset of the greater Narragansett Bay located in the eastern portion of Rhode Island at an approximate latitude of N 41.5 degrees. The NBTF includes the following ranges: The North Test Area, Hole Test Area, and the Outer Range. Figure 9 shows Narragansett Bay in relation to Providence and Newport, RI.

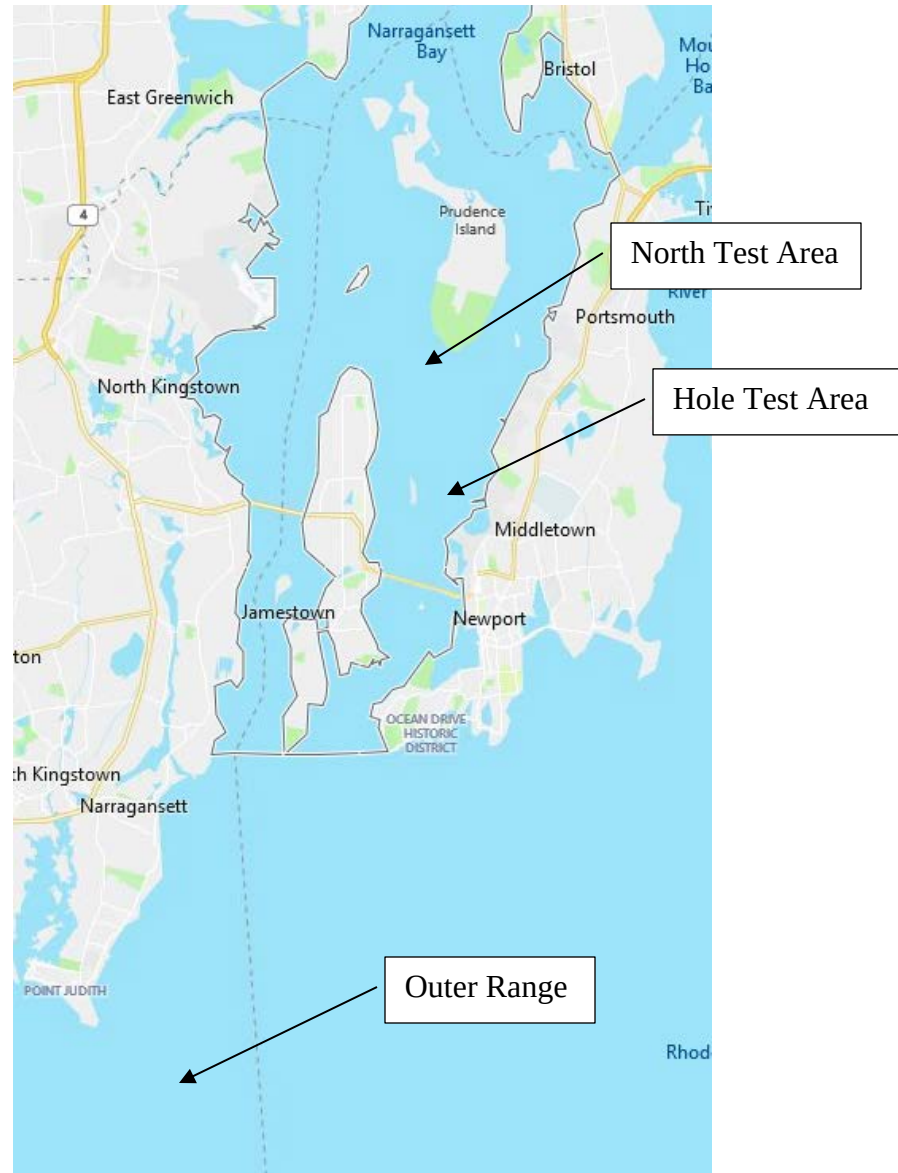


Figure 9. Narragansett Bay with NBTF Range Locations. Adapted from Bing Maps (2019).

The North Test Area, shown in Figure 10, is 10,000 by 2,750 yards with depths ranging from 20–60 feet (NAVSEA n.d.-c). The range can be patrolled to restrict operations of commercial and recreational vessels during testing. The North Range also contains 16 moored shallow water acoustic tracking system (SWATS) buoys to provide tracking throughout the area (NAVSEA n.d.-c).

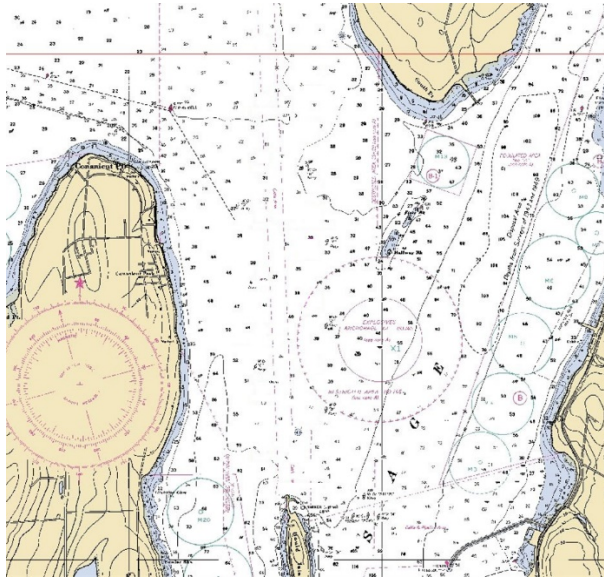


Figure 10. Narragansett Bay Test Facility North Test Area. Source: NAVSEA (n.d.-c).

The Hole Test Area, shown in Figure 11, is a smaller range containing a depression and is located on the east side of Gould Island. The maximum depth is 127 feet and SWATS buoys can provide a tracking area of 1 mile by 1/2 mile (NAVSEA n.d.-c). The Hole Test Area is located nearby to testing and shore-based facilities.

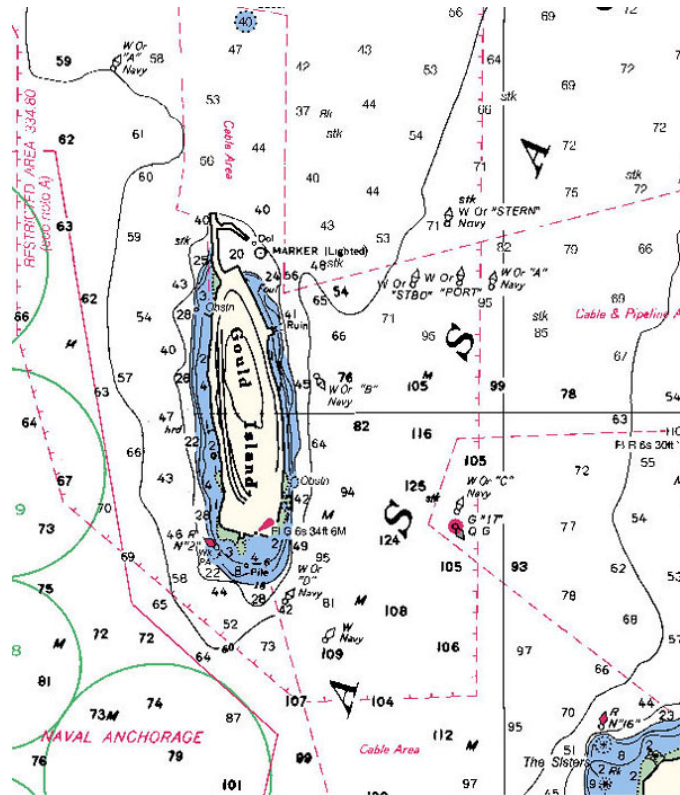


Figure 11. Narragansett Bay Test Facility Hole Test Area. Source: NAVSEA (n.d.-c).

The Outer Range, shown in Figure 12, is another restricted area with dimensions of 17,500 by 4,000 yards (NAVSEA n.d.-c). The depth is consistent across the range varying between 100 and 120 feet. The Outer Range is a Restricted Area and can be patrolled to eliminate interference from other vessels during testing. The range can use up to 16 buoys to provide eight square miles of tracking coverage (NAVSEA n.d.-c).

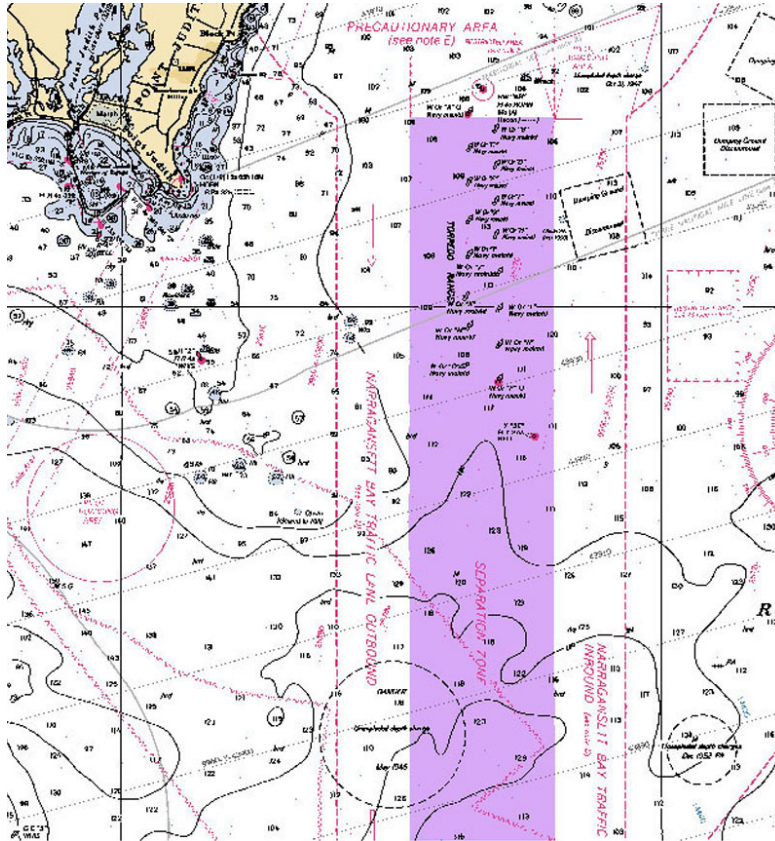


Figure 12. Narragansett Bay Test Facility Outer Range. Source: NAVSEA (n.d.-c).

The design of the NGWR shall enable safe operation and navigation during operations in the projected operating environment. The NBTF is afforded protection from adverse sea conditions due to its location inside of Narragansett Bay. The National Oceanographic and Atmospheric Administration (NOAA) National Ocean Service owns and maintains weather stations and maintains historical climate data. Historical data from weather station NWPR1 located in Newport, Rhode Island, shows the following climatic conditions for the NBTF area.

Wind speed is consistent, averaging below 10 knots regardless of the time of year (NOAA 2018). Figure 13 shows the mean and standard deviation of wind speed by month from November 2004 to December 2012.

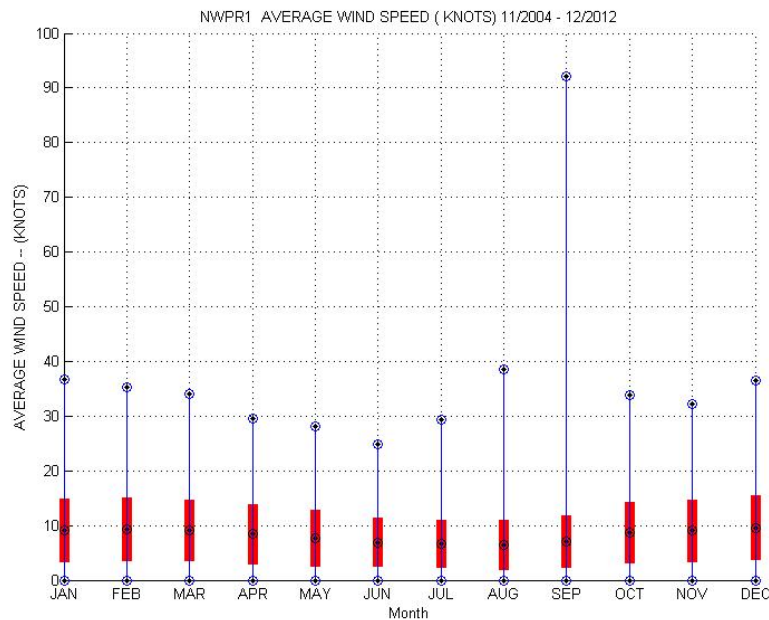


Figure 13. Station NWPR1 Historical Average Wind Speed 2004–2012. Source: NOAA (2018).

Peak sustained wind speeds are most robust through the winter months averaging between 35 and 40 knots. During the summer, maximum sustained winds fall to under 30 knots. Wind gusts show a similar seasonal pattern with peak gusts at winter hitting between the mid and high 40-knot range. During the summer, peak wind gusts subside to the mid-30 knot range (NOAA 2018). Figure 14 shows the mean and standard deviation of peak wind gust by month from November 2004 to December 2012.

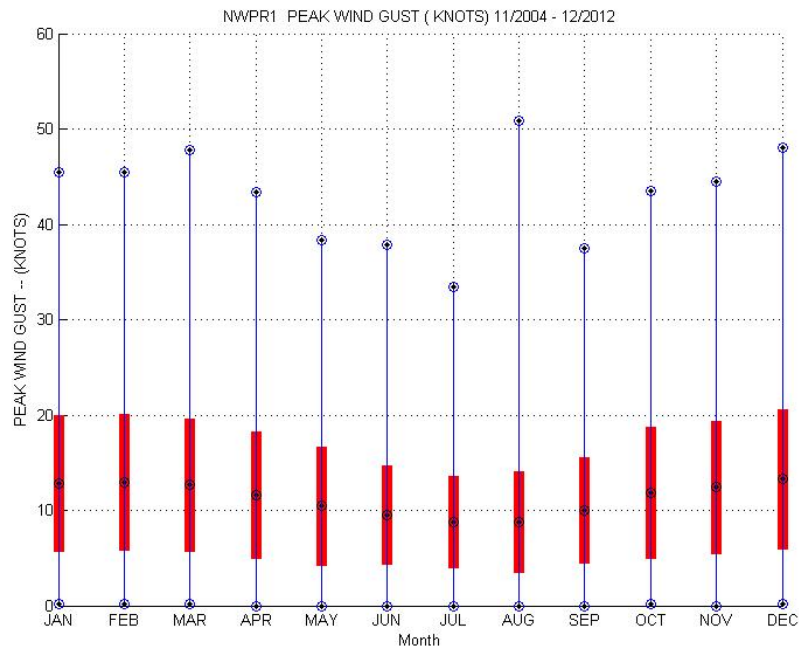


Figure 14. Station NWPR1 Historical Peak Wind Gust 2004–2012.
Source: NOAA (2018).

Water temperatures during the winter months average between 2–7 degrees Celsius. During the summer months, temperatures range between 18–23 degrees Celsius with the peak observed temperatures reaching near 30 degrees Celsius (NOAA 2018). Figure 15 shows the mean and standard deviation for sea temperature by month from November 2004 to December 2012.

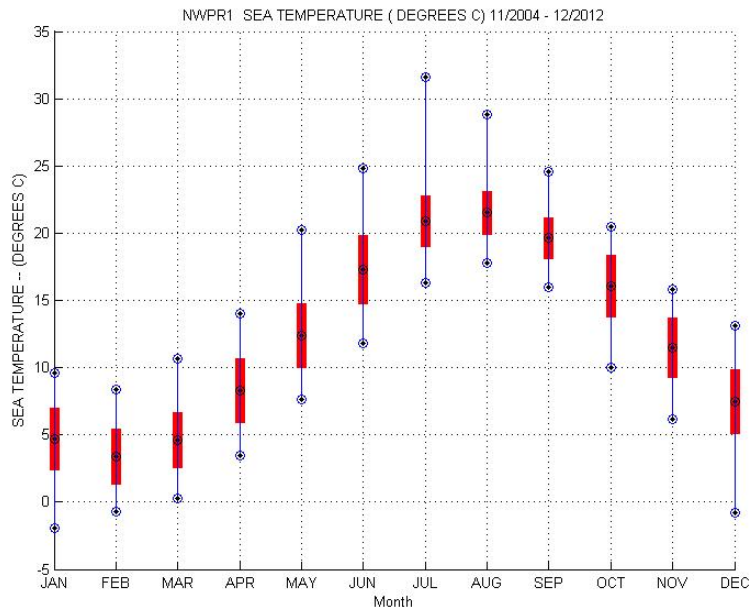


Figure 15. Station NWPR1 Historical Average Sea Temperature 2004–2012 Source: NOAA (2018).

B. OPERATIONS

The operations defined for this DRM are the primary tasks conducted by TWR-841 at the NBTF. The operation set includes heavyweight and lightweight torpedo launch and recovery, UUV launch and recovery, anti-submarine warfare (ASW) target launch and recovery, and sensor research and development testing. Table 3 provides the operations conducted by TWR-841 and are categorized by system type and year (Lawrence Rainey, personal communication, January 17, 2019).

Table 3. Historical TWR Operations by System Type and Year.
Adapted from Lawrence Rainey (personal communication,
January 17, 2019).

Year	Torpedo Mission Support (Days)	UUV Mission Support (Days)	Sensor Mission Support (Days)
2015	0	10	4
2016	0	10	10
2017	12	3	1
2018	9	10	9
2019	2	2	17
5 Year Total	23	35	41

TWR-841 averages between 20–30 days of underway operation annually. The TWR provides training and exercising of equipment when not supporting operations directly. Safety stand-down and training occurs once a month for a duration of one to two days (Rodney Griffith, personal communication, February 22, 2019).

1. Torpedo Mission

The TWR vessel was designed to launch and recover exercise heavyweight and lightweight torpedoes. Lightweight and heavyweight torpedo missions differ in that the TWR can mount and use the MK32 Surface Vessel Torpedo Tubes. Thus, enabling the TWR to perform both launch and recovery actions for the lightweight torpedo. Due to its flexible nature, the TWR-841 is also adept at recovering exercise heavyweight torpedoes deployed from other platforms (NAVSEA n.d.).

a. *Lightweight Torpedo Launch and Recovery*

The lightweight class of torpedoes consists of the MK46 and MK54 torpedoes that perform both offensive and defensive missions for the U.S. Navy (The Office of the Director, Operational Test, and Evaluation n.d.). Both weapons are similar in size with a 12.75-inch diameter, 107 inches in length, and a weight of 600 pounds (USN 2013).

A typical launch and recovery operation consists of the launching of a lightweight torpedo from the deck of the TWR using an MK32 Surface Vessel Torpedo Tube (SVTT) seen in Figure 16.



Figure 16. MK32 Surface Vessel Torpedo Tube Launching an MK46 Lightweight Torpedo. Source: Seaforces-Online (n.d.).

After the mission, the TWR uses its over-the-side crane to recover the torpedo. Figure 17 depicts a MK54 torpedo being hoisted back onto the TWR after its mission. As part of the recovery evolution, support personnel install a lifting harness using a small support vessel. This harness enables the over the side crane to lift the torpedo out of the water without interference with the inflated buoyancy system.



Figure 17. Recovery of MK54 Lightweight Torpedo Using an Over-the-Side Crane. Source: C4 Defence (2018).

b. Heavyweight Torpedo Recovery

The heavyweight torpedo class consists of multiple MK48 torpedo variants. A submarine platform deploys the MK48, seen in Figure 18, for both offensive and defensive missions. It has a diameter of 21 inches, a length of 19 feet, and weighs approximately 3,500 pounds (FAS Military Analysis Network 1998).



Figure 18. MK 48 Heavyweight Torpedo on Maintenance Carts.
Source: Ordnance Technology Services (n.d.).

A submarine or specialty vessel with an integrated torpedo tube deploys the MK48 series of exercise torpedoes. After the completion of the run, the TWR recovers the torpedo using its cable reel and stern ramp. The ramp, installed on the aft portion of the vessel, lowers itself into the water. This position provides a leveled platform for recovering torpedoes being reeled in by the winch. Once the torpedo has been reeled in, the crew places it on the deck rollers for storage.

2. UUV Launch and Recovery

The torpedo weapon retriever currently performs launch and recovery missions for UUVs (Lawrence Rainey, personal communication, January 17, 2019). According to Variant Market Research, UUV fielding and usage is anticipated to grow through 2025 (Variant Market Research, n.d.). UUVs typically fall into either the remotely operated vehicle (ROV) or autonomous underwater vehicle (AUV) categories.

a. Remotely Operated Vehicles

Remotely Operated Vehicles (ROV) are tethered unmanned undersea vehicles that personnel on the surface operate remotely. Remotely Operated Vehicles typically conduct inspection and salvage operations, but operation sets are adaptable based on customer needs and system design. Alternate less frequent activities are subsea manipulation tasks using appendages for tooling found on specialty ROVs (Oceaneering 2018).

ROV launch and recovery is conducted using an over the side crane. Figure 19 shows a representative vessel deploying the Deep Drone ROV from a boom crane. TWR-841 similarly uses its crane when conducting ROV missions. Execution of the ROV mission requires the installation of onboard support systems. A typical ROV workstation consists of a custom 20-foot long CONEX box configured for the requirements of the test crew (Rodney Griffith, personal communication, February 22, 2019).



Figure 19. Launching of Remotely Operated Vehicle from Unknown Vessel. Source: NAVSEA (n.d.).

The typical ROV system varies significantly in size based on the intended mission. Sensing ROVs are typically the smallest and lightest with a weight of approximately 2000 pounds. Recovery of extreme depth ROV systems, by contrast, can exceed 4100 pounds (NAVSEA n.d.).

b. Autonomous Underwater Vehicle Launch and Recovery

Autonomous Underwater Vehicles (AUV) operate without an operator onboard the system for the execution of a variety of missions. Operations consist of environmental sensor data gathering, seafloor, and structure mapping, payload delivery and a variety of other user-specific tasks. Autonomous Underwater Vehicles range in size from 3 inches in diameter to larger than 84 inches in diameter (Department of Defense 2016). This DRM focuses on the medium diameter vehicles that range from 10 to 21 inches in diameter.

Medium diameter vehicles' reliance on surface vessels for launch and recovery was cause for their selection. Small diameter AUVs are considered man-portable and rely on smaller watercraft such as a Rigid Hull Inflatable Boat (RHIB). Large and extra-large AUV dimensions prevent them from being recovered using a TWR.

Commercial examples of the most popular medium size AUVs are the Hydroid REMUS 600 and General Dynamics Mission Systems Bluefin-21. Figure 20 and Figure 21 show both these systems.



Figure 20. REMUS 600. Source: Hydroid (2017).



Figure 21. Bluefin-21. Source: Bluefin Robotics (2010).

Medium sized AUVs have similar mass and shapes due to their need to be neutrally buoyant. Because of this, vehicles of similar diameter and length have similar weights based on water displacement. Table 4 provides the physical properties of the REMUS 600 (Hydroid 2017) and Bluefin-21 (Bluefin Robotics 2010).

Table 4. Medium Size AUV Physical Properties. Adapted from Hydroid (2017); Bluefin Robotics (2010).

	REMUS 600	Bluefin-21
Diameter	12.75 inches	21 inches
Length	9–18 feet	10.8–16.2 feet
Weight	500–850 pounds	785–1650 pounds

The AUV mission starts with the AUV on the deck of the support vessel. When ready, a small support craft such as an RHIB launches with support personnel or divers. The AUV is placed in the water over the side of the launch vessel with the help of an overhead crane. The support personnel disconnect the AUV from the crane and remove any lift-specific hardware. Using vehicle specific auxiliary equipment, the AUV begins its mission when commanded by the operators.

The TWR crew recovers the AUV in a similar manner to the launch. Support personnel or divers in the water intercept the loitering AUV after mission completion. The Team installs required lift specific hardware. Once in place, the AUV is lifted out of the water onto the vessel deck with the overhead crane.

3. Anti-submarine Warfare Target Operations

Weapon system validation and fleet training exercises use Anti-Submarine Warfare (ASW) targets to simulate submarines. The typical ASW Target launched and recovered from the TWR is the MK30 Mod 1 ASW Target. The MK30 provides a radiated noise signature and a submarine-like magnetic signature for simulating larger targets for ASW training (USN 2012a).

The MK30 target is similar in size to that of the MK48 heavyweight torpedo. The MK30 measures 21 inches in diameter with an overall length of 21 feet and weighs approximately 2700 pounds (USN 2012a). Figure 22 shows a MK30 ASW target on rollers.



Figure 22. MK30 Mod 2 Anti-Submarine Target. Source: Granite State Manufacturing (n.d.).

The MK30 ASW target traditionally is a submarine-launched system. However, the TWR can launch them using a Telescopic Target Launcher (TTL). The TTL consists of a launch cradle assembly and uses the TWR crane for moving the target and cradle from the target storage position to the launch position over the water (NAVSEA 2007).

To recover a MK30 target, the TWR crew attaches a retrieval line to the MK30 and winches it onto the deck. Depending on the sea-state and environmental conditions, they attach the retrieval line using personnel in an inflatable watercraft, a retrieval pole, or swimmers. Once connected, the TWR recovers the MK30 onto the vessel via its aft ramp and winch (NAVSEA 2007).

The TWR does not communicate with the MK30 during its mission and system operators are not required to be onboard the TWR during a typical launch and recovery evolution. Even though the TWR-841 did not conduct any ASW target missions during the 2015–2019 timeframe, the MK30 is an active system managed by NUWC Division Newport, and future efforts may require testing (Lawrence Rainey, personal communication, January 17, 2019).

4. Sensor Research and Development Operations

The TWR performs various sensor related missions at the NBTF. These missions include towed cables, sonobuoy launch and recovery, portable node launch and recovery, sensor testing, fiber optic survivability, and towed mine detection systems.

Due to the wide variety of sensors tested at the NBTF, the TWR must be flexible to accommodate the various systems under test. One reference sensor system is the AN/AQS-20C SONAR mine detection set shown in Figure 23. Systems such as the AN/AQS-20C system are launched and recovered from the TWR using the over-the-side crane similar to the ROVs.



Figure 23. AN/AQS-20C System. Source: Military & Aerospace (2006).

IV. REQUIREMENTS GENERATION

To identify a solution for the TWR replacement, a set of requirements was needed to break out the operational requirements defined in Chapter III into system requirements that can be used to determine vessel performance. The Team reviewed the existing system architecture and worked closely with the stakeholders at the NBTF to identify critical needs and move forward with establishing the capabilities that would create solutions to the problem statement. The Team followed an iterative requirements generation and analysis process using stakeholder feedback.

The problem space definition phase laid the groundwork for defining the top-level requirements for the replacement vessel. This phase included reviewing existing architecture and conducting an operational analysis on the system via a DRM. The requirements were verified with the TWR-841 stakeholders and broken down into derived requirements for each category. Refinement of the derived requirements happened through an iterative process reviewing specifications, prior work, and operational constraints. Future capabilities or gaps were addressed when feasible for the new system. Once the requirements were sufficiently refined, they were used in the AoA to compare the performance of the identified alternatives.

A. FUNCTIONAL REQUIREMENTS

The TWR functional requirements listed in this section define the operations and general capabilities that NGWR must perform. To identify the required capabilities, the Team generated 10 top-level requirements, each containing supporting derived requirements.

1. Operational and Environmental

Chapter III defines the typical test ranges and environmental conditions where the NGWR is expected to operate. These locations include the Narragansett Bay near the test facility and other U. S. Navy sites on the East Coast. While the system will not likely need to operate in severe weather conditions, it is critical that the NGWR remains flexible. The

craft may be needed to travel long distances to support multiple locations with different operating conditions and operate in a range of sea states to accommodate various mission requirements. The Team generated the operational environment requirements from these conditions and listed them in Table 5.

Table 5 also defines the baseline capabilities and performance for the projected operations. The NGWR must have sufficient speed to conduct missions such as towed sonar array validation and must have the range required to perform a full day's activities without refueling. These minimum performance requirements are generated from the capabilities of the current system, as defined by the NUWC Newport Division, TWR-841. Lower performance thresholds for speed and range would negatively impact the types of missions the NGWR could conduct.

Table 5. Operational and Environmental Requirements

Requirement	Description
1.1	The NGWR shall be able to operate in a range of environmental conditions.
1.1.1	The NGWR shall be capable of operating between 15 and 100 degrees Fahrenheit (-9 and 38 degrees Celsius).
1.1.2	The NGWR shall be capable of operating at water depths between 30 and 5000 feet.
1.1.3	The NGWR shall be capable of operating in sea states up to 6, and maximum wind speeds of 35 knots.
1.2	The NGWR shall have sufficient speed and range capabilities to complete mission packages.
1.2.1	The NGWR shall have a minimum operational range under normal cruising speed and operational load of 2000 nautical miles.
1.2.2	The NGWR shall have a minimum cruising speed of 10 knots.
1.2.3	The NGWR shall have a maximum speed of at least 12 knots.

2. Flexible Payload Support

Multiple types of payloads are deployed and retrieved by the TWR-841 and flexibility in the design was an important consideration. The payload support requirements listed in Table 6 originated from this need to handle multiple types of payloads. The NUWC Newport Division's TWR-841 was used to generate the baseline capabilities for payload

deployment and retrieval, available cranes, and stowage space. The Team adjusted the metrics with input from the stakeholders to incorporate other possible payloads that the new system may need to include.

TWR-841 uses rollers near the stern of the vessel for quicker retrieval of torpedo-like payloads without the need to use a crane. These payloads must then be restrained while stowed, generating a requirement to physically restrain the payloads while underway. The minimum stowage and restraint capacity of 3,500 pounds is based on the heavyweight torpedo, one of the largest payloads currently used on the rollers of the TWR-841. Currently, the TWR-841 operates a 4,000-pound crane. To avoid issues of obsolescence of future unknown payloads, the Team chose to increase the maximum crane capacity to 5,000-pounds, to account for an up to 25% increase in payload weight.

Since the NBTF sometimes receives requests to conduct missions on short notice, it is important to the stakeholders that the vessel retains its flexibility. By requiring the system to have a modifiable working deck that is interchangeable within 24 hours, the NGWR will be able to handle more of these requests. Some of the missions described in Chapter III, such as UUV operations, require the use of a CONEX box for support equipment and project personnel space. This lab equipment includes laptops, measuring tools, batteries, charging stations and other apparatus required for the project personnel to successfully carry out the mission (Dillon Fournier, personal communication, March 07, 2019). The vessel will be required to provide auxiliary power for this equipment, including redundancy to minimize the risk of failure. For the NGWR to conduct several of the towed array and sensor testing operations discussed in Chapter III, a 5,000-pound A-Frame is required. The A-Frame supports the forces generated by the winch and also supports the large crane when handling near-max loads.

Table 6. Flexible Payload Support Requirements

Requirement	Description
2.1	The NGWR shall be capable of deploying, retrieving, and stowing required payloads.
2.1.1	The NGWR shall contain rollers for torpedo-like payload deployment and retrieval.
2.1.2	The NGWR shall be capable of holding and operating a cable reel for deployment or recovery of various payloads via rollers and towable systems.
2.1.3	The NGWR shall contain physical restraints to prevent the stowed payloads of up to 3,500 pounds from moving during vessel transit or operations.
2.1.4	The NGWR shall have a minimum 5,000lb knuckle boom crane.
2.1.5	The NGWR shall be capable of retrieving and stowing a minimum of 12 heavyweight or 18 lightweight torpedoes, or a payload of 17 tons.
2.2	The NGWR shall be able to operate successfully to accommodate mission packages.
2.2.1	The NGWR shall be modifiable within 24 hours to accommodate defined mission packages.
2.2.2	The NGWR shall have a flat, modifiable working deck.
2.2.3	The NGWR shall be capable of holding at least one convertible 8ft by 20ft CONEX box for office space or lab use while underway.
2.2.4	The NGWR shall provide a 70kW power minimum generator with back up for powering test equipment and mobile lab setups for hosted payloads.
2.2.5	The NGWR shall have a minimum 5,000lb A-Frame at the stern for handling large tow-bodies.

3. Habitability

As defined in Chapter II, one of the unique benefits of TWR-841 is the ability to conduct overnight and multi-day missions. This requirement requires the craft to be capable of accommodating larger crews including berthing for the personnel. Typical overnight mission packages consist of nine people. This package includes a captain, an engineer, two deckhands, a backup for each, and a cook. The craft would also be required to accommodate at least nine project personnel, separate from the crew, to allow for successful mission operations. Table 7 describes the habitability requirements that define the required minimum crew sizes and berthing for projected operations. Standard

operations are not expected to exceed five days, with the majority remaining under two (Lawrence Rainey, personal communication, January 10, 2019).

Table 7. Habitability Requirements

Requirement	Description
3.1	The NGWR shall accommodate personnel for mission packages, including overnight operations.
3.1.1	The NGWR shall accommodate berthing for a minimum of 18 people (nine crew & nine project personnel). Crew size is to be minimized. If a smaller crew is feasible while maintaining safe operations, space is to be made available to project personnel.
3.1.2	The NGWR shall accommodate 18 people (5 crew and 13 project personnel) for daytime mission packages.
3.1.3	The NGWR shall contain a galley and scullery capable of handling a load of 18 personnel for three meals a day.
3.1.4	The NGWR shall provide sinks, showers, heads, and related potable water and waste-handling systems per Naval Ships' Technical Manual (NSTM), Chapter 533.
3.1.5	The NGWR shall provide heating, ventilation, and air conditioning (HVAC) systems per NSTM, Chapter 510 to support a crew of 18.

4. Communications and Electronics Requirements

TWR-841 is outfitted with several communication and electronic systems, which support standard boat operation and specific mission requirements. These requirements, listed in Table 8, are defined from the baseline capabilities in the NUWC Newport Division, TWR-841 Specification Sheet. Specialty hardware includes the WQC underwater phone, which is used for communications with under-water vehicles. Standard military grade electronics for radar, at-sea communications and radios, depth sounders, and weather receivers are used where possible (NAVSEA n.d.-f).

Table 8. Communications & Electronics Requirements

Requirement	Description
4.1	The NGWR shall have proper communications systems and electronic equipment for service and operation.
4.1.1	The NGWR shall have marine VHF and HF radios.
4.1.2	The NGWR shall have an AIS class B transponder.
4.1.3	The NGWR shall have Sirius marine weather receivers.
4.1.4	The NGWR shall have a WQC underwater phone.
4.1.5	The NGWR shall have a surface-search radar system as required under The International Regulations for Preventing Collisions at Sea (COLREGs) for navigation.
4.1.6	The NGWR shall have a military grade GPS in accordance with the National Marine Electronics Association (NMEA) data outputs.
4.1.7	The NGWR shall have a 220/50kHz depth sounder for depth sensing.
4.1.8	The NGWR shall have an SBE 19 plus SEACAT profiler CTD, or equivalent.

5. Auxiliary Requirements

Additional auxiliary requirements listed in Table 9 for the NGWR are defined as any conventional boat equipment needed for standard operation and power generation for the vessel. The required boat equipment and portable parts are defined in the Naval Ships Technical Manual (NSTM). These include personal protective equipment, moorings, chains, boat hooks, hand tools, etc. (Lawrence Rainey, personal communication, January 10, 2019). Portable parts also include horns, slings, towing posts, engine accessories, and electrical systems, among others (Command 1998). These are either required by law for at-sea operations or are in place to avoid needing to change or update the existing shore infrastructure that supports the current system.

Table 9. Auxiliary Requirements

Requirement	Description
5.1	The NGWR shall have auxiliary equipment required for standard operation of a working boat of this size and class.
5.1.1	The NGWR shall provide conventional boat equipment and portable parts as identified in NSTM, Chapter 583.
5.1.2	The NGWR shall have a sufficient power plant to generate and distribute a minimum of 150kW electrical power for ship propulsion and electrical systems IAW NSTM, Chapter 320.

B. NON-FUNCTIONAL REQUIREMENTS

The non-functional characteristics detail the requirements not defined for operational performance and include availability, safety, and cost. The new system must be affordable for the Service Cost Center at the Narraganset Bay Test Facility to be a serviceable option and the NGWR must be available when needed.

1. Availability

One major advantage of the NBTF is the ability to support NAVSEA needs on short notice. The NGWR should be readily available to the greatest extent possible to maintain this advantage. Table 10 defines the availability requirements for the NGWR. The TWR-841 requires a major inspection every three years based on its size and hull thickness (Rodney Griffith, personal communication, March 7, 2019). Based on aging systems and re-certification requirements, a major overhaul of a sub-system is conducted during each 3-year period. The NGWR needs to meet or exceed this requirement to maintain suitable availability. It is assumed the vessel would be supported by required routine maintenance between these cycles.

The operational availability is based on the weekly time the vessel must be serviced for routine maintenance and weekly training conducted by the crew. During portions of these maintenance and training actions, the vessel would not be available for supporting missions. The Navy Planned Maintenance System (PMS) actions take approximately 70 man-hours per week and include all equipment maintenance on the vessel (Rodney Griffith, personal communication, March 7, 2019). From these PMS actions, the vessel is non-

operational approximately one work day a week out of a five-day work week (Rodney Griffith, personal communication, March 7, 2019). From this, it was estimated that the operational availability of the vessel is currently 80%, which the proposed alternatives would be expected to meet or exceed.

Currently, the TWR-841 undergoes a thorough Navy-required inspection every three years to ensure the vessel is still serviceable. In its current state, the TWR-841 requires corrective maintenance approximately once a year to repair various sub-systems or replace aging components. For a new vessel, it is desired to significantly reduce this corrective maintenance requirement to reduce operational costs. The Team defined the goal for this requirement to only require corrective maintenance every three years. This would coincide with the required inspection timeline, where the vessel would already be out of the water and out of service.

Table 10. Availability Requirements

Requirement	Description
6.1	The NGWR shall be reliable, available, and maintainable to carry out mission packages.
6.1.1	The NGWR shall have a mean time between depot maintenance of at least three years.
6.1.2	The NGWR shall have an operational availability (A_o) of at least 80%.
6.1.3	The NGWR shall require no more than 70 man-hours per week of preventative, organizational-level maintenance.

2. Safety

Safety considerations must always be taken into account, not only for the NGWR and its crew but also for other vessels, as the NGWR will be operating in open water in addition to closed-off areas such as the Narragansett Bay. Table 11 details these safety requirements, which include general best practices, personal protection equipment (PPE) requirements for small craft, and casualty response equipment and procedures. The Naval Ships Technical Manual (NSTM) details these safety requirements for boats and small craft in the Navy.

Chapter 77 of the NSTM details the PPE requirements for Navy operations. These include life preservers, breathing support equipment in the case of fire, protective clothing, and hearing protection devices (NAVSEA 1998). Chapter 583 discusses various safety precautions and operating procedures, electronic safety switches, and life rafts (NAVSEA 1998).

Table 11. Safety Requirements

Requirement	Description
7.1	The NGWR shall have safety taken into consideration for the design.
7.1.1	The NGWR shall minimize safety hazards to the crew, project personnel, and ship equipment.
7.1.2	The NGWR shall minimize safety hazards to other ships operating in proximity and any external equipment.
7.1.3	The NGWR shall provide personal protection equipment IAW NSTM, Chapter 077.
7.1.4	The NGWR shall provide for safety precautions including fire-suppression and flooding control IAW NSTM, Chapter 583.

3. Cost

Cost constraints are a major consideration for the generated alternatives, as the NBTF facility is limited in the amount of funding available for procurement and maintenance. An estimated limit for initial design and procurement cost of \$15M and annual operation and sustainment (O&S) cost of \$1M per year were identified by the NBTF (Kip Rainey, personal communication, April 11, 2019). Table 12 details the cost requirements used in consideration of the alternatives in Chapter VI.

Table 12. Cost Requirements

Requirement	Description
8.1	Total Ownership Costs (TOC) considerations shall be taken into account for the NGWR procurement.
8.1.1	The initial procurement cost shall not exceed \$15M.
8.1.2	The average annual operations and sustainment cost shall not exceed \$1M.

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V. ALTERNATIVE GENERATION

A. ALTERNATIVE GENERATION PROCESS

The Team analyzed several different procurement or contracting options for the replacement of the TWR-841. Internet research and subject matter expert feedback were used to identify potential vessels as the NGWR. Potential NGWR systems were compared to capabilities identified in the DRM and alternatives that had the best opportunity to meet the system requirements were chosen for analysis.

To find suitable replacements for the TWR-841, the Team investigated both commercial and research vessels with similar size or capabilities of TWR-841. The Team assumed that small vessels would not have the capability to carry enough personnel or utilize a large enough crane to conduct required operations. Eight vessels were selected as potential alternatives for further analysis.

B. PROPOSED ALTERNATIVES

The proposed alternatives fall into three primary categories:

- new procurement or bottom-up construction
- procurement and modification of an operational vessel
- contracting out operations to commercial ships as a service on an as-required basis

1. New Procurement

Vessel alternatives that require the procurement of a new vessel were identified as alternatives for the NGWR. The alternatives are based on representative procurements of new vessels or keel-up designs with similar specifications to the NGWR, using Shipbuilding and Conversion, Navy (SCN) funds. To identify cost estimates for the new construction, the Team used historical contract data for development of similar-sized vessels with comparable capabilities. The three alternatives explored are the Multi-Purpose

Craft (MPC), Research Vessel (R/V) Sally Ride, and a new Deep Sea Research Vessel design.

a. Multi-Purpose Craft

The MPC is a family of four vessels procured in 2010 as a replacement to aging Torpedo Weapons Retrievers. The MPCs are fabricated by Modutech Marine in Tacoma, Washington and procured through the Government Service Administration's (GSA) e-Buy website as a fixed-price delivery order of \$8.3 million per vessel (Gibson 2010). The MPCs reside at Commander, Submarine Squadron 11 (CSS-11) in San Diego, Naval Submarine Support Command (NSSC) Pearl Harbor, and the Pacific Missile Range Facility (PMRF) in Hawaii (Richard Thornton, personal communication, February 07, 2019)

The MPC is 97 feet long with an overall beam of 28 feet (Hockema & Whalen Associates 2013). It has a stern ramp with rollers to aid in the recovery of torpedo-like systems and a crane mounted on both port and starboard sides. These features are shown in Figure 24.



Figure 24. MPC-2 Docked at PMRF Showing Stern Ramp and Cranes.
Source: Within Range (2014).

b. *R/V Sally Ride*

Research Vessel (R/V) Sally Ride was launched in 2014 at a cost of \$71 million. The R/V Sally Ride is an Ocean Class Auxiliary General Oceanographic Research (AGOR) vessel owned by the US Navy and operated by Scripps Institution of Oceanography under a charter agreement with the Office of Naval Research (Scripps Institution of Oceanography 2019) and is shown in Figure 25.



Figure 25. R/V Sally Ride. Source: Scripps Institution of Oceanography (2019).

The vessel is designed to perform global oceanographic research and has a length of 238 feet with a beam of 50 feet. To move equipment and gear, it utilizes a 10,000-pound main crane and 30,000-pound A-frame crane (Scripps Institution of Oceanography 2019). Though significantly longer than the baseline TWR-841, R/V Sally Ride is a representative system based on the architecture that supports the launch and recovery of a variety of research vessels.

c. Deep Sea Research Vessel

Designed by Marcelo Penna Yacht Design Group of Spain, this 131-foot long deep-sea research vessel design has an estimated fabrication cost of \$10 million (SeaBoats 2017). This vessel, shown in Figure 26, has a stern mounted hydraulic A-frame crane and deck space to accommodate a variety of systems.



Figure 26. Deep Sea Research Vessel Design Rendering. Source: SeaBoats (2017).

2. Procurement and Modification of Operational Vessel

The procurement of existing operational vessels is identified as an alternative for the NGWR. These operational vessels vary between currently available research vessels or vessels designed for an alternate purpose that require modifications to meet the NGWR requirements.

a. *Hydrographic Research Vessel*

First procured as a survey ship for NOAA in 1967 and refurbished by its current owners in 2002, this vessel located in Seattle, Washington is being offered for sale for \$1.75 million (SeaBoats 2016). An image of the R/V is provided as Figure 27.



Figure 27. Hydrographic Research Vessel. Source: SeaBoats (2016).

The hydrographic research vessel is 231 feet in length with a large deck that can be adapted for a variety of missions. It has four cranes which are essential for the NGWR system. The cranes are a 20,000-pound stern A-frame, 3.6-ton vestravit, 5-ton knuckle crane, and a 9-ton 43-foot telescoping boom crane (SeaBoats 2016).

b. *Single Screw Trawler*

Built in 1998, this ex-fishing vessel, shown in Figure 28, is located in Indonesia and is being offered for sale for \$350,000 (SeaBoats 2019). Over the past five years, it has been working as a shallow survey and utility vessel. It is 81 feet in length with a beam of 22 feet (SeaBoats 2019). It features a large back deck space which can be configured to support various research vessel needs.



Figure 28. Single Screw Trawler Source: SeaBoats (2019).

Due to its time in service and unknown maintenance status, this vessel is likely to require a major overhaul for modifications and repairs to ensure that the system meets the needs of the NGWR system.

3. Contracting of Vessel as Service

Contracting a commercial vessel is provided as an alternative. Specific mission capabilities or operational requirements can be used to select the ideal vessel to satisfy the NBTF customer needs. Vessels would be contracted out as a service and only utilized when required.

By requesting and reviewing contracts and quotes from NUWC DIVNPT for contracting capabilities to commercial vessels, the Team identified several vessels that met requirements outlined by the NBTF to conduct different mission packages defined in Chapter III (DRM).

a. M/V GO America

M/V Go America is a 150-foot long vessel operated out of Louisiana by Guice Offshore (Guice Offshore n.d.). It is included as a contracting option due to similar features to other alternatives and previous history of contracting with NUWC Division Newport (Justin Andrade, personal communication, February 7, 2019). It features a transom-mounted 11-ton A-frame, 7000-pound knuckle boom crane, and 27-inch diameter moonpool. The rear deck measures 90 feet by 30 feet which can accommodate a wide variety of user needs. An image of M/V GO America is provided as Figure 29 (Guice Offshore n.d.).



Figure 29. M/V GO America. Source: Guice Offshore (n.d.).

b. M/V Warren Jr.

The M/V Warren Jr. is a 150-foot long vessel operated by Boston Harbor Cruises (Eclipse Group 2018). Its working deck is 92 feet long and has a 10,000-pound deck crane and stern-mounted 10-ton H-frame crane. It is located in Boston, Massachusetts (Eclipse Group 2018). An image of the M/V Warren Jr is provided as Figure 30.



Figure 30. M/V Warren Jr. Source: Eclipse Group (2018).

c. OSV Determination

Offshore Support Vessel (OSV) Determination is a 115-foot long vessel operated by Silvetti Marine Services out of Lafayette, Louisiana (Silvetti Marine Services n.d.). This vessel is the only OSV classed vessel of its size that includes a 7,500-pound knuckle boom crane, 10-ton A-frame, and bow thruster (Silvetti Marine Services n.d.). An image of the OSV Determination is provided as Figure 31.



Figure 31. OSV Determination. Source: Silvetti Marine Services (n.d.).

VI. ANALYSIS OF ALTERNATIVES

The Team performed an analysis of alternatives (AoA) from options that have the potential to meet the defined system requirements. This AoA allows for the comparison of the alternatives regarding the degree to which they fulfill the system requirements. Quantitative and qualitative comparisons relied on the critical performance measures identified from the system requirements. The Team used several comparison metrics defined from these requirements to grade each alternative effectively. The performance of each alternative is estimated and ranked for each in all measures and compared using a Pugh Matrix.

The Team generated a life-cycle cost estimate (LCCE) for each alternative. The costs are organized into a cost breakdown structure (CBS), which includes initial procurement, modification (if required), operations, and support. The most cost-effective solution is identified by comparing each alternative's performance against the total cost and identifying which choice provides the most value. An evaluation matrix provides a visual tool for analyzing the proposed replacements against each other and aides in selecting the most cost-effective solution.

A. PERFORMANCE ANALYSIS

The TWR-841 and alternative vessel performance parameters are summarized in Table 13. These performance parameters are selected from the requirements defined in Chapter IV due to their importance in meeting the overall system requirements.

Table 13. Vessel Performance Data

Performance Requirement	TWR-841	New Procurement			Existing Vessel Procurement		Contracting as Service		
		Multi Purpose Craft	R/V Sally Ride	Deep Sea Research Vessel	Hydrographic Research Vessel	Single Screw Trawler	M/V GO America	M/V Warren Jr	OSV Determination
Berthing (# of personnel)	18	12	45	28	48	14	20	19	18
Cruising Speed (knots)	10	12	10.5	10	10	8.5	10	9	7.5
Max Speed (knots)	12	18	13	12	14	10 (est.)	11	10	9.5
Operational Range (nautical miles)	2000	500	10545	3114	10925	6630	5300 (est.)	10700 (est.)	12000 (est.)
A- Frame Crane Capacity (pounds)	5000	0	30000	8818	20000	5000	22000	20000	20000
Knuckle Boom/deck crane Capacity (pounds)	4000	11000	22000	4409	10000	5500	14330	10000	7800
Deck Space (square feet)	1372	1179	3036	1521	1950	826	2700	1564	1950

Adapted from: Eclipse Group (2018); Guice Offshore (n.d.); NAVSEA (n.d.-e); NAVSEA (n.d.-f); Scripps Institution of Oceanography (2019); SeaBoats (2017); SeaBoats (2016), SeaBoats (2019); Silvetti Marine Services (n.d.).

Comparing performance parameters for each system are against the NGWR requirements, the team found the following:

The Multi-Purpose Craft meets cruising speed, maximum speed, knuckle boom crane capacity, and deck space requirements. However, the vessel only has berthing for 12 versus 18, endurance of 500 versus 2000 nautical miles, and does not have provisions for an A-frame crane (John Lattanzi, personal communication, April 11, 2019).

The M/V Sally Ride, Deep Sea Research Vessel, and Hydrographic Research Vessel alternatives meet or exceed all NGWR requirements (Scripps Institution of Oceanography 2019; SeaBoats 2017; SeaBoats 2016).

M/V GO America and M/V Warren Jr. meet or exceed all requirements with the exception of the maximum speed being less than the required 12 knots (Guice Offshore n.d.; Eclipse Group 2018).

OSV Determination meets or exceeds personnel space, A-frame crane capacity, knuckle boom crane capacity, and deck space requirements. However, the cruising and maximum speeds are 7.4 and 9.4 knots versus the required 10 and 12 knots respectively. The Team estimated that the vessel's endurance was 12,000 nautical miles based on a fuel consumption rate of 1025 gallons per day and fuel tank capacity of 74,552 gallons (Silvetti Marine Services n.d.).

The Single Screw Trawler vessel exceeds the endurance requirement of 2000 nautical miles but does not meet personnel space, cruising speed, maximum speed, A-frame crane capacity, knuckle boom crane capacity or deck space requirements (SeaBoats 2019). Maximum vessel speed was estimated by multiplying the cruising speed by 1.2 which is consistent with the compared alternatives.

1. Evaluation Measures

The Team identified several evaluation criteria to compare the performance of the proposed alternatives. The measures defined in the DRM and used for evaluation in the AoA are described in the following sections.

a. *Initial Date of Operation for the NGWR*

The initial operational date of the vessel is critical due to the continuous operation of the NBTF. Downtime between the TWR-841's removal from service and when the new vessel is operational is expected to affect their daily operations significantly. This metric is affected by the construction time due for a new build, time to modify a currently operational vessel, or contracting time for services. The sooner the replacement is operational at the NBTF, the higher the score.

b. *Degree to Which the NGWR Meets Payload Support Flexibility Requirements*

Flexibility is a qualitative measure that affects how many types of missions the vessel can undertake. The vessel's ability to handle multiple types of payloads is critical for this metric. Aft deck rollers, heavy cranes, and a modifiable deck are all examples of design features that add additional flexibility for the NBTF. This flexibility allows the operators to adjust the platform as necessary to accommodate different payloads or mission equipment. Maintaining flexibility is critical to take on many of the operations that are requested by NUWC Division Newport every year. Ratings for general payload support requirements such as crane number and capacity, operational load, and cable reel capacity are also evaluated here. Vessels with more flexibility and more equipment included or available will be rated higher.

c. *Degree to Which the NGWR Meets Base Performance Requirements*

The base performance requirements are derived from the hull, mechanical, and electrical (HM&E) requirements of the system. These include different types of equipment including communication systems, electrical power, propulsion, and other auxiliary systems. Vessel equipment meeting these requirements is critical for the normal operation of the vessel at the NBTF. Failing to meet these base performance requirements may affect the overall capabilities or require additional equipment to be added to the vessel. A high rank means exceeding these requirements, allowing for more freedom in the types of operations currently available using the TWR-841.

d. Degree to Which the NGWR Meets Habitability Requirements

For the vessel to conduct extended or overnight operations, there shall be accommodations for the crew and project personnel. The habitability requirements define how many crew members the vessel needs to support, available berthing, and galley provisions. A high rating means the alternative meets or exceeds all habitability requirements with a minimal requirement for modification.

e. Degree to Which the NGWR Meets Operational and Environmental Requirements

The Team used the range and speed of the vessel to compare the operational and environmental requirements against the alternative options. Longer operational ranges are preferred, as missions can extend multiple days at sea, or require deep ocean environments. These mission sets need the vessel to operate for extended periods without refueling and have their unique challenges for the ship and crew. Vessel speed determines the various types of towing operations that can be completed and a larger available range being preferred for additional flexibility. The Team also considered the working sea-state limitations of the vessel in relation to these speeds and endurance to evaluate the performance of the vessel.

f. Degree to Which the NGWR Meets Availability Requirements

Availability analyzes the number of days per year the ship is available for use by the NBTF. This measure takes into account the maintenance down time and the time to conduct both preventative and corrective maintenance on the vessel. Sustaining high availability is critical to the NBTF maintaining their capabilities and accepting new missions on short notice.

2. Requirements Comparison

Alternative vessel features are used to identify the ability of each vessel to meet performance requirements. The Team compared the performance of each alternative and used the results for ranking.

a. *Requirements Comparison Methods*

Each alternative is assessed to rank how well each vessel achieved the evaluation measures based on the system requirements. The functional and non-functional requirements are both included in the evaluation measures. Each alternative is compared based on the current configuration of the vessel, with the exception of the Single Screw Trawler and Hydrographic Research Vessel. Proposed modifications to these two vessels were identified to add missing capabilities.

b. *Initial Date of Operation for the NGWR*

Schedule was captured by analyzing the initial date of operation of each alternative. This is a critical comparison as there will be a period with a capability shortfall between the TWR-841 coming out of service, and when the NGWR can be placed into service.

The five alternatives categorized as a new procurement or modification of an existing vessel were found to be worse than the baseline vessel. Each of these alternatives has a significant lead time for procurement. This procurement time for new build vessels is assumed to include preparation and award of a contract with the shipyard, fabrication time of the new vessel, and test and evaluation (T&E) for acceptance of the vessel. While procurement of an existing vessel would eliminate the fabrication time, there would be additional investment required to modify the vessel to meet performance requirements.

The three contracted-as-a-service options are considered to be ranked more favorably than the baseline TWR-841 vessel, as they are currently operational. These vessels would be maintained by the operating company, and are currently in better working condition than the TWR-841. Limiting these options is the time for the generation of the initial services contract which may take up to one year to award with subsequent tasking executed in five days to one month. The company may also need to stand-up the vessel, which is not expected to exceed 24 hours (Eclipse Group. n.d.).

c. *Degree to Which the NGWR Meets Payload Support Flexibility Requirements*

The payload support flexibility of the vessel evaluates how adaptable the vessel is to different missions and the equipment available to complete them. Table 13 listed many of the defined performance metrics for the proposed alternatives. The Team used each vessel's equipment to determine how well they matched against the defined requirements.

The Multi-Purpose Craft is of very similar build to the TWR-841. It includes a ramp with rollers for torpedo-like payload retrieval and two cranes for over the side retrieval. This, along with sufficient deck space for a CONEX box, provides a lot of flexibility for its operators. Although the crane capacity and flexibility are better, the MPC does not utilize an A-Frame which may limit the capabilities. Due to these factors, the MPC is rated the same as the baseline.

Out of the new procurement options, the R/V Sally Ride had the best performance. With space available for four CONEX boxes, a much larger working deck, and significantly increased crane and frame capacity, the R/V Sally Ride easily handles various mission requirements. While it does not specifically have a ramp with rollers as the TWR-841 does, the variety of cranes and winches allow for many types of payloads and the potential for multiple retrievals at once. Overall, the R/V Sally Ride was rated significantly higher than the baseline.

The Deep Sea Research Vessel provides some similar capabilities to the TWR-841, with a four-ton A-Frame and three-ton winch. It also has an over the side crane with similar capabilities as the TWR-841, with a larger estimated deck space. The Team rated this vessel similar to the baseline as the vessel does not have an aft ramp with rollers, offsetting the increased crane capacities.

For proposed repurposed vessels, the Hydrographic Research Vessel was found to have greater performance than the Single Screw Trawler. Its crane capacity was better than that of the baseline vessel. Due to this and its increased deck space, the vessel was rated slightly better than baseline, despite lacking a ramp with rollers. The Single Screw Trawler, due to its size and fishing boat design, showed poor performance overall. It has no A-frame,

limited crane capacity and deck space, and no ramp with rollers in the base design. With significant modifications adding a 5,000-pound A-Frame and a 5,500-pound knuckle boom crane, the vessel would be feasible. Due to the smaller working deck and lack of aft ramp and rollers, the vessel is rated slightly worse than baseline.

For the three contracting-as-a-service options, two were found to be better than the baseline, and one on par. The vessel M/V GO AMERICA contains an 11-ton A-frame on the stern which is significantly better than the requirement, and a 10-ton knuckle boom crane which would easily accommodate the required loads proposed (Guice Offshore 2019). It also has approximately 2,450 square feet of deck space (Guice Offshore 2019), which is an improvement on the current TWR-841 vessel at 1372 square feet (Lawrence Rainey, personal communication, April 11, 2019). While the M/V GO America does not have any ramps or rollers, it does contain a moonpool. A moonpool allows for underwater deployment and storage of payloads, allowing for additional flexibility for customers than using only an over-the-side crane (wiseGEEK n.d.). The vessel also allows for the installation of a 20-foot CONEX box upon request. Overall, the M/V GO America was rated better than the baseline of the TWR-841.

The M/V Warren Jr., provides significantly better crane capacity than the baseline, but lacks the flexibility provided by the ramp and rollers. The Team rated this vessel as better than the baseline because the large deck space allows for more equipment and the significantly better crane capacity.

The final rental option, the OSV Determination has a 3.5-ton knuckle boom crane and a 10-ton A-Frame on the stern (Silvetti Marine Services n.d.). It provides ample deck space for use by project personnel and the option to include a 20-foot CONEX upon request (Silvetti Marine Services n.d.). The vessel, however, does not have any type of ramp with rollers for payload retrieval. Payloads can only be deployed and recovered over the side of the vessel using this design. Due to this, the Team rated the OSV Determination approximately the same as the baseline for this category. It has better crane capacity and A-Frame strength, but lacks the flexibility a different deployment method provides.

d. Degree to Which the NGWR Meets Base Performance Requirements

We assume that all vessels contain sufficient working space and provide required basic sea keeping equipment for standard operations. The following ratings are focused on the available power and electronic equipment on the vessels.

Performance of the MPC was determined to be similar to the baseline, with similar horsepower and electronics suite provided and only slightly less deck space. Similar to the payload support flexibility analysis, the R/V Sally Ride provided the highest base performance out of all the alternatives. It is rated better than the baseline as it provides significantly more power to the vessel and carries a wide variety of electronic equipment in addition to the minimum requirements such as bottom profilers, survey sensors, and broadband satellite. The Deep Sea Research Vessel provides more power than the baseline vessel, but only carries similar electrical equipment and was rated similar to the baseline.

Both the Hydrographic Research Vessel and the Single Screw Trawler provide sufficient power and both only provide the standard functional electronics. Additional scientific equipment would need to be installed onto the vessels separately. Due to the high power provided, the Hydrographic Research Vessel is rated higher than the baseline while the Single Screw Trawler is rated the same as the baseline.

The M/V GO America provides total horsepower and standard electronic systems matching that of the baseline and therefore is rated similar to the baseline. Similar reasoning was applied to the M/V Warren Jr. and OSV Determination as both provided acceptable power levels and a sufficient electronics suite.

e. Degree to Which the NGWR Meets Habitability Requirements

Each vessel specifications were examined for their available crew and personnel size, available heads, HVAC systems, and the supplied galleys.

Being a new vessel, the MPC provides modernized accommodations. This results in a rating of slightly better than the baseline despite having fewer allowable personnel on board. As with the previous sections, the R/V Sally Ride provides the best habitability performance of all the alternatives with significant available crew sizes, services, and

HVAC systems, leading to a rank of significantly higher than the baseline. The Deep Sea Research Vessel also provides significantly more room for scientific personnel and more working space. Based on this, the vessel was rated higher than the baseline.

The Hydrographic Research Vessel provides significant habitability equipment as a result of the vessel being designed for long-term mission deployments. There is significantly more room for project personnel, multiple heads and kitchens, laundry service, and a much larger galley. Due to these factors, it is rated significantly better than the baseline. The Single Screw Trawler, due to its size, provides minimal support with a slightly smaller personnel size than the baseline. It has similar galley and head provisions, giving it a rating of slightly worse than the baseline.

The M/V GO America provided similar resources as the TWR-841, and was rated the same as the baseline. Both the M/V Warren Jr. and the OSV Determination were rated slightly higher than the baseline. The M/V Warren Jr provides more heads, a laundry area, and more lounge space for personnel to work, while the OSV Determination was found to have better galley and scullery size and availability.

f. Degree to Which the NGWR Meets Operational and Environmental Requirements

The MPC does not perform well due to a significantly lower operational range compared to the TWR-841, resulting in a Team ranking of worse than the baseline despite the vessel having slightly higher speed capabilities. Performance of the R/V Sally Ride was rated significantly higher than the baseline due to its longer operational range and the capability of operating in sea-ice. Its cruising and maximum speed are comparable to the TWR-841. Performance of the Deep Sea Research Vessel also had similar cruising and maximum speeds, however it is comparable in other metrics and is rated similar to the baseline.

The Hydrographic Research Vessel has similar cruising and maximum speeds as the baseline, but has a significantly higher operational range, causing the Team to rate it significantly higher than the baseline. The Single Screw Trawler is rated similar to the baseline, with a noticeably lower cruising speed, but longer operational range.

The Team was unable to determine the operational and environmental performances directly for the three rental options. It is estimated that these options are comparable to the baseline based on their size and known missions conducted.

g. Degree to Which the NGWR Meets Availability Requirements

While every vessel will require weekly required routine maintenance, it is assumed that newer vessels would encounter fewer major overhauls or failures between inspection cycles. Due to this, the newer build vessels were rated higher than existing vessels that are already fielded. The rental vessels were assumed to have similar availability, even though the maintenance would be the responsibility of the contractor between mission deployments. Only emergency maintenance would need to be conducted in times that would affect the operational availability of the system. They are not considered to have higher availability because the NBTF would not be the only customers using the vessels, and it is possible that individual vessels would not be available for use by the NBTF for a specific mission due to conflicts with other customers.

Based on this reasoning, all three contracting-as-a-service options, the M/V GO America, M/V Warren Jr, and OSV Determination were rated similar to baseline. The three new vessels (MPC, R/V Sally Ride, and Deep Sea Research Vessel), were considered significantly better than the baseline. Since the Hydrographic Research Vessel has been in service longer than the TWR-841, it was rated slightly worse than the baseline, despite being refurbished in 2002 (SeaBoats 2016). The Single Screw Trawler, while already in service, is relatively new compared to the TWR-841 and of similar size granting a rating slightly higher than the baseline.

B. COST ANALYSIS

System life-cycle costs are used to compare the identified alternatives against each other. The life-cycle of the NGWR starts at system design and concludes at disposal. Expenses are analyzed using the elements defined in the cost breakdown structure (CBS) which provides a functional breakdown of expenses to ensure a standard comparison between alternatives.

Using the CBS, categories are established and costs assigned to each for a total life-cycle costs comparison. The comparison does not factor in DoD funding types and phasing.

1. Cost Breakdown Structure

A CBS provides a functional breakdown of system expenses over the vessel's life-cycle. "The cost breakdown structure links objectives and activities with resources and constitutes a logical subdivision of cost by functional activity, major element of a system, and one or more discrete classes of common or like items" (Blanchard and Fabrycky 2011, 576).

To compare the life-cycle cost of each alternative, the Team developed a CBS depicted in Figure 32. The elements reflect the expected life-cycle cost of the NGWR and will be used to ensure that there is no overlap or double counting between the cost elements.

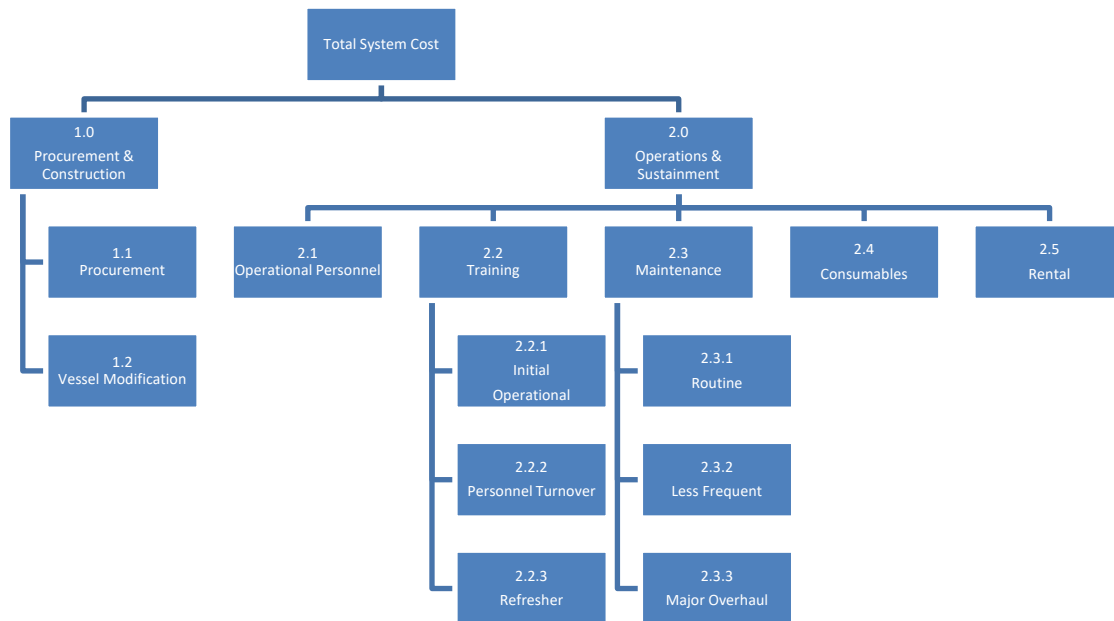


Figure 32. NGWR Cost Breakdown Structure

a. *Procurement and Construction*

Procurement and construction costs consist of expenses incurred during the process of obtaining or modifying the vessel. The Team assumes that the alternative is a complete vessel with all equipment already in its designated location. This equipment will include the engine, frame, cranes, and any other essential items attached to the vessel. If the alternative vessel requires any custom modifications to meet system requirements, the associated costs of material and labor will be captured in vessel modifications.

b. *Operations and Sustainment*

Operations and Sustainment (O&S) costs are expenditures incurred during system operations. They include operational personnel, training, maintenance, consumables, and rental costs. The cost associated with personnel consists of labor costs for the crew needed to perform the operational missions. These individuals will typically include a captain, engineer, watch deck patrol, and chef required for the operation (Rodney Griffith, personal communication, January 24, 2019). A typical mission will last for a single day, while some operations may extend the at-sea period to 15 days (Rodney Griffith, personal communication, January 24, 2019).

Costs associated with training will be broken down into three main categories; initial operational, personnel turnover, and refresher training. Initial operational is the cost to learn how to operate the vessel and any new equipment. Personnel turnover is the cost required whenever a new worker is coming aboard the vessel. Refresher training is the cost for mandatory refresher training to stay compliant with NAVSEA regulations.

The majority of the cost elements for the operation and support belong to maintaining the vessel. The costs are separated into routine, less frequent, and major overhaul maintenance.

Routine maintenance consists of performing Navy PMS checks, damage checks, and planned equipment maintenance. Less frequent maintenance consists of corrective maintenance of subsystem failures and major overhaul maintenance consists of major repairs or service that require shipyard level repairs.

Consumables for this analysis consists of fuel for normal vessel operation.

Rental is the cost for acquiring the contracting-as-a-service alternatives for daily operations.

2. Disposal

Disposal cost is the price associated with the end of service life preparation and disposal of the system. The Team does not include disposal costs in the CBS due to the assumption that costs for disposal are negligible. When the vessel requires disposal, it will go back to the boat inventory manager at PMS325 (Rodney Griffith, personal communication, March 7, 2019). Once the manager takes possession of the vessel they will determine whether to sell the vessel or to break it down for parts.

3. Life-Cycle Cost Estimations

Twenty-year life-cycle cost estimates for each system were calculated for the operation of the NGWR. Table 14 contains the cost breakdown aligning to the CBS.

Table 14. NGWR Alternative System Costs

Cost Element	New Procurement			Existing Vessel Procurement		Contracting as Service		
	Multi Purpose Craft	R/V Sally Ride	Deep Sea Research Vessel	Hydrographic Research Vessel	Single Screw Trawler	M/V GO America	M/V Warren Jr	OSV Determination
20 Year Total System Cost	\$21,113,192	\$93,724,756	\$24,396,630	\$24,396,917	\$11,810,820	\$9,582,387	\$10,264,387	\$6,740,587
1.0 Production & Construction	\$8,300,000	\$71,000,000	\$10,000,000	\$2,081,620	\$683,470	\$0	\$0	\$0
1.1 Procurement	\$8,300,000	\$71,000,000	\$10,000,000	\$1,750,000	\$350,000	\$0	\$0	\$0
1.2 Vesel Modification	\$0	\$0	\$0	\$331,620	\$333,470	\$0	\$0	\$0
2.0 Operation & Support	\$12,813,192	\$22,724,756	\$14,396,630	\$22,315,297	\$11,127,350	\$9,582,387	\$10,264,387	\$6,740,587
2.1 Operational Personnel	\$1,595,264	\$3,988,160	\$2,592,304	\$3,988,160	\$1,196,448	\$1,584,387	\$1,584,387	\$1,584,387
2.2 Training	\$735,997	\$1,839,992	\$1,195,995	\$1,839,992	\$551,998	\$0	\$0	\$0
2.2.1 Initial Operational	\$507,584	\$1,268,960	\$824,824	\$1,268,960	\$380,688	\$0	\$0	\$0
2.2.2 Personnel Turnover	\$101,517	\$253,792	\$164,965	\$253,792	\$76,138	\$0	\$0	\$0
2.2.3 Refresher	\$126,896	\$317,240	\$206,206	\$317,240	\$95,172	\$0	\$0	\$0
2.3 Maintenance	\$7,755,931	\$11,632,604	\$8,690,731	\$14,231,145	\$8,907,025	\$0	\$0	\$0
2.3.1 Routine	\$2,666,931	\$6,543,604	\$3,601,731	\$6,351,145	\$2,227,025	\$0	\$0	\$0
2.3.2 Less Frequent	\$289,000	\$289,000	\$289,000	\$680,000	\$680,000	\$0	\$0	\$0
2.3.3 Major Overhaul	\$4,800,000	\$4,800,000	\$4,800,000	\$7,200,000	\$6,000,000	\$0	\$0	\$0
2.4 Consumables	\$2,726,000	\$5,264,000	\$1,917,600	\$2,256,000	\$471,880	\$1,598,000	\$1,880,000	\$1,156,200
2.5 Rental	\$0	\$0	\$0	\$0	\$0	\$6,400,000	\$6,800,000	\$4,000,000

a. *Procurement and Construction Estimate Cost*

To obtain the procurement costs, each alternative's cost to procure or procure and modify to meet NGWR requirements were captured. Vessel modifications are the costs required to modify the existing vessel procurement alternatives to meet the NGWR requirements and upgrades due to age. The modifications to new procurement alternatives were not assessed as it is assumed that these vessel alternatives are delivered ready to use in an as-is configuration to customer needs.

The Hydrographic Research vessel meets all NGWR requirements but requires upgrades to its engines and electrical equipment due to age. The purchase price of a representative Caterpillar 3512 engine is \$160,000 per engine for a combined total of \$320,000 (Machine Trader n.d.). The electronic equipment currently aboard the Hydrographic Research vessel is functional but lacks a digital radar, LORAN antenna, and weather receiver. These electronics are estimated at \$5,200 (Furuno n.d.-b), \$110 (West Marine n.d.), and \$500 (Furuno n.d.-a) respectively for a total cost of \$5,810. Using the assumption that labor costs match unit costs, an additional cost of \$5,810 was added to install the units, leading to a total install price of these electronics as \$11,620 for the Hydrographic Research Vessel.

The Single Screw Trawler does not meet the berthing, cruising speed, A-frame crane capacity, knuckle boom crane capacity, and deck space NGWR requirements. Berthing, cruising speed, and deck space are assumed to be architecture-based attributes which would require significant vessel modification. The Team omitted these costs due to their significant expense of implementation. The cost to add a knuckle boom crane rated at 5500 pounds is estimated to be \$100,000. This is calculated using representative cranes and using a rough order of magnitude assumption that labor for installation is the same as the unit cost of \$50,000 (Crane Trader n.d.). The cost to add an A-frame crane rated at 5000 pounds is estimated to be \$200,000. This estimate is based on a rough order of magnitude comparison to install a knuckle boom crane with an increase of 100% to account for the custom installation and vessel modifications.

The electronic equipment currently aboard the Single Screw Trawler is functional but lacks a black box, LORAN antenna, and weather receiver. These electronics are estimated at \$16,125 (Husick 2007), \$110 (West Marine n.d.), and \$500 (Furuno n.d.-a) respectively for a total cost of \$16,735. Again, using the assumption that labor costs match unit costs, an additional cost of \$16,735 was added to install the units, leading to a total install price of these electronics are \$33,470 for the Single Screw Trawler.

For vessels contracted-as-a-service, no procurement or vessel modifications were included and cost to contract the vessel is included in consumables.

The total Procurement and Construction cost for each alternative is calculated by adding the procurement and vessel modification costs.

b. Operation and Sustainment Estimate Cost

The Operation and Sustainment (O&S) costs consist of sustainment cost incurred from personnel, training, maintenance, and consumables.

(1) Operational Personnel

The operators of the NGWR are assumed to consist of ND-04 (GS-12 Step 6) grade crew members. The mean hourly wage for an ND-04 pay band employee is \$45.32 per hour and the typical mission will consist of a period of 11 hours (U.S. Office of Personnel Management n.d.). Based on the historical TWR operations provided in Table 3, the Team assumed that the NGWR is expected to perform 20 missions per year.

To develop the total cost for the operational support of each alternative vessel, the total number of crew members for each vessel can support was multiplied by the hourly wage, typical mission duration, and number of missions per year.

Operational personnel costs for the alternatives categorized as contracting-as-a-service include labor from a government contracting specialist for contract generation, contract administration, vessel scheduling, and other labor to manage the vessel availability. This cost for each vessel was estimated to be one full time equivalent person.

(2) Training

The total estimated training cost is broken down into three groups: initial operational, personnel turnover, and refresher training.

Initial operational training consists of the crew members learning how to operate and inspect the vessel and its equipment. Using historical training hours, the assumption was made that it would take the employees 70 hours per year for initial operational training (Rodney Griffith, personal communication, March 7, 2019). The total cost of the initial operational training is calculated by multiplying the total training hours, crew size, and hourly wage of the ND-04 band employees.

Personnel turnover training accounts for potential loss of crew members that may leave the vessel due to different factors such as illness or life-changing events. The assumption was made that each vessel can be expected to lose and have to re-train 20% of the maximum number of their crew members. These crew members will be required to complete the same initial operational training of 70 hours. The total cost for personnel turnover is 20% of the crew size multiplied by hourly rate of ND-04 band employee and the initial operational training hours.

Refresher training consists of a reduced level of initial operational and equipment training. It is assumed that only a quarter of the material will be included in the training. The total cost of the training is calculated by multiplying the crew size, hourly rate of ND-04 band employee, and 25% of the initial operational training hours.

(3) Maintenance

To find the total estimated maintenance cost, the overall maintenance was broken down into three groups; routine, less frequent, and major overhaul.

Routine maintenance cost is applicable for all alternative vessels s excepting the contracted-as-a-service options. This is based on the vessel maintenance being the responsibility of the contractor who manages the vessel.

For the other alternative vessels, the routine maintenance required includes performing the Navy PMS maintenance checks estimated to take 70 man-hours a week.

These PMS maintenance checks will need to be performed weekly regardless if the vessel has conducted an operation or not. The total cost for routine maintenance is calculated by multiplying the hourly rate of an ND-04 employee by weekly maintenance labor-hours and the number of workweeks in a year. Each vessel's routine maintenance cost was scaled based on the vessel's length.

Less frequent maintenance cost is defined as corrective maintenance of subsystem failures. This maintenance is for all vessel options with the exception of the alternatives contracted-as-a-service where the contractor who manages the vessel is responsible for maintenance.

Less frequent maintenance cost is estimated using the average of subsystem failures repairs for the TWR-841 from 2015-2017. In 2015, there was a cost of \$35,000 to perform a top-end overhaul. In 2016, there was a cost of \$43,000 to perform a main reduction-gear repair. In 2017, there was a cost of \$23,000 to replace a new HVAC system (Rodney Griffith, personal communication, January 17, 2019). Taking the average of these repair costs, the estimated less frequent maintenance cost is \$34,000 per year.

Newly procured vessels are assumed to have negligible less frequent maintenance costs for the first five years of operation. For years 6–10, it is estimated that 20% of the baseline \$34,000 less frequent maintenance costs are incurred. For years 11–15 it is estimated that 50% of the baseline less frequent maintenance costs are incurred and for years 15–20, it is estimated that 100% of the baseline \$34,000 less frequent costs are incurred. For the Single Screw Trawler and Hydrographic Research Vessel 100% of the less frequent maintenance costs are applied each of the 20 years based on age as a conservative assessment.

Major overhaul maintenance costs are any major repairs or service that require shipyard-level repairs. The baseline cost for shipyard-level repair is calculated using TWR-841 historical repair costs. In 2015 and 2016, approximately \$800,000 was spent for major repairs for an average of \$400,000 per major overhaul maintenance (Rodney Griffith, personal communication, March 7, 2019). Due to the condition-based nature of major overhaul maintenance actions, the Team assumed a number of shipyard level repairs based

on vessel age using a fixed average cost. New vessels are assumed to have 12 shipyard level repairs over the 20-year timeframe. The Single Screw Trawler is assumed to have 15 shipyard level repairs over the 20-year timeframe, and the Hydrographic Research Vessel is assumed to have 18 shipyard level repairs over the 20-year timeframe. Alternative vessels contracted-as-a-service do not have any major overhaul maintenance costs. The vessel maintenance is the responsibility of the contractor who manages the vessel.

(4) Consumables

Items considered as consumables for this analysis only consist of fuel. Other consumables identified are assumed to be negligible and constant across vessels. Fuel costs are calculated using current estimated fuel cost of \$2.82 per gallon (Waterway Guide 2019) and fuel consumption rates were provided or estimated based on total vessel horsepower.

(5) Rental

The rental costs are the average cost of renting each contracting-as-a-service vessel for the average number of operational days a year. Included costs are rental of the vessel, captain, essential crew and the vessel's baseline equipment. This cost is calculated by multiplying the daily rate of each vessel by 20 operational days a year. The M/V GO America has an estimated daily rate of \$16,000 (Eclipse Group 2018). The M/V Warren Jr. has an estimated daily rate of \$17,000 (Eclipse Group 2018). The OSV Determination has an estimated daily rate of \$10,000 (Richard Thornton, personal communication, February 07, 2019).

C. ANALYSIS OF ALTERNATIVES SUMMARY

Alternatives are compared using the cost, performance, and qualitative data provided in Sections A and B of this chapter. The data is compared using graphs as visual models and a Pugh Matrix to rank each alternative. Alternatives that are dominated when comparing performance versus cost are eliminated and trade-offs are identified for a recommendation.

While the performance analysis and cost analysis individually show clear favorites, it is critical to examine them together to analyze the entire picture of each alternative. The

R/V Sally Ride is the best performing vessel out of all the alternatives. When looking at its relative cost however, the production and construction cost of \$71M is significantly over the \$35 million maximum life-cycle cost. Based on this up-front cost, the Team eliminated the R/V Sally Ride as a feasible alternative.

Similarly, the Single Screw Trawler is the cheapest option out of the procurement options. The vessel's performance is significantly worse than the other alternatives, even with modifications to add a crane and A-Frame. Its speed and deck space are lower, and it has less available space for project personnel. Due to these factors, the Single Screw Trawler was eliminated as a feasible alternative based on the inability to meet the majority of the NGWR performance requirements.

1. Performance versus Cost

To compare alternatives to total vessel cost, graphs are provided to allow for trade-offs to be conducted. Total system cost for 20 years of future service use was graphed against the performance requirements summarized in Table 13.

Requirement 3.3.1 states that the NGWR shall have berthing for 18 personnel. Shown in Figure 33, all alternatives exceed the requirement with the exception of the MPC alternative with the OSV Determination providing the best value for berthing followed by the M/V GO America.

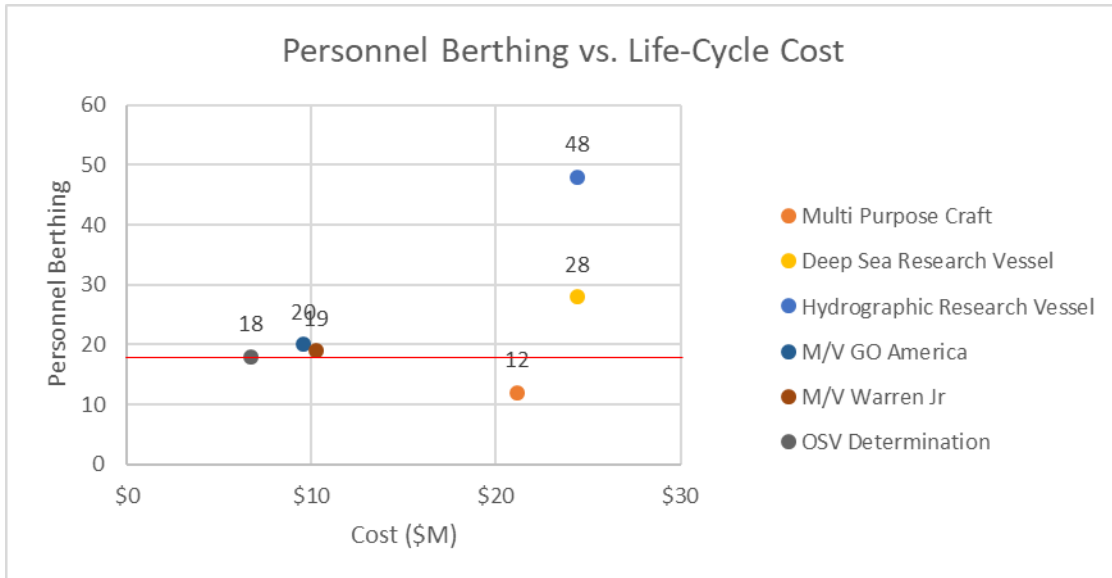


Figure 33. Personnel Berthing versus Life-Cycle Cost

Requirement 1.2.3 states that the NGWR shall have a minimum cruising speed of 10 knots. Shown in Figure 34, the MV GO America provides the best value based on cruising speed while meeting the requirement.

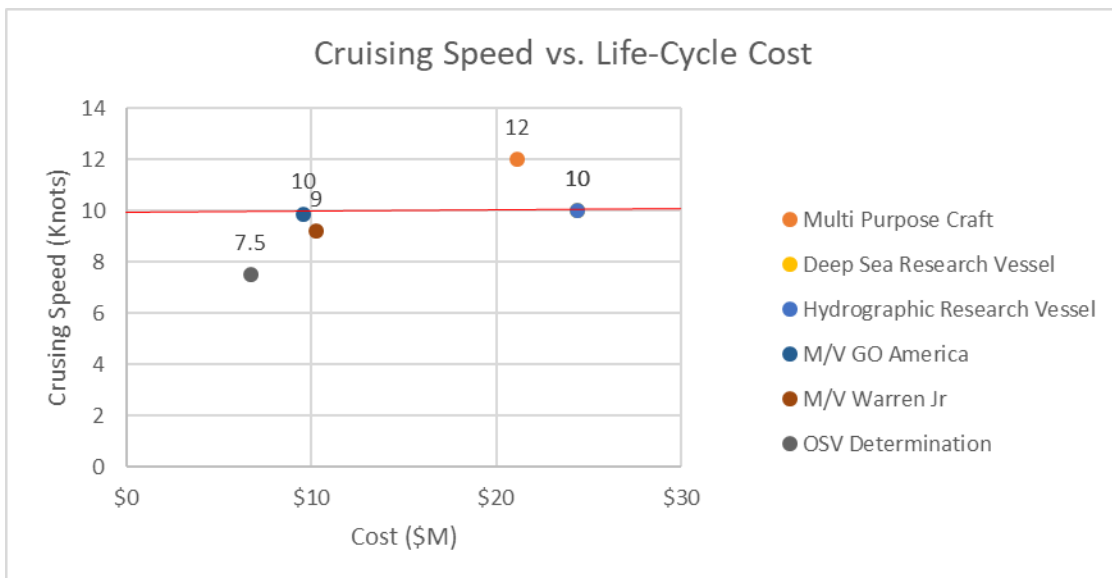


Figure 34. Cruising Speed versus Life-Cycle Cost

Requirement 1.2.4 states that the NGWR shall be able to reach or exceed a maximum speed of 12 knots. Shown in Figure 35, the MPC provides the best value based on maximum speed while meeting requirements.

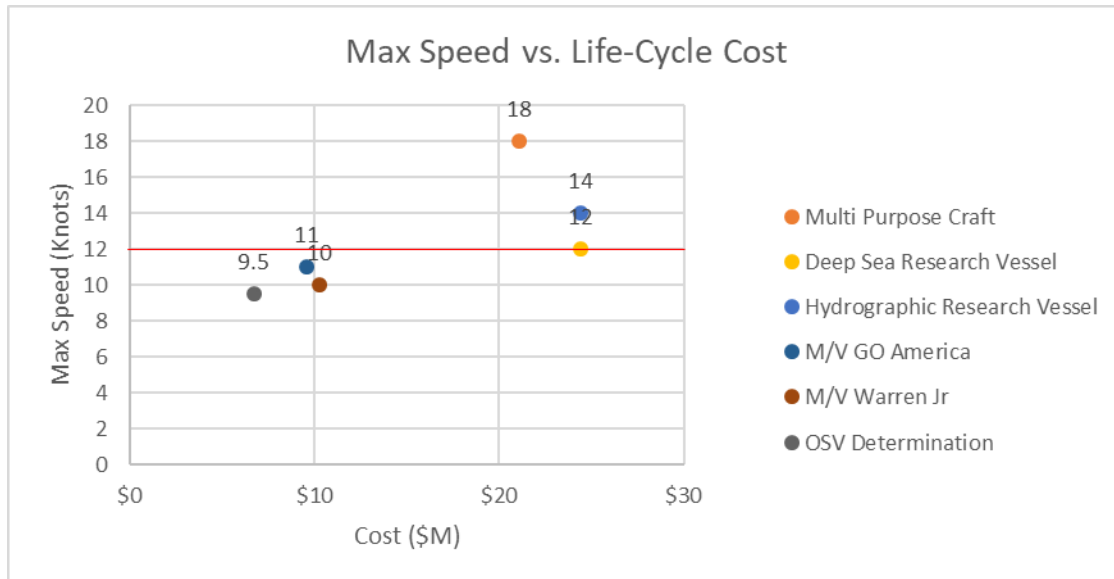


Figure 35. Maximum Speed versus Life-Cycle Cost

Requirement 1.2.2 states that the NGWR shall have a minimum operational range under normal cruising speed and operational load of 2000 nautical miles. Shown in Figure 36, the estimated operational range calculated for the OSV Determination provides the best value based on operational range.

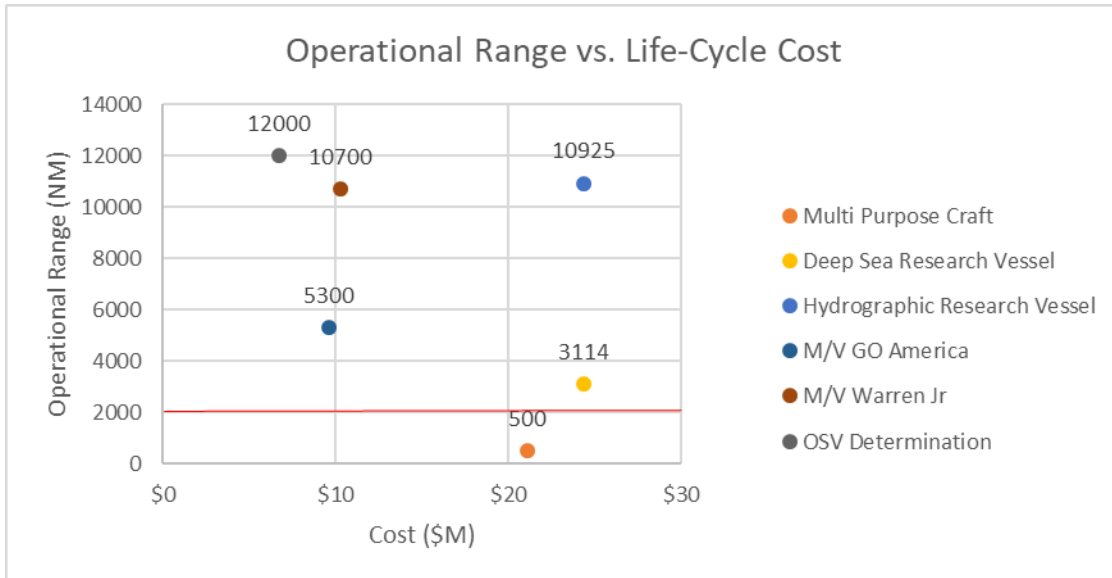


Figure 36. Operational Range versus Life-Cycle Cost

Requirement 2.2.6 states that the NGWR shall have a minimum 5,000-pound A-Frame at the stern for handling large tow-bodies. Shown in Figure 37, OSV Determination provides the best value based on A-Frame crane capacity. The MPC shows a value of zero as it does not have an A-Frame installed on the vessel.

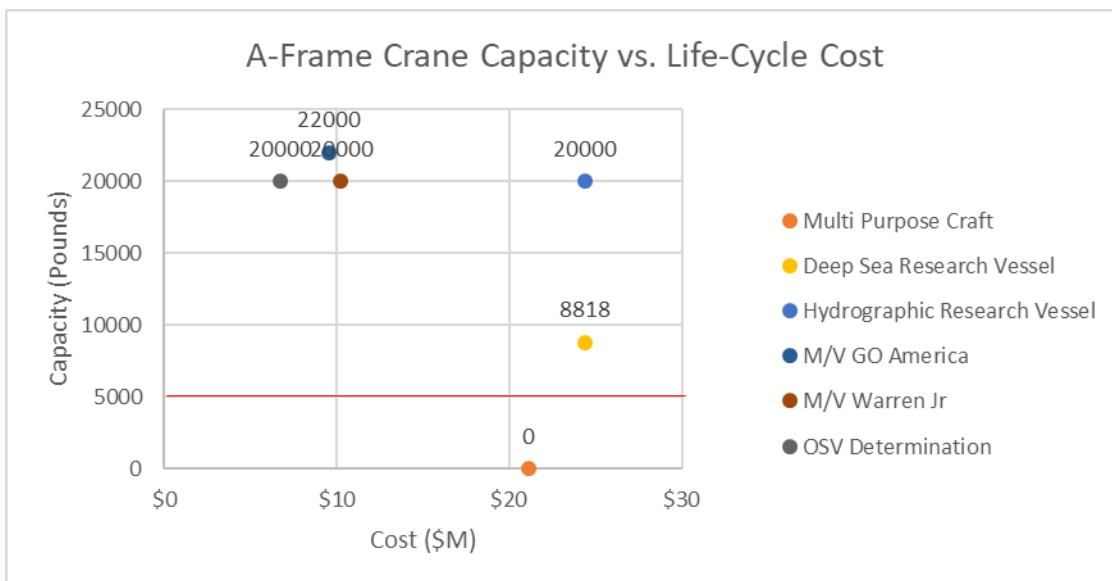


Figure 37. A-Frame Capacity versus Life-Cycle Cost

Requirement 2.1.5 states that the NGWR shall have a minimum 5,000-pound knuckle boom crane. Shown in Figure 38, the OSV Determination provides the best value based on knuckle boom crane capacity.

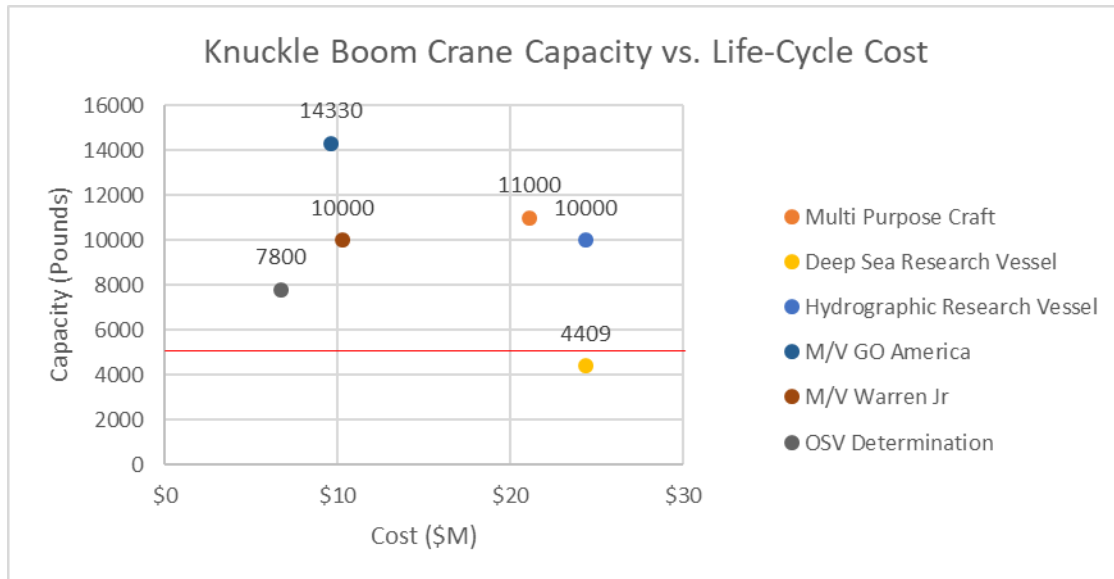


Figure 38. Knuckle Boom Crane Capacity versus Life-Cycle Cost

Requirement 2.1.5 states that the NGWR shall be capable of retrieving and stowing a minimum of 12 heavyweight or 18 lightweight torpedoes, or a payload of 17 tons. Because not all alternatives currently support torpedo-based operations, vessels are compared based on total deck space. The Team determined that to support the requirement, a minimum deck space of approximately 1300 square feet is required. Shown in Figure 39, OSV Determination and M/V GO America provide the best value based on deck space.

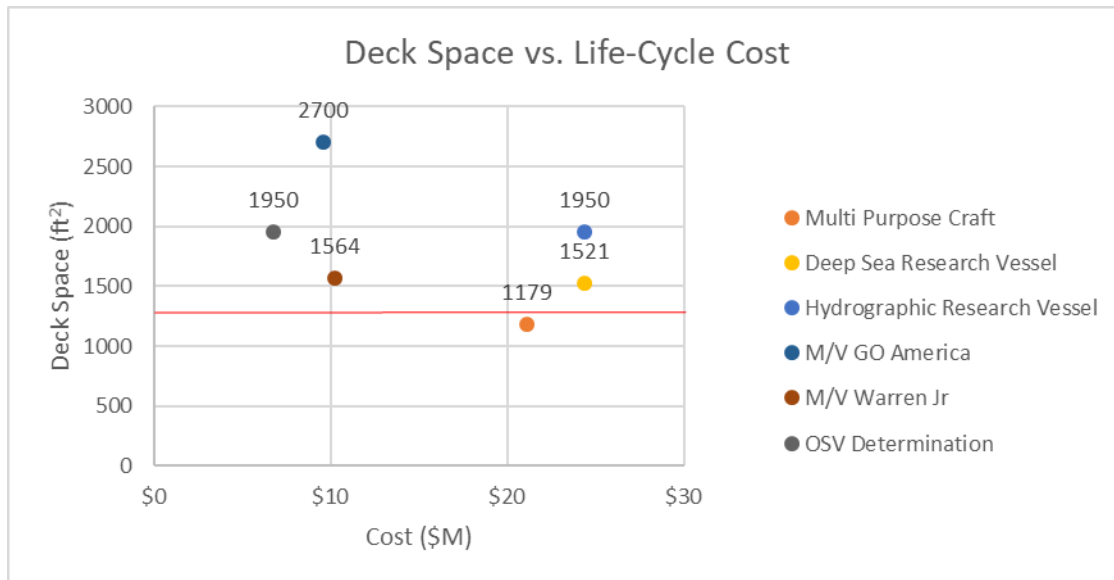


Figure 39. Deck Space versus Life-Cycle Cost

2. Performance Evaluation

To rank and visually compare the performance evaluations of each alternative, a Pugh Matrix is used. A Pugh Matrix “is a type of Matrix Diagram that allows for the comparison of a number of design candidates leading ultimately to which best meets a set of criteria” (Burge 2009, 1). Burge further explains that it utilizes pairwise comparisons for identified alternatives against various measures or criteria. While the ratings are subjective based on the data gathered and experience of the analysts, it is a useful tool for conducting a sensitivity analysis on the data, providing knowledge to the users on the strength of a particular alternative decision (Burge 2009).

The Team ranked each alternative against the baseline of the TWR-841 vessel. An “S” is used to designate that the alternative is ranked the same as the baseline for the measure. In signifying a ranking is better than the baseline, a “+” is used, while a “-” is used for a performance worse than the baseline. A “++” or “--” is used when the alternative is ranked significantly better or worse than the baseline, respectively. The scores are then totaled for each alternative with “S” being zero, “+” and “-” scoring as one and negative one, and “++” and “--” scoring as two and negative two, respectively. The total scores are then used to rank the alternatives, with the highest total score giving a rank of one, and the

lowest total score a rank of eight. A completed Pugh Matrix for the NGWR alternatives is shown in Table 15. As previously discussed in section VI.1, the R/V Sally Ride and Single Screw Trawler alternatives were removed from the final comparisons.

Table 15. Completed Pugh Matrix Ratings

		Alternatives						
		TWR-841	Multi-Purpose Craft (MPC)	Deep Sea Research Vessel	Hydrographic Research Vessel	M/V GO America	M/V Warren Jr.	OSV Determination
Criteria	Initial Date of Operation	S	-	-	-	+	+	+
	Payload Support Flexibility	S	S	S	+	+	+	S
	Base performance	S	S	S	+	S	S	S
	Habitability	S	+	+	++	S	+	+
	Operational & Environmental	S	-	+	++	NR	NR	NR
	Availability	S	++	++	-	S	S	S
	Total +	0	3	4	6	2	3	2
	Total -	0	2	1	2	0	0	0
	Total Score	0	1	3	4	2	3	2
	Ranking	-	6	2	1	3	2	3

3. Analysis of Results

After reviewing the combined results, a preferred option was chosen from both a procurement alternative and vessel contracted-as-a-service. This was due to the fundamental differences in the two types of alternatives. All of the vessels contracted-as-a-service have significantly lower 20-year total system cost than the procurement options, with comparable performance levels. This leads to the conclusion that the contracting-as-a-service alternatives are the best option only considering these two factors.

When considering the flexibility provided if the NBTF owned and managed the boat, different trade-offs are identified. The rental options require time to prepare and award a contract initially and for each individual mission. Combined with the dependence on the availability of the vessel, customers would need to plan out missions far in advance. The specific vessel desired may also not be available, and a different vessel would need to be used for the mission. However, rental options provide the flexibility of choosing a different type of vessel in the future based on changing mission requirements. If the NBTF owned and managed the vessel, they would maintain control over its availability and would be able to take on more requests on short notice. This provides more schedule flexibility, but the NBTF is then responsible for the larger up-front acquisition cost and the maintenance of the vessel. Ultimately, the type of acquisition is the determination of the stakeholders, so the Team decided to propose the preferred options for both methodologies. The contract-as-a-service option was chosen as a preferred type of vessel based on its performance characteristics.

The 20-year total system cost and overall performance of the three procurement alternatives (MPC, Deep Sea Research Vessel and Hydrographic Research Vessel), are very comparable. All three are within \$5M total cost, and ranked within three points of each other on the Pugh Matrix. The Hydrographic Research Vessel provides the highest performance of the three with a relatively low up-front acquisition cost. Since the vessel is over 30 years old, it has significantly higher operation and support costs due to the assumed maintenance efforts required to keep the vessel operational. Ultimately, the Team decided it was not preferred to replace one aging vessel with another, even though its performance was better.

Comparing the Deep Sea Research Vessel and the MPC, each had comparable system cost. The performance was also comparable with the exception of the operational and environmental and payload support flexibility performance. The MPC does not meet berthing requirements, operational range requirements, and does not have an A-Frame, compared to the Deep Sea Research Vessel, which meets all three. The MPC, however, does contain an aft end ramp with rollers similar to the TWR-841 baseline vessel. As the Team researched alternatives, we discovered that the aft end ramp and rollers is a unique feature and is not included in the vast majority of similar types of vessels. It is a unique feature specifically included for simplifying the operation of retrieving torpedo-like payloads. If the NBTF identifies this feature as a “must have” for the NGWR, then the Team would recommend the MPC. If not, the Deep Sea Research Vessel is the preferred option based on the better overall performance in almost all categories for \$3M more over the 20-year period.

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VII. CONCLUSIONS

A. TWR-841 REPLACEMENT RECOMMENDATION

The goal of compiling all of the discussed performance and cost data for the identified alternatives is to provide the NBTF with a recommended path forward for the replacement of the aging TWR-841. By analyzing the data gathered, various trends were identified with advantages and disadvantages. Contracting vessels-as-a-service in general provides a cheaper alternative than the replacement of TWR-841. This comes at the cost of a lack of vessel and personnel flexibility due to availability constraints. Purchasing a vessel requires a much higher up-front cost, but is available on short notice and its government staffing allows for the easier conduct of classified missions.

Taking these into consideration, the Team chose alternatives that would provide the best value for the NBTF. If the NBTF concurs that the contracting of a vessel-as-a-service meets the operational needs of the test facility, The OSV Determination provides the best value. OSV Determination provides sufficient payload support flexibility while meeting the base performance and habitability requirements of the baseline vessel. The vessel's speeds are lower than the minimum requirements, but it provides larger crane capacity and deck space compared to the other contracting options that the Team believes to be an overall advantage.

The Deep Sea Research vessel, which is a new procurement alternative, provides high performance and flexibility. Its combination of crane support, significant habitability features, and larger operational range provides new capabilities to the NBTF. System cost is also comparable to the MPC with the trade-off of not including the aft ramp with rollers.

B. FUTURE WORK

To further refine the analysis covered in this paper, the Team recommends that the following efforts be conducted to validate assumptions and provide a more complete and accurate analysis.

1. Continue conducting a thorough requirements analysis with the NBTF and the Support Ships, Boats, and Craft Program Office PMS 325 to identify further specifications required of the new vessels and to validate the assumptions made during the system requirements development.
2. Continue work to conduct a complete LCCE to expand and refine the costs included in accordance with Cost Assessment and Program Evaluation (CAPE) recommendations.
3. Further explore actual alternatives available for each variety of vessel identified. The Team chose a variety of vessel to capture a broad snapshot of alternatives in order to aid in defining an acquisition approach. Further definition of vessels within individual acquisition approaches should be explored to capture a larger sub-set of alternatives.
4. Use forecasting methods to better predict required mission packages in the future and further refine the Design Reference Mission to capture additional future capabilities.

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