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MISSION ENGINEERING METHODOLOGY FOR REALIZATION OF UNMANNED SURFACE VESSEL OPERATIONS

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

MISSION ENGINEERING METHODOLOGY FOR REALIZATION OF UNMANNED SURFACE VESSEL OPERATIONS

by

Raffianne N. Doyle

September 2022

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13. ABSTRACT (maximum 200 words)

The Navy has included unmanned systems as a key enabler for the future fleet. Congress has mandated that the Navy (PMS 406) provide demonstrated testing and documentation sufficient to support transition of Unmanned Surface Vessels (USVs) from prototype to operational.

Commercial USV certification examples only address safety of navigation and do not provide certification requirements for autonomy, nor do they consider the operational mission context or requirements for the USVs. No current methodology exists that decomposes the certification metrics and standards, including the complexity of the intended USV missions. Mission engineering (ME) provides the systems engineering rigor and methodology to ensure that the USV prototypes are evaluated in their intended missions. The mission objectives were captured in Design Reference Missions (DRMs). The DRMs provided the operational sequence of events for the USVs to accomplish their mission in support of commander's intent. The DRMs decomposed into mission essential tasks (METs). The METs were mapped to the critical systems performing the METs. This methodology can be further analyzed to produce the complete complement of certification requirements for PMS 406. Analysis revealed several gaps. The communications systems and the human-in-the-loop interaction with the USVs need to be reevaluated based upon the mission analysis.

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MISSION ENGINEERING METHODOLOGY FOR REALIZATION OF UNMANNED SURFACE VESSEL OPERATIONS

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ABSTRACT

The Navy has included unmanned systems as a key enabler for the future fleet. Congress has mandated that the Navy (PMS 406) provide demonstrated testing and documentation sufficient to support transition of Unmanned Surface Vessels (USVs) from prototype to operational.

Commercial USV certification examples only address safety of navigation and do not provide certification requirements for autonomy, nor do they consider the operational mission context or requirements for the USVs. No current methodology exists that decomposes the certification metrics and standards, including the complexity of the intended USV missions. Mission engineering (ME) provides the systems engineering rigor and methodology to ensure that the USV prototypes are evaluated in their intended missions. The mission objectives were captured in Design Reference Missions (DRMs). The DRMs provided the operational sequence of events for the USVs to accomplish their mission in support of commander's intent. The DRMs decomposed into mission essential tasks (METs). The METs were mapped to the critical systems performing the METs. This methodology can be further analyzed to produce the complete complement of certification requirements for PMS 406. Analysis revealed several gaps. The communications systems and the human-in-the-loop interaction with the USVs need to be reevaluated based upon the mission analysis.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABS	American Bureau of Shipping
AiP	Approval in Principle
BMD	Ballistic Missile Defense
BV	Bureau Veritas
CNO	Chief of Naval Operations
COLREGs	International Maritime Regulations for Preventing Collisions at Sea
EEIs	Essential Elements of Information
EMCON	emissions control
EW	electronic warfare
HAZID	Hazard Identification
ISR	intelligence, surveillance, reconnaissance
LPD	low probability of detection
LPG	low probability of geolocation
LPI	low probability of interception
MDUSV	Medium Displacement Unmanned Surface Vessel
ME	mission engineering
MET	mission essential tasks
NDAA	National Defense Authorization Act
NISTIR	National Institute of Standards and Technology Interagency/Internal Report
ONR	Office of Naval Research
OPSIT	Operational Situations
OUSV	Overlord Unmanned Surface Vessel
PEO USC	Program Executive Office for Unmanned and Small Combatants’
PMS 406	Program Manager Unmanned Maritime System 406
PSA	Perception and Situational Awareness
SCO	Strategic Capability Office
STA	Senior Technical Authority
T&E	Test and Evaluation

UARV	unmanned armed reconnaissance vehicles
UAV	unmanned air vehicles
UGV	unmanned ground vehicles
USV	unmanned surface vessel

EXECUTIVE SUMMARY

To regain and maintain a strategic advantage against current and future adversaries, the Navy has included unmanned systems as a key enabler for the future of the fleet. The Department of the Navy, Unmanned Campaign Framework dated March 16, 2021, provides the Navy unmanned vision to "Make unmanned systems a trusted and sustainable part of the Naval force structure, integrated at speed to provide lethal, survivable, and scalable effects in support of the future maritime mission." Congress has mandated that the Navy provide demonstrated testing and documentation sufficient to support transition of the USV from prototype to operational.

The American Bureau of Shipping (ABS) Autonomous and Remote Control Guide was developed by ABS to provide industry with requirements for maritime vessels. The Bureau Veritas (BV) performed the first certification of a USV for commercial use and awarded the first Approval in Principle (AiP) to the French company iXblue for the vessel DriX. Both commercial USV certification examples only address safety of navigation and do not provide certification requirements for autonomy nor consider the operational mission context or requirements for the USVs. No current methodology exists that decomposes the certification metrics and standards and includes the complexity of the missions intended for the unscrewed vessels in their strategic objectives. The Navy does not have certification metrics, which consider the complexity of the USV missions as the operational climate transitions from peacetime to conflict or war.

Mission engineering (ME) provides the systems engineering rigor and methodology to ensure that the USV prototypes are evaluated in the missions they are intended to support, and this methodology represented in Figure 1, can provide the basis for the certification metrics.

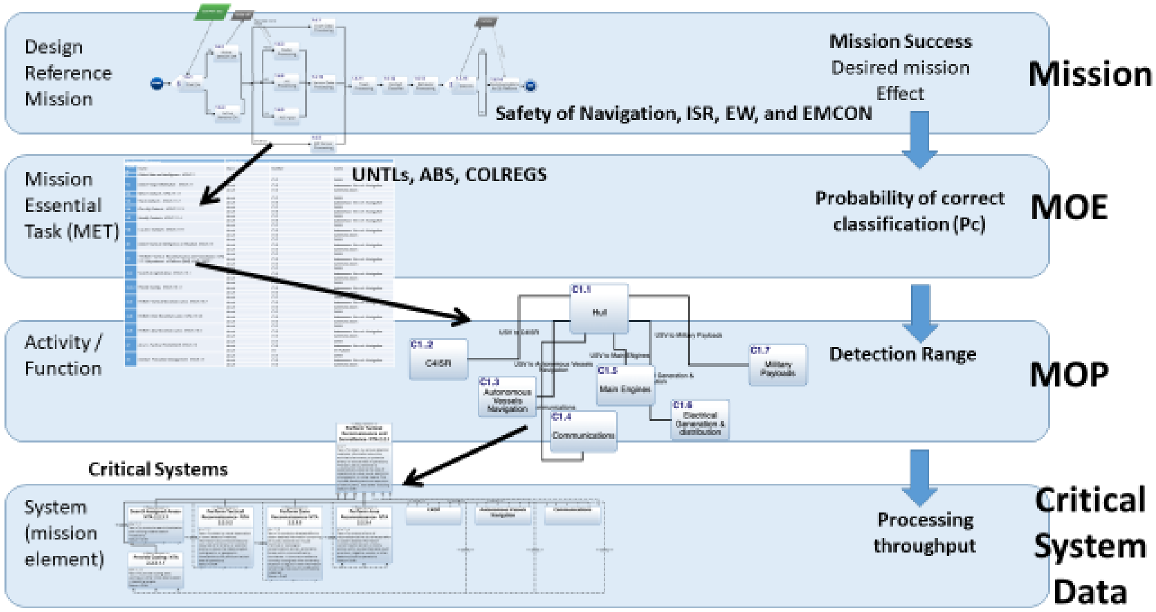

Figure 1. Mission Engineering Methodology for the USV Fleet

The Navy has established strategic objectives for the USVs as a critical component of the future fleet. To ensure that these strategic objectives are met, this thesis began with the end in mind to ensure that the operational mission objectives for the USV are the high-level basis for certification. The mission objectives were captured in mission threads or Design Reference Missions (DRMs). The DRM provided the operational sequence of events for the USVs to accomplish their mission in support of military objectives or commander's intent. The DRMs were decomposed into mission essential tasks (METs) required for mission success. To fulfill the objectives assigned by Congress in the 2019 National Defense Authorization Act (NDAA), the METs were mapped to the Critical Systems performing the METs. This ensures metrics for mission success mapped to Critical Systems include the operational context of the USVs for the fleet. This methodology can be further analyzed to produce the complete complement of certification requirements for PMS 406.

In the analysis performed in this thesis through this decomposition, several gaps were identified. The first mission capability gap identified is in communications. The current Communications systems on the USVs will not support the emissions control

(EMCON) mission and perform in support of intelligence, surveillance, reconnaissance (ISR), and electronic warfare (EW) as the operational climate transitions from peacetime. The Communications systems need to be replaced with low probability of detection (LPD) / low probability of interception (LPI) / low probability of geolocation (LPG) communications systems to support the ISR, EW, and EMCON missions.

Additionally, the complexity of the missions as the transition from peacetime to conflict and war will require an increase in human-in-the-loop interaction. The level of autonomy should change as the transition from peacetime to conflict and wartime to account for the significant increase in emergent behaviors as the complexity of the environment increases due to commanders' intent and interaction with threat assets. This also supports the need for LPD / LPI / LPG communications systems on the USVs to allow for continued communications between the Command Vessel and the USVs as this transition occurs.

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I. INTRODUCTION

To regain and maintain a strategic advantage against current and future adversaries, the Navy has included unmanned systems as a key enabler for the future of the fleet. The Department of the Navy, Unmanned Campaign Framework dated March 16, 2021, p 8, provides the Navy unmanned vision to “Make unmanned systems a trusted and sustainable part of the Naval force structure, integrated at speed to provide lethal, survivable, and scalable effects in support of the future maritime mission.” Additionally, the Framework specifically calls out the need for Unmanned Surface Vehicles (USVs) to execute independent missions in set operating boxes performing “Near-Independence” on an autonomy scale.

Program Executive Office for Unmanned and Small Combatants’ (PEO USC) Program Manager Unmanned Maritime System (PMS) 406 has six prototype efforts to develop and operationalize unmanned surface vehicles (USV). The two prototype classes that are currently under development and testing by PMS 406 are Medium Displacement USV (MDUSV) and Overlord USV (OUSV). PMS 406 is to provide the critical information that will be the basis for certification of the USV fleet, with a focus on MDUSV and OUSV. The 2019 Congressional National Defense Authorization Act (NDAA) created the Senior Technical Authority (STA) and required that the STA certify, “Each critical USV system has been demonstrated through testing of a prototype or identical component in its final form, fit, and function in a realistic environment.” The critical systems are defined as: “critical hull, mechanical, electrical, propulsion, and combat systems of such class of vessels, including systems relating to power generation, power distribution, and key operational mission areas identified by the Fleet (Congress 2019).” This thesis provides the methodology and initial decomposition of mission essential tasks (METs) needed for PMS 406 to build the certification standards for the USVs. The mission assigned to the USV in this analysis is to perform maritime intelligence, surveillance, reconnaissance (ISR), electronic warfare (EW), and emissions control (EMCON) with International Maritime Regulations for Preventing Collisions at Sea (COLREGs) compliant navigation and obstacle avoidance autonomously (O’Rourke 2022). As a baseline, the USVs must perform successful autonomous COLREGs compliant navigation through successful detection and avoidance of static and moving objects of diverse sizes.

A. BACKGROUND

The 2021 Chief of Naval Operations (CNO) Navigation Plan sets the commander's intent for the use of USVs in the fleet.

> Unmanned platforms play a vital role in our future fleet. They will expand our intelligence, surveillance, and reconnaissance advantage, add depth to our missile magazines, and provide additional means to keep our distributed force provisioned. Furthermore, moving toward smaller platforms improves our offensive punch while providing affordable solutions to grow. (Chief of Naval Operations [CNO] 2021)

In order to realize the CNOs commander's intent, a data-driven certification methodology is required that considers the complexity of the operational mission the USVs are envisioned to perform. The methodology requires decomposition, which begins with the missions. Essential Elements of Information (EEIs) are the information that needs to flow between the functional elements for a system to operate within the construct of a given mission. A mission can be defined as the highest level of a task assigned to a system. The mission assigned to the USV in this analysis is to perform maritime ISR, EW, and EMCON with COLREGS-compliant navigation and obstacle avoidance autonomously. The 4D/RCS Reference Model Architecture as articulated in the National Institute of Standards and Technology Interagency/Internal Report (NISTIR) 6910 (2002), provides a clear decomposition of the command and information structure required for the operation of unmanned air vehicles (UAV), unmanned armed reconnaissance vehicles (UARV) and unmanned ground vehicles (UGV). PMS 406 can use this reference architecture to identify the USV critical systems, the hierarchy of commands, the flow of information between the critical systems, and sensory elements. This knowledge can also be applied to the architecture of the USV to decompose the EEIs in common between the UXSs and those that may be unique due to the change in environment between the various unmanned systems and those critical variables that only apply to maritime operations.

Each unmanned platform is broken down into four subsystems: Reconnaissance, Surveillance, Target Acquisition (RSTA), Communication, Weapons, and Mobility. For the USV, the Mobility subsystems vary from those of the other domains due to different environmental factors that are introduced by the maritime domain. Specifically, USVs must abide by and operate within the International Maritime Regulations for Preventing Collisions at Sea (COLREGs) as well as the United Nations Convention on the Law of the Sea (UNCLOS) while unmanned (USCG 2020).

B. PROBLEM STATEMENT

Congress mandated that the Navy provide demonstrated testing and documentation sufficient to support the transition of the USV Fleet with a special focus on the MDUSV and OUSVs (Overlord USV) from prototype systems to operationally viable combat platforms. The current methods for verification and validation for the USV prototypes evaluate only safety of navigation and obstacle avoidance in peacetime. No current methodology exists that provides the certification metrics and standards and includes the complexity of the missions intended for the unscrewed vessels in their strategic objectives. COLREGS and the American Bureau of Shipping (ABS) standards for commercial USVs, provide baseline references to develop metrics for certification for operation of USVs in peacetime. The Navy does not have certification metrics, which consider the complexity of the USV missions as the operational climate transitions from peacetime to conflict or war.

C. BENEFIT OF STUDY

In the fiscal 2022 report to Congress on shipbuilding, the Navy proposed building a fleet of between 321 and 372 manned ships over the next three decades, augmented by between 77 and 140 uncrewed ships. To meet operational requirements, the Fleet intends to augment the current manned Fleet with USVs. The Fleet does not have a methodology to certify that the USVs can support these operational roles. This thesis provides a methodology to develop the operational performance measures of the USV against the Fleet mission objectives. The thesis provides PMS 406 with a methodology to develop the certification requirements needed to answer the 2019 Congressional NDAA.

D. PROJECT OBJECTIVES

To establish the clearly defined metrics and objectives needed for the Navy to certify that the USVs can support their operational missions, the missions need to be defined, decomposed and their METs mapped from these missions. The METs can be mapped to the critical systems identified by Congress in the 2019 NDAA that require demonstrated testing and documentation. Using the Mission Engineering (ME) approach and methodology to establish mission definitions and characterization, this thesis decomposes the ISR, EW, and EMCON missions intended for the USV Fleet. Design Reference Missions (DRM) were developed to clearly define the strategic objectives intended for the USVs and provide an initial MET list and mapping to critical systems which can be used for development of the certification plan. The current test and evaluation program for the USVs has focused on the autonomy, perception and situational awareness (PSA) Systems in support of autonomous COLREGS navigation and obstacle avoidance missions in peacetime (Bautista and Jardot 2021) The proposed methodology takes into consideration and provides the initial identification of the METs and associated critical systems required for the more complex execution of the ISR, EW and EMCON missions intended for the USV Fleet. This thesis decomposes and models the DRMs, defines METs, and maps them to critical systems for the MDUSV and OUSV during mission execution.

E. KEY ASSUMPTIONS

This analysis relies on three key assumptions. The first assumption is that all prototype experimentation, test, and evaluation to date has primarily focused on the performance of the USV autonomy in safety of navigation and obstacle avoidance during peacetime operations. The complexity of operational missions intended for the USV by the Fleet have not been considered in the transition from peacetime into conflict and wartime operations. The second assumption is that to perform the intended roles of the USV in conflict and wartime there needs to be a modification of the human-on-the-loop interactions to manage the complexity. The third assumption is that Mission Engineering (ME) is the methodology needed to fully illustrate the complexity of the operational missions intended for the USVs.

F. THESIS OVERVIEW

This thesis provides an overview of the gap in certification metrics needed for the Navy to transition the USV fleet from prototype to operational. Current test and evaluation objectives and analysis methodologies are reviewed.

Chapter II provides an overview of previous work performed around certification of autonomous surface vessels in the commercial world. This previous work is used as a baseline set of metrics, which lack the complexity introduced as the USVs transition from peacetime operations to supporting their operational missions in crisis and wartime. Additionally, Chapter II will provide an overview of the previous work performed using the ME methodology. Chapter III ME methodology is then used as a framework to analyze and outline the methodology for development of the certification methods needed to incorporate this level of complexity. Design Reference Missions (DRMs) are developed to map and characterize the mission complexity. The commercial standards and the METs identified in the DRM are used as the basis of the metrics for decomposition and mapping to the USV critical systems. Chapter IV provides analysis of the DRMs, MET and model development in support of this thesis. Chapter V provides recommendations and future work

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II. PREVIOUS WORK

The United States Navy is developing USVs for use in warfighting mission execution. Because autonomous systems are still new, the validation and certification methodologies are still evolving. While USVs are being used in the commercial shipping domain, the Navy has not developed standards for certification of USVs for warfighting missions. The Bureau Veritas (BV) performed the first certification of a USV for commercial use. BV awarded the first Approval in Principle (AiP) to the French company iXblue for the vessel DriX. DriX is intended for use in hydrographic and geographical surveys for both the U.S. (United States) National Oceanographic and Atmospheric Administration (NOAA) and the French Navy's Hydrographic and Oceanographic Service (Bureau Veritas 2022). The BV AiP certified the system architecture, the operational envelop, hull, and autonomy functions. All surface vessels, manned and autonomous, need to abide by the International Regulations for Preventing Collisions at Sea (COLREGS) but currently no accepted certification or associated metrics exist for USVs in support of a naval operational mission specifically none for certification of autonomy in support of Naval operational missions. The BV AiP certification is the first ever awarded and it only considers autonomous operations for COLREGS and specifically hazard avoidance in a peacetime situation.

The United States Government Accountability (GAO) Report dated April 2022, titled "Uncrewed Maritime Systems, Navy should improve its approach to maximize early investments," evaluated the Navy's strategy to counter our adversaries' aggressions at sea with uncrewed surface and undersea vehicles. While this may be a good strategy from an operational standpoint, technological development needs to be there to support the operational missions intended by the Navy. The GAO findings from this review of the current MDUSV and OUSV programs identify that the Navy has yet to:

> Establish criteria to evaluate prototypes in order to inform readiness of prototype efforts to transition to acquisition programs and develop improved schedules for prototype efforts. (GAO 2022, p. 2)

The Office of Naval Research (ONR), Strategic Capabilities Office (SCO) and now PMS 406 have been performing test and evaluation (T&E) of the prototype USVs at sea. The T&E programs for the MDUSV and OUSV to date have primarily focused on the ability of the USVs to perform successful COLREGS operations autonomously in a peacetime environment.

To transition from prototype to operational, the USVs must pass a Technology Readiness Assessment (TRA). The TRA requires the critical systems called out in the 2019 NDAA to achieve Technology Readiness Levels (TRLs) of 6. TRLs define the readiness levels for systems to progress from prototype to acquisition by their technical maturity (Office of the Director, Defense Research and Engineering [DDR&E] 2009). The TRLs are based on a scale from 1 to 9 with 9 being the most mature. TRL6 is the point at which a system or subsystem representative model or prototype has been tested in a relevant environment (Office of the Director, Defense Research and Engineering 2009). TRL6 is the threshold that needs to be met for the MDUSV and OUSVs to progress from prototype to acquisition. The relevant environment as described in the DRM helps define the key metrics for the TRA evaluation for the MDUSV and OUSVs (DDR&E 2009). The TRA (Title 10 U.S.C. 2366b) is a formal, metric-based process and accompanying report that assesses the maturity of critical hardware and software technologies called Critical Technology Elements (CTE) to be used in the systems (Office of the Director, Defense Research and Engineering. 2009). The operational missions intended for the USVs are a critical consideration in this transition, to fully map these considerations; a mission engineering methodology can be implemented. This methodology has been used in development, integration, evaluation, and fielding of prototype systems in autonomous air vehicles, and the Ballistic Missile Defense Systems(BMDS).

A. COMMERCIAL USV STANDARDS

Although the Navy does not currently have the standards for certification of the USVs in support of operational missions, the commercial shipping industry has standards, which provide a baseline for the safety of navigation needed for the USV to perform during peacetime. COLREGS and ABS in addition to the AiP from BV, provide this baseline. However, they do not specifically cover the certification of autonomy.

1. COLREGS

The International Regulations for Preventing Collisions at Sea 1972 (COLREGS) are the internationally accepted navigation regulations that all vessels must comply with. All vessels (manned and unmanned) which operate on waters outside of established navigational lines of demarcation and specifically all vessels flying the Unites States flag must comply with these "rules of the road." (USCG 2020). The USVs must comply with COLREGS maneuvers and hazard avoidance with one nautical mile closest point of approach.

2. ABS Autonomous and Remote-Control Guide

The ABS Autonomous and Remote-Control Guide provides commercial shipping industry with requirements for maritime vessels and offshore units installed with autonomous or remote control functions for compliance (ABS 2021). This guide does not provide certification metrics or requirements for the autonomy systems onboard the vessels. The requirements only address maritime safety of navigation and operations in accordance with COLREGS.

3. Bureau Veritas (BV) Approval in Principle (AiP)

The BV AiP for USV addresses the safety requirements of a maritime drone operating under the concept of remotely supervised autonomy. BV conducted a Hazard Identification (HAZID) study in support of NI641, the guidelines for autonomous shipping (Bureau Verita 2019). This study and approval are the first certification of a USV; however, the certification only covers the autonomous operations of the machinery in the vessel and hazard avoidance. It does not cover the complex mission autonomy that the Navy has planned for the USVs in support of ISR, EW and EMCON missions.

B. USV TEST AND EVALUATION PROGRAM

PEO USC has been conducting tests and evaluation of the prototype MDUSV and OUSV ships over the past several years through a series of at sea and underway events (Bautista and Jardot 2021). The overarching objectives for these events have been primarily to demonstrate the ability of the vessels to perform safety of navigation and obstacle avoidance in the autonomous mode (Bautista and Jardot 2021). Data collection and limited data analysis has been performed from these events primarily to validate the number of hours spent in autonomy and to understand the behaviors performed by the vessels while in autonomous mode (Bautista and Jardot 2021). The following data is available from MDUSV and OUSV for evaluation and analysis (Bautista and Jardot 2021).

The data sources in Table 1 (Bautista and Jardot 2021) have been used to perform root cause analysis of any anomalies seen during the at sea events. The data collected can be used to support a date-driven analysis and certification once the certification metrics and methodologies have been developed.

Table 1. USV Test and Evaluation Data. Source: Bautista and Jardot (2021).

Autonomy
• Autonomy contacts
• COLREGS state (duration of engagements, minimum distance to ownship, starting distance to ownship)
C2
• Control requests • Communication logs
HM&E
• Vessel machinery time series: propulsion, steering, electrical, HVAC, alarms
Missions
• Start & end times of each mission
• Autonomy mission input parameters
Sensors
• INS (GPS, pitch, roll, heading)
• AIS
• Radar tracks

C. MISSION ENGINEERING TO SUPPORT CERTIFICATION

"Mission Engineering (ME) is the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system of capabilities to achieve desired warfighting mission effects" (DDR&E 2020).

Mission Engineering (ME) provides the systems engineering rigor and methodology to ensure that the USV prototypes can be evaluated in the missions they are intended to support, and that this methodology can provide the basis for the certification metrics (DDR&E 2020).

The ME methodology used during the Fight the Naval Force Forward (FNFF) 21st Century Combined Arms (C2A) Advanced Naval Technology Exercise (ANTX) Live, Virtual and Constructive (LVC) (FNFF 21st C2A ANTX LVC) conducted in 2019 at the Naval Information Warfare Center (NIWC) Pacific (Doyle 2019). During this exercise, thirty-two prototype technologies were evaluated for their performance and mission effectiveness as integrated within the context of eighteen mission threads. Each individual prototype had been assessed for the performance of their systems individually, but it was not until the prototypes were integrated within the context of their potential missions were the warfighters and acquisition community able to determine if they would meet their intended impact on the operational mission.

Ballistic Missile Defense (BMD) uses ME as a phased adaptive approach to the for development, T&E, certification, and deployment of their Ballistic Missile Defense System (BMDS) (Braunger, Sacco, and Anderson 2012). ME is critical in the certification of the BMDS because of the interconnections and integrated capability that the BMDS provides. It is through the ME process that this complex system of systems can be evaluated and understood within the complex mission context.

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III. METHODOLOGY

This chapter provides an overview of the methodology developed and used in the analysis needed to certify the USV meets the requirements to support the operational missions intended by the Fleet.

> Begin with the end in mind, a carefully articulated problem statement, the characterization of the mission and identification of metrics, and working through the collection of data and models needed to analyze the mission and document/convey the outputs (results). (USDR&E 2020, p. 5)

A. MISSION ENGINEERING

The Navy has established strategic objectives for the USVs as a critical component of the future fleet. To ensure that these strategic objectives are met, this thesis will begin with the end in mind and ensure that the operational mission objectives for the USV are the high-level basis for certification. The mission objectives are captured in mission threads or DRMs. The DRM provides the operational sequence of events for the USVs to accomplish their mission in support of a military objectives or commander's intent. DRMs provide the overarching criteria for mission success. The DRMs are decomposed into mission essential tasks (METs). These METs break down the mission into tasks that are required for success and can be used to assign metrics for evaluation of the mission success. To fulfill the objectives assigned by Congress in the 2019 NDAA, the METs can then be mapped to the Critical Systems performing the METs to ensure that the metrics for mission success and the Critical Systems can be appropriately analyzed to produce the appropriate certification requirements. Figure 1 provides a depiction of the Mission Engineering methodology implemented for this purpose. The next chapter includes an example implementation of the ME methodology in support of the USV certification objectives and analysis of the initial implementation..

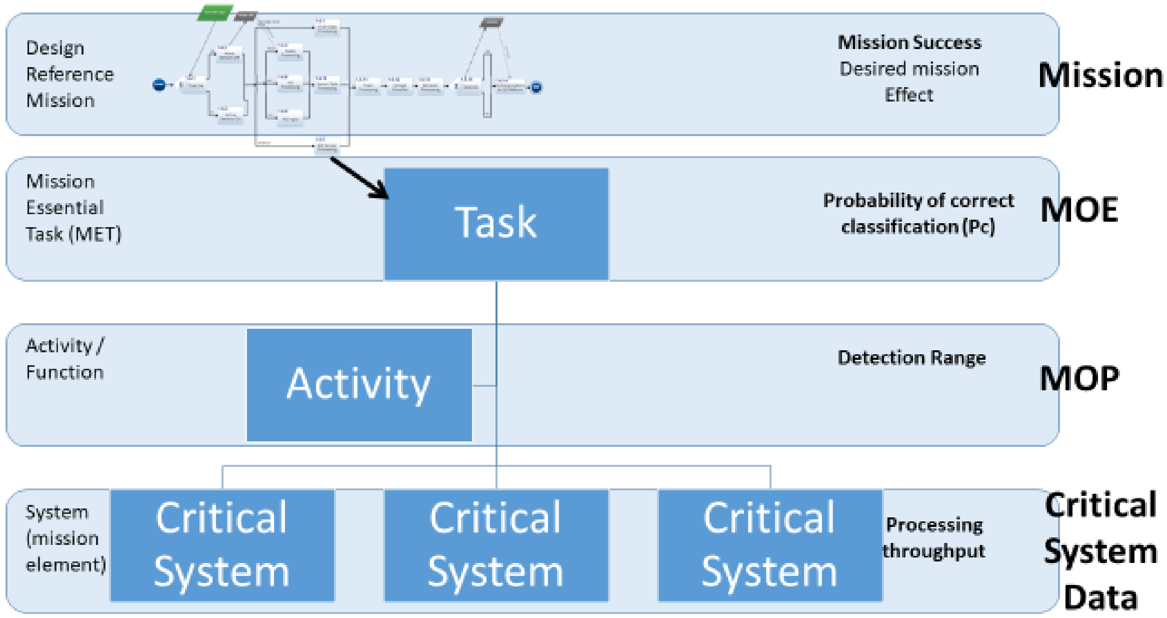

Figure 1. Mission Engineering Methodology Implementation. Adapted from DDR&E (2020).

IV. ANALYSIS AND RESULTS

This chapter explores the use of the ME methodology for development of the certification criteria for the USVs in support of the ISR, EW and EMCON missions. This exploration provides an initial implementation of this methodology that can be used as a framework and the basis for the initial certification plan for the USV Fleet.

A. MISSION ENGINEERING IMPLEMENTATION

Development of the mission required for the USV in the form of a DRM is the first step in the implementation of the ME process as depicted in Figure 1.

B. DESIGN REFERENCE MISSION AND MODELS

According to Giammarco, Hunt, and Whitcomb (2015), "For defense systems, where the word 'mission' refers to the operational sequence of events to accomplish military tasks, the use of a mission context provides a useful way to access the effectiveness of a system in familiar terms."

1. DRM Objective

This DRM outlines an operational context for the MDUSV and OUSVs to augment the intelligence, surveillance, and reconnaissance (ISR) and electronic warfare (EW) of the manned surface fleet. To do so, the MDUSV and OUSV need to meet performance standards for autonomous operations. The analysis question motivating the development of this DRM is the following: *Can the MDUSV or OUSV successfully augment ISR and EW capabilities of the manned surface fleet while in autonomous operations?* This DRM contains several examples of successful autonomous operations during ISR and EW mission execution to support the analysis of the METs and associated Critical Systems to support the development of metrics needed for certification of the vessel's performance.

2. Mission Background

The manned U.S. Naval forces are charged with the mission to perform Distributed Maritime Operations (DMO) to support the day-to-day freedom of navigation mission and be prepared for the high-end fight. A key enabler for these operations has been identified as unmanned systems, which will augment and operate in coordination with the manned surface fleet. To support operations all over the globe including some of the highest traffic and strategically sensitive waters, the USVs must perform a level of Mission Autonomy to support this wide range of operations.

3. Operational Context Projected Operating Environment (POE)

The projected operating environment (POE) in which the USV is expected to operate is in all operations areas currently supported by the U.S. naval fleet however, this DRM will focus on the Western Pacific area of operations to provide and frame the severity of the operational situation in which the USV must be able to operate due to the current threat in the Western Pacific.

4. Threat Details

In the Indo-Pacific Operating Area, the biggest threat facing the U.S. Naval forces is China (O'Rourke 2022). Complicated by the fact that Russia borders this area in the north and often operates their naval forces in this operating area as well (O'Rourke 2022). This creates a significant challenge to the U.S. naval fleet in their mission to achieve and maintain freedom of navigation and wartime control of this area. China's naval ships, aircraft and weapons are much more capable than in the past due to China's significant Navy Modernization efforts. Part of this modernization effort has significantly increased the rate and number of Chinese naval ships being built, manned and deployed (O'Rourke 2022). It is for this reason that the U.S. Navy seeks to augment their currently manned fleet with USVs.

5. Mission Success Requirements

For the mission to be considered successful, all the following high-level requirements must be met through autonomous operations. The USV must successfully perform autonomous operations to the required level of autonomy in order to support ISR, EW, and EMCON capabilities of the manned surface fleet.

The USV shall execute the preplanned missions and support all COLREGS compliant Maneuvers and hazard avoidance within one nautical mile closest point of approach (Bautista and Jardot 2021).

The USV shall execute mission tasks and commands according to the Mission Management functionality to include (Bautista and Jardot 2021):

- Hover: acquire a geographic position and maintain an explicit heading orientation
- Loiter: maintain a radius within a geographic position
- Station Keep: achieve a given position relative to a surface contact
- Vector: maintain commanded course and speed

6. Mission Definition Mission Essential Task (MET)

In accordance with the Department of the Navy's Universal Naval Task List and Joint Mission Essential Task List Handbook, a mission essential task (MET) is an activity (task) selected by a commander, deemed critical to mission accomplishment (2007). The USVs are expected to be able to operate in the same range of operations as the crewed Navy fleet (O'Rourke 2022). In as such, the USV must navigate based on the principles of COLREGS first and foremost. COLREGS are then the baseline METs for the USV to conduct all other missions. The USV must perform COLREGS-compliant maneuvers and hazard avoidance within one nautical mile of closest point of approach of another vessel or obstacle (Bautista and Jardot 2021). COLREGS is divided into six parts. Part B, Steering and sailing rules which includes rules 4 through 19 contain the safety of navigation guides for all vessels (manned and unmanned). The USV will be required to perform the following operations to demonstrate proficiency in this area. The USV provides a series of waypoints to navigate to a specified final waypoint at a designated time and location (USCG 2020). The USV observes and correctly navigates around surface vessel obstacles, geographic obstacles, large biological obstacles, and designated Keep-out zones (KOZs) (Bautista and Jardot 2021). It is expected that the USVs intermediate route planner will generate sufficient intermediate waypoints and routing to safely navigate around all the expected and unexpected hazards and obstacles in accordance with COLREGS guidelines (Bautista and Jardot 2021). Figure 4 depicts the MET action diagram for the baseline safety of navigation and obstacle avoidance missions for the USV. The environment provides both sea states and maritime obstacles, which the USV must continuously perform behaviors to accommodate for any changes in state. The supervisory control station (SCS) is the system and mechanism for humans on the loop to create and send missions in the form of a BPMN file to the USV for execution. A behavior is a specifically executable piece of code that captures a specific functionality. A BPMN describes a mission plan for how individual behaviors will act within the mission plan.

The USV performs behaviors based on the environmental inputs from the sea states and maritime obstacles while concurrently attempting to perform the missions tasked by the SCS. The four mission management tasks as depicted in Figure 2 are Station Keep, Loiter, Hover and Vector. Each of these mission tasks are further decomposed into the action diagram represented in Figure 3.

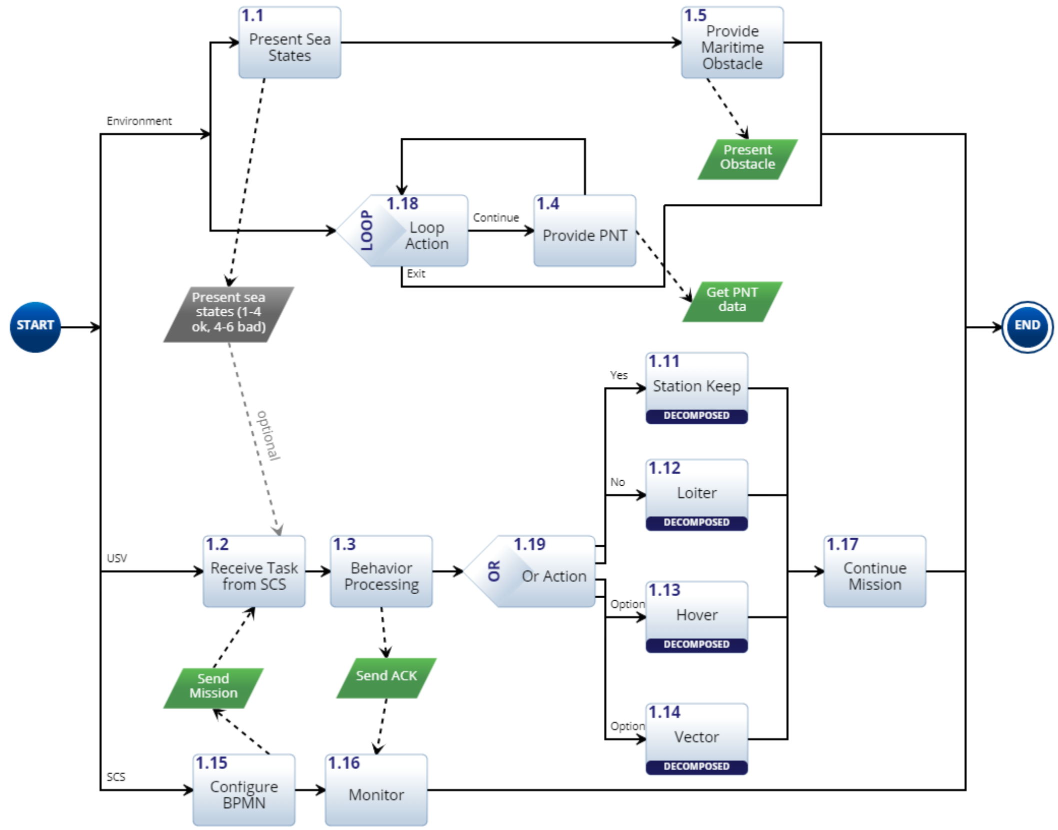

Figure 2. DRM for MET

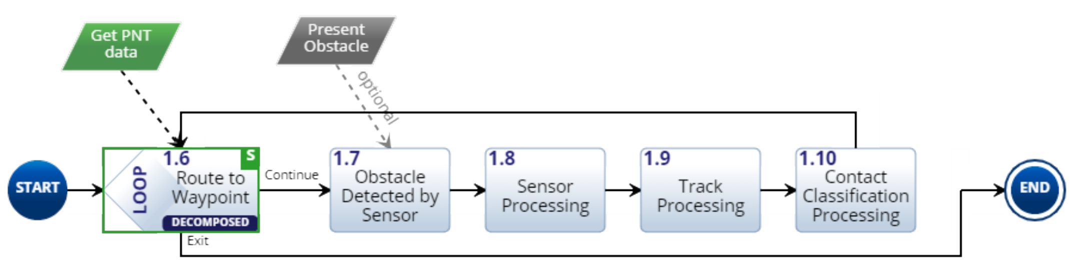

Figure 3. DRM for MET Station Keep, Loiter, Hover, and Vector Loops

(1) ISR and EW Support to DDG OPSIT

The ISR and EW capabilities of the crewed U.S. Naval fleet are performed by various systems and platforms to be able to "find, fix, track and target" all forces both hostile and friendly in the battlespace. The USV, in the role to augment the crewed U.S. naval fleet, needs to be equipped with and operate various sensors, electronic warfare systems and exploit the data from the onboard sensors and pass this data to their command ship, the DDG. The greatest gaps for ISR and EW missions in support of the U.S. naval fleet are persistent area coverage to detect and identify surface threats and providing wide-area coverage. Critical to successful accomplishment of this mission is also timely exploitation of data to feed to the supported DDG. The USV must be outfitted with the appropriate ISR and EW sensors, onboard data exploitation capabilities and network capabilities to feed this information back to the supported DDG. The USV is to perform this mission while also successfully performing Mission Autonomy in accordance with COLREGS.

(2) EMCON support to DDG OPSIT

Building upon the first OPSIT, the USV is required to perform both the successful Mission Autonomy in accordance with COLREGS as well as the ISR and EW support to DDG and add the mission of emissions control (EMCON) steps to reduce emissions to avoid detection by the enemy (Jones 2013). Figure 4 provides the DRM for ISR, EW and EMCON. EMCON is a form of electronic warfare that is employed primarily to prevent enemy forces from localizing and identifying ships. For the USV to successfully support the role as a gap filler to all missions currently performed by the crewed U.S. naval fleet, the USV needs to be able to maneuver and operate as un-detected as possible while in the enemy area of operations. This is critical to successful performance of their support role to the crewed U. S. naval fleet and enables the USV to survive and operate. This mission when successfully performed provides increased advantage for the crewed U.S. naval fleet. In this posture, the USV can be used as a deception tactic, which allows the supported vessel to perform other missions, which may distract the enemy while the USV is in EMCON. When the USV is in EMCON Alpha (maximum level of stealth) it can maneuver to a designated waypoint then either emit to distract the enemy's attention or perform another mission objective such as deployment of weapons or collection with passive sensors to cover the enemy targets of interest. The use of low probability of detection (LPD) / low probability of interception (LPI) / low probability of geolocation (LPG) communications have been identified as a requirement for both the crewed and uncrewed vessels for successful execution of this mission. This capability is a requirement for successful execution of the EMCON mission for the USV.

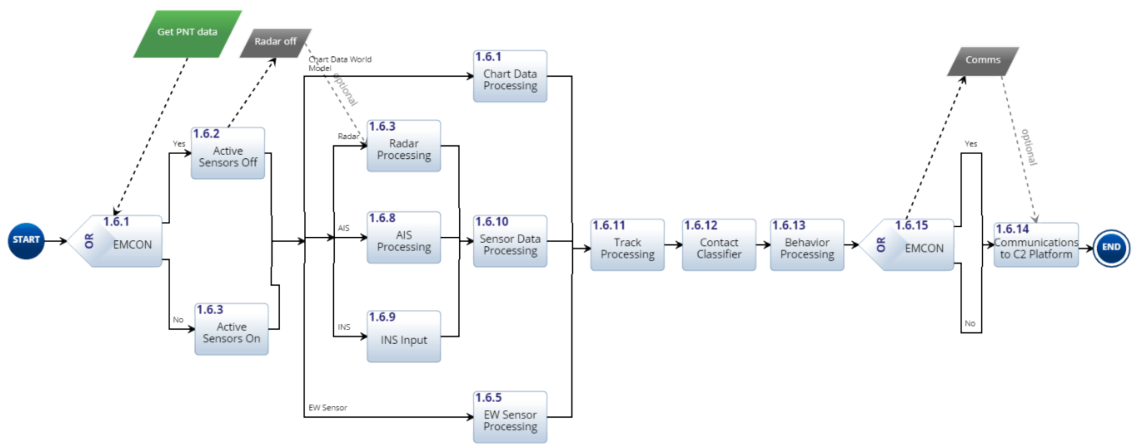

Figure 4. DRM for ISR, EW and EMCON

C. MEASURES FOR MISSION SUCCESS

The Universal Naval Task List (DOD 2007) is used to identify the tasks required for a crewed vessel to perform an ISR and EW mission. The following commercial standards and COLREGS provide the baseline requirements for the USVs to operate in peacetime operations. The UNTLs will serve as the measures for mission success for the USV to operate in the same missions. The gap in regulations that has been identified is the variance that can occur during conflict or wartime operations that would potentially cancel some of the commercial and peacetime COLREGS guidance and introduce a level of uncertainty that would significantly increase the potential behavioral responses to interactions with other vessels and maritime obstacles. There is a level of probabilistic variability that is not currently captured in the metrics captured in Table 3, as the vessel transitions from peacetime to conflict or wartime. The accepted and required COLREGS and commercial requirements will in some cases no longer apply for the vessel to perform commander's intent. This variability needs to be captured in the significantly increased number of potential behaviors that the USVs will be anticipated to perform due to this transition from peacetime to conflict and wartime. The ability to manage and handle this significant increase in variability can be managed in a combination of ways. The autonomy software and algorithms that are developed to be able to take in the inputs from the environment and be able to transition the accepted safety of navigation guard-rails to supporting commander's intent for transition from peacetime to conflict and wartime will require the ability to handle emergent behaviors. The additional mechanism that can provide this transition is the level of human-on-the-loop interactions that are provided in the transition. Table 1 provides the Levels of Autonomy (LoA). The LoA scale provides a reference as to the human and machine scale interactions that may need to change as the USV transitions between peacetime and conflict and war as the complexity of the environment and interactions in support of the Commander's Intent change.

Table 2. Levels of Autonomy (LoA). Adapted from Utne et al. (2017).

LoA	Title	**Description**
1	Automatic operation (remote control)	System operates automatically at a distance from its human operators. Human operator directs and controls all functions; some functions are preprogrammed. System states, environmental conditions and sensor data are presented to operator through HMI (human-in-the-loop/human operated).
2	Management by consent	System automatically makes recommendations for mission or process actions related to specific functions, where system prompts human operator at important points for information or decisions. At this level, a system may have

LoA	Title	**Description**
		limited communication bandwidth, including time delay due to, e.g. physical remoteness. System can perform many functions independently of operator control when delegated to do so (human-delegated).
3	Semi-autonomous operation or management by exception	System automatically executes mission-related functions when and where response times are too short for human intervention. Human operators may override or change parameters and cancel/redirect actions within defined time constraints. Operator's attention is only brought to exceptions for certain decisions (human-supervisory control).
4	Highly autonomous operation	System automatically executes mission- or process-related functions in unstructured environment with capability to plan and re-plan mission or process. The human operator may be informed about progress, but the system is independent and "intelligent" ("human-out-of-the loop"). In manned systems, the human operator is in the loop, has a more supervisory role, and may intervene

D. PERFORMANCE METRICS

The 2021 Congressional NDAA identified ''critical mission, hull, mechanical, and electrical subsystems, with respect to a covered vessel," includes the following quoted list of subsystems that follows:

(A) Command, control, communications, computers, intelligence, surveillance, and reconnaissance.

(B) Autonomous vessel navigation, vessel control, contact management, and contact avoidance.

(C) Communications security, including cryptography, encryption, and decryption.

(D) Main engines, including the lube oil, fuel oil, and other supporting systems.

(E) Electrical generation and distribution, including supporting systems.

(F) Military payloads.

(G) Any other subsystem identified as critical by the Senior Technical Authority for the class of naval vessels that includes the covered vessel.

Figure 5 depicts the USV with all external assets that impact the USV in the USV Universe. As identified in the DRM, the external actors that impact the USV are the environment, Maritime Obstacles, the Common Controller or SCS, the C2 Platform, and any potential threats.

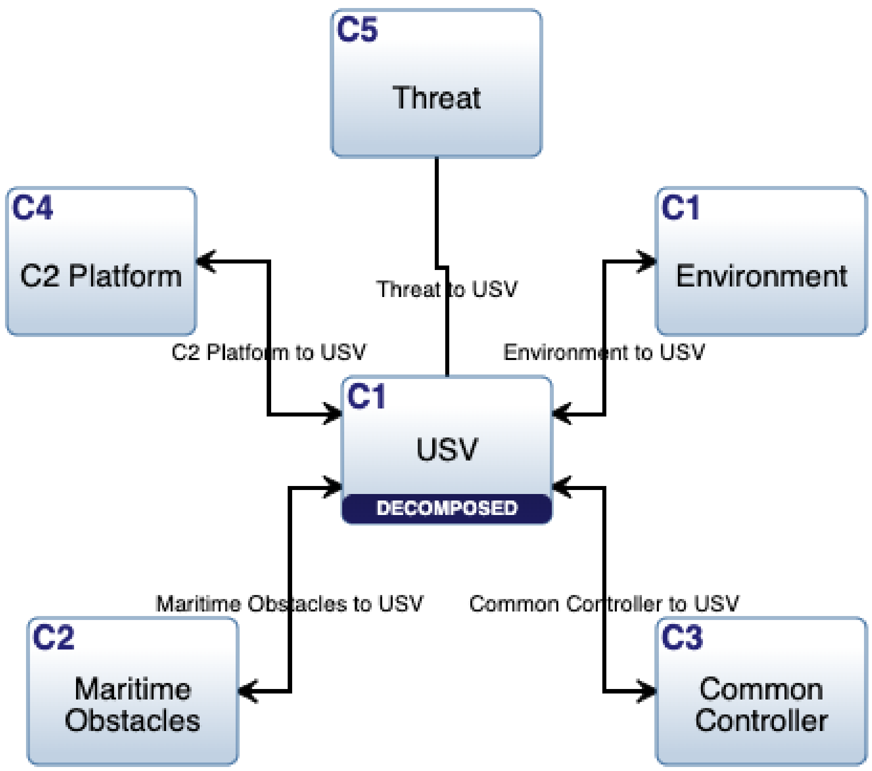

Figure 5. USV Universe

Figure 6 depicts the decomposition of Figure 5 USV C1 into the Critical Systems identified in the 2021 NDAA.

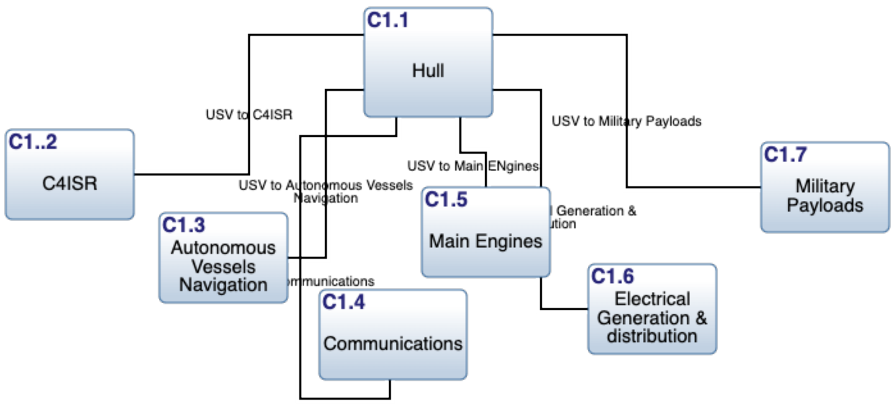

Figure 6. Decomposition of Figure 5, C1 USV Universe into USV Critical Systems

The UNTLs for ISR and EW and their associated metrics are mapped to the critical systems. Additionally, the COLREGs and ABS certification requirements are mapped to the critical systems to create a full complement of the performance objectives for which metrics can be developed. Appendix A provides the complete list of METs developed through the ME methodology developed in this thesis. Appendix B provides a complete list of the METs mapped to the Critical Systems. This list can serve as a basis for full development of the certification metrics needed for PMS 406. Table 3 provides the subset of the METs specific to the tasks, which identified as requirements that the USVs must perform to support their operational missions ISR, EW, and EMCON. Appendix A provides a full listing of all METS and UNTL's which could be considered for the USVs, their descriptions and source reference.

Table 3. UNTLs Required for ISR, EW, and EMCON. Adapted from DOD (2007).

Requirement/Statement		Satisfied by		
Number	Name	Class	Number	Name
9	Collect Data and Intelligence- NTA 2.2			
9.1	Collect Target Information -NTA 2.2.1	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
9.2	Detect Contacts- NTA 2.2.1.1			
9.3	Track Contacts - NTA 2.2.1.2	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
9.4	Classify Contacts - NTA 2.2.1.3	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
9.5	Identify Contacts - NTA 2.2.1.4	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
9.6	Localize Contacts- NTA 2.2.1.5	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications

Requirement/Statement		Satisfied by		
10	Collect Tactical Intelligence on Situation -NTA 2.2.2	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11	"Perform Tactical Reconnaissance and Surveillance- NTA 2.2.3 (Department of Defense [DOD] UNTL 2007)."	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.1	Search Assigned Areas- NTA 2.2.3.1	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.1.1	Provide Cueing- NTA 2.2.3.1.1	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.2	Perform Tactical Reconnaissance- NTA 2.2.3.2	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.3	Perform Zone Reconnaissance- NTA 2.2.3.3	Asset	C1.2	C4ISR

Requirement/Statement		Satisfied by		
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.4	Perform Area Reconnaissance- NTA 2.2.3.4	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
12	Assess Tactical Environment- NTA 2.2.4	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C4	C2 Platform
13	Conduct Perception Management- NTA 6.1.2	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications

E. DATA ANALYSIS

This thesis provides the mapping of the requirements identified through the ME process and DRM development specifically focusing on the Safety of Navigation and the UNTLs required for execution of ISR, EW, and EMCON. Figure 6 depicts the safety of navigation requirements mapped to critical systems.

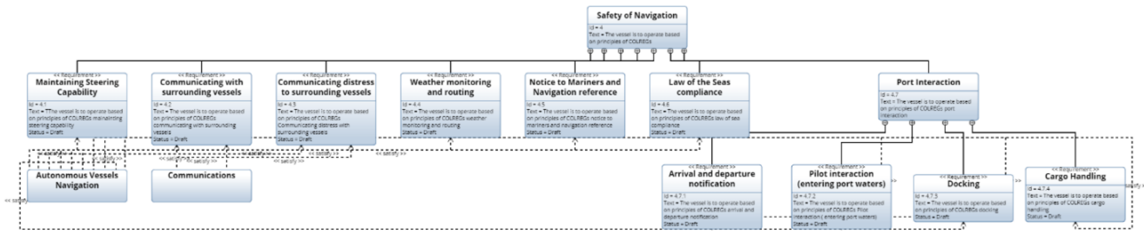

Figure 7. Mapping of Safety of Navigation Requirements to Critical Systems

Figures 8, 9, and 10 provide the mapping of the UNTLs required for ISR, EW, and EMCON to the critical systems

Figure 8 provides the mapping of Perform Tactical Reconnaissance and Surveillance UNTL required for ISR, EW and EMCON mapped to the Critical Systems.

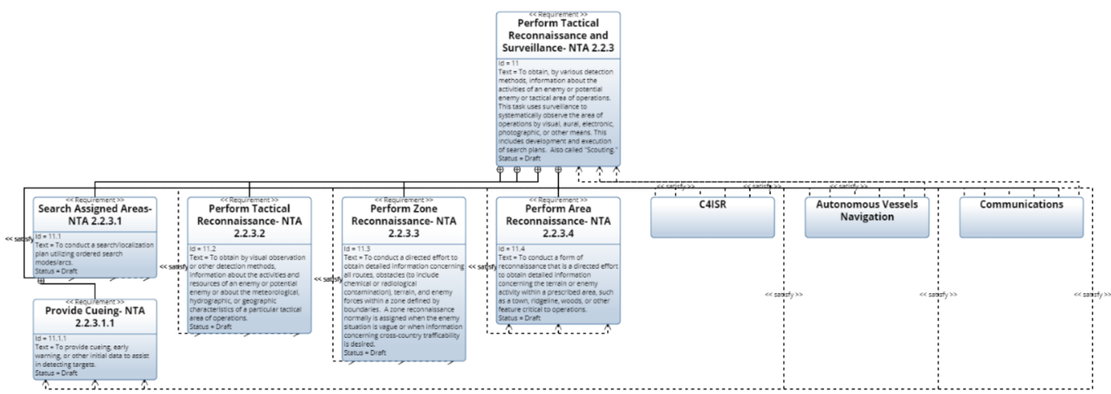

Figure 8. Mapping of Perform Tactical Reconnaissance and Surveillance to Critical Systems.

Figure 9 provides the mapping of the Collect Data and Intelligence UNTL required for ISR, EW, and EMCON to the Critical Systems

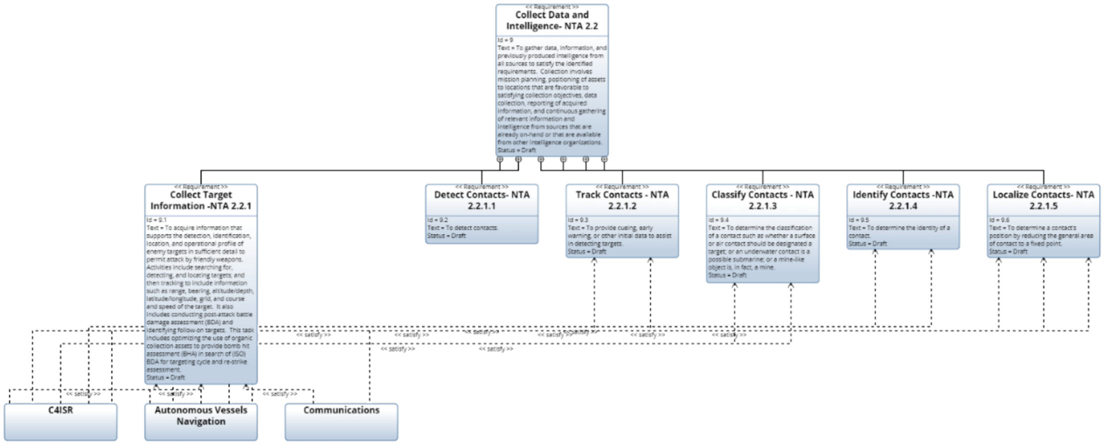

Figure 9. Mapping of Collect Data and Intelligence to Critical Systems.

Figure 10 provides the mapping of the Conduct Perception Management UNTL required for ISR, EW, and EMCON to the Critical Systems.

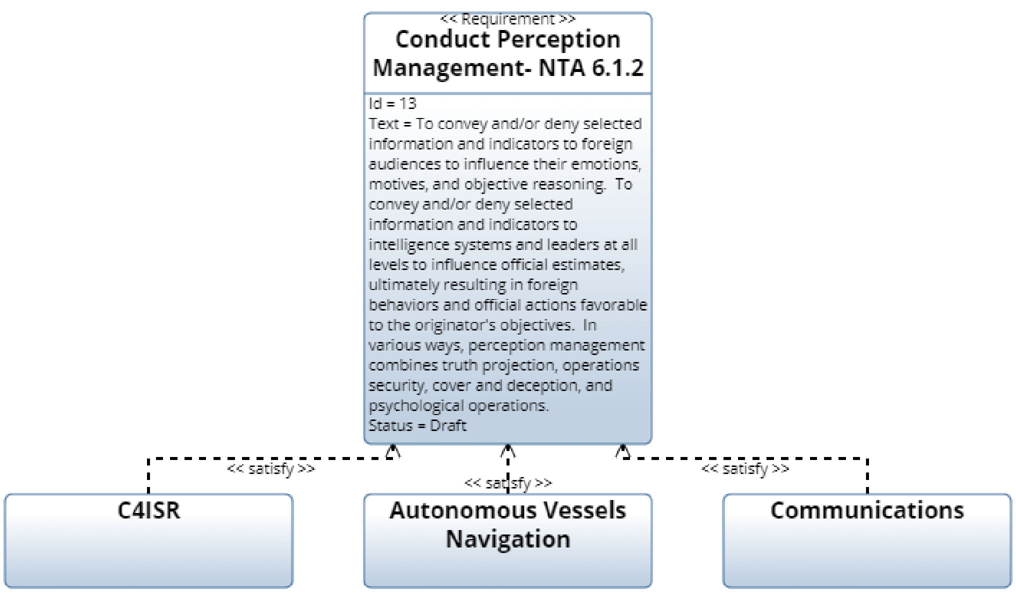

Figure 10. Mapping of Conduct Perception Management to Critical Systems.

The USVs as they are intended to be more than just autonomous vessels but to be able to augment the operational fleet in their current missions need to be analyzed through a perspective that is greater than just supporting safety of navigation and obstacle avoidance. It is only through the ME process decomposition of the USVs DRMs that we can understand the scope of their intended missions and develop the METs and UNTLs for evaluation. With the consideration of the evaluation measures used for the commercial USVs we can capture the baseline METs required for operations of the USVs in peacetime. It is with the evaluation of the USVs METs required to support the operational ISR, EW, and EMCON missions that we expand the complexity of the requirements that the USV needs to meet. The ME methodology and the METs and UNTLs developed in this thesis can be used as the basis for evaluation criteria needed to support the 2019 NDAA certification metrics for the critical systems.

In the analysis performed in this thesis through this decomposition, several gaps were identified. The first mission capability gap identified is in communications. The current Communications systems on the USVs will not support the EMCON mission and perform in support of ISR and EW as the operational climate transitions from peacetime. The Communications systems need to be replaced with LPD / LPI / LPG communications systems to support the ISR, EW, and EMCON missions.

Additionally, the complexity of the missions as the transition from peacetime to conflict and war will require an increase in the human-in-the-loop interaction. The level of autonomy should change as transition from peacetime to conflict and wartime to account for the significant increase in emergent behaviors as the complexity of the environment increases due to commander's intent and interaction with threat assets. This also supports the need for LPD / LPI / LPG communications systems on the USVs to allow for continued communications between the Command Vessel and the USVs as this transition occurs.

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V. CONCLUSION

This thesis provides a methodology for PMS 406 to certify operational performance against Fleet mission objectives.

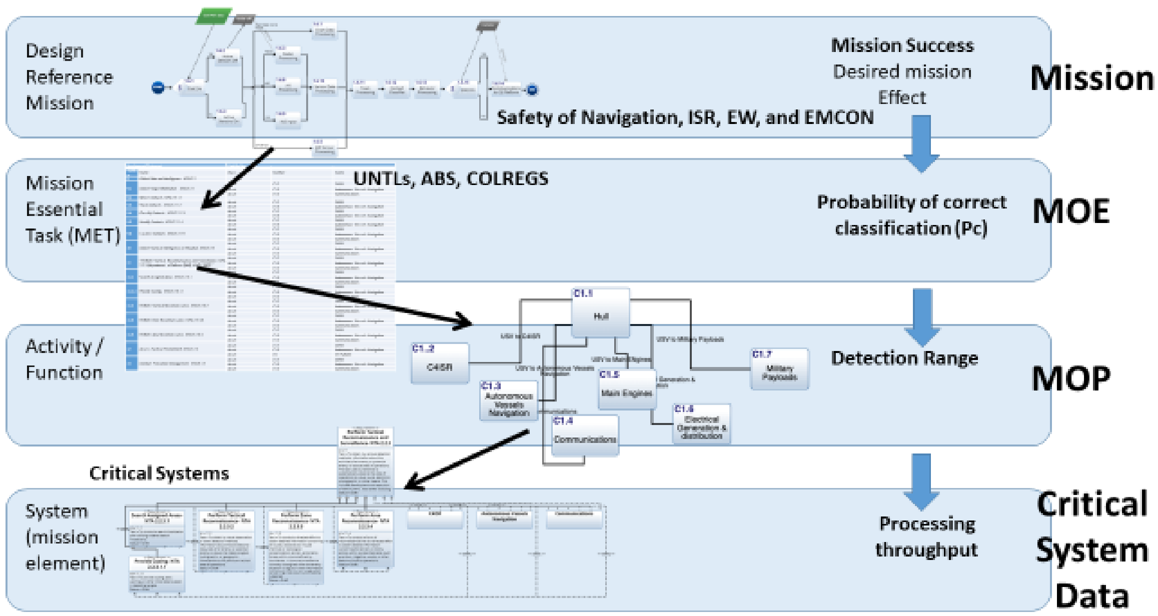

Figure 11. Mission Engineering Methodology for the USV Fleet

The ME methodology represented in Figure 11, was used to develop the DRMs for ISR, EW, and EMCON mission performance. These DRMs were decomposed into METs for safety of navigation and obstacle avoidance which have been the current standards against which USVs have been measured. These requirements are taken from COLREGS and the ABS standards. Expanding on this baseline with the ME process and DRM development, the METs for the operational missions were added. UNTLs were added to the METs to include the tasks needed to support ISR, EW, and EMCON. All tasks were mapped to the Critical Systems identified in the 2019 NDAA. This methodology provides the framework for the identification and decomposition of the requirements to perform these missions. This provides the initial work needed by PMS 406 to perform certification of the USV Fleet to transition from prototype to operational.

Further work is recommended to continue the decomposition of the critical systems into the subsystems and software performing the tasks identified in the DRM process as mission essential. Tactics, techniques, and procedures need to be developed to accommodate for the additional human-on-the-loop interactions required to ensure successful mission accomplishment as the operational climate transitions from peacetime to conflict and wartime. Additional development is needed on the number of potential actions and behaviors that can be performed by the autonomy software in addressing the significant increase in potential variability introduced in the transition from peacetime to conflict and wartime operations to meet commander's intent.

The communications systems currently fielded on the prototype USVs need to be re-considered and potentially replaced by LPD / LPI / LPG communications systems to support the ISR, EW, and EMCON missions. Additional decomposition of the critical systems and mapping of those lower-level systems to the METs and UNTLs identified in the DRMs are recommended for future work. Command and control of the USVs and the consequences of the missions assigned to the USVs need further analysis. In order to support the ISR, EW, and EMCON missions the human-on-the-loop supervision needs to transition from highly autonomous to semi-autonomous or supervisory control in order to adjust for the complexity and severity of the operational environment.

APPENDIX A

Appendix A provides a full listing of all METS and UNTLs that could be considered for the USVs, their descriptions, and source reference. Adapted from DOD (2007) and ABS (2021).

Num	Name	Description	Class	Reference
1	Maintain Steering and Propulsion		Statement	(ABS 2021)
1.1	Continuity of propulsion power	The USV shall provide continuity of propulsion power	Requirement	(ABS 2021)
1.2	Continuity of electrical power	The USV shall provide electrical power	Requirement	(ABS 2021)
1.3	Continuity of position / course	The USV shall provide continuity of position /course	Requirement	(ABS 2021)
2	Safety of Vessel & Security		Statement	(ABS 2021)
2.1	Maintain continuity of electrical power	The USV shall maintain continuity of electrical power	Requirement	(ABS 2021)
2.2	Manage fire risk	The USV shall manage fire risk	Requirement	(ABS 2021)
2.3	Maintain the machinery management system	The USV shall maintain the machinery management system	Requirement	(ABS 2021)
2.4	Prevent cyber security intrusions	The USV shall prevent cyber intrusion	Requirement	(ABS 2021)
2.5	Detect and contain flooding	The USV shall detect and contain flooding	Requirement	(ABS 2021)

2.6	Mitigate risks from hazardous cargo	The USV shall mitigate risks from hazardous cargo	Requirement	(ABS 2021)
3	Protection against Flooding & Maintaining Stability	The USV shall protect against Flooding & maintain Stability	Requirement	(ABS 2021)
3.1	Correct operation of bilge system	The USV shall perform correct operation of bilge system	Requirement	(ABS 2021)
3.2	Correct operation of sea valves	The USV shall perform correct operation of sea valves	Requirement	(ABS 2021)
3.3	Correct operation of Ventilation openings	The USV shall perform correct operation of ventilation openings	Requirement	(ABS 2021)
3.4	Damage Stability management	The USV shall perform correct operation of damage stability management	Requirement	(ABS 2021)
3.5	Correct operation of Watertight doors and automated closures	The USV shall perform correct operation of watertight doors and automated closures	Requirement	(ABS 2021)
4	Safety of Navigation	The vessel is to operate based on principles of COLREGs	Statement	(ABS 2021) COLREGS
4.1	Maintaining Steering Capability	The vessel is to operate based on principles of COLREGs maintaining steering capability	Requirement	(ABS 2021), COLREGS

4.2	Communicating with surrounding vessels	The vessel is to operate based on principles of COLREGs communicating with surrounding vessels	Requirement	(ABS 2021), COLREGS
4.3	Communicating distress to surrounding vessels	The vessel is to operate based on principles of COLREGs Communicating distress with surrounding vessels	Requirement	(ABS 2021), COLREGS
4.4	Weather monitoring and routing	The vessel is to operate based on principles of COLREGs weather monitoring and routing	Requirement	(ABS 2021), COLREGS
4.5	Notice to Mariners and Navigation reference	The vessel is to operate based on principles of COLREGs notice to mariners and navigation reference	Requirement	(ABS 2021), COLREGS
4.6	Law of the Seas compliance	The vessel is to operate based on principles of COLREGs law of sea compliance	Requirement	(ABS 2021), COLREGS
4.7	Port Interaction	The vessel is to operate based on principles of COLREGs port interaction	Statement	(ABS 2021), COLREGS
4.7.1	Arrival and departure notification	The vessel is to operate based on principles of COLREGs arrival and departure notification	Requirement	(ABS 2021), COLREGS

4.7.2	Pilot interaction (entering port waters)	The vessel is to operate based on principles of COLREGs Pilot interaction (entering port waters)	Requirement	(ABS 2021), COLREGS
4.7.3	Docking	The vessel is to operate based on principles of COLREGs docking	Requirement	(ABS 2021), COLREGS
4.7.4	Cargo Handling	The vessel is to operate based on principles of COLREGs cargo handling	Requirement	(ABS 2021), COLREGS
5	Communicate Distress	The vessel is to operate based on principles of COLREGs Communicate distress	Statement	(ABS 2021), COLREGS
5.1	In the event of distress or emergency conditions, the vessel is to be capable of communicating distress signals to shore control station	The vessel is to operate based on principles of COLREGs the vessel is to be capable of communicating distress signals to shore control station	Requirement	(ABS 2021), COLREGS
5.2	In the event of distress or emergency conditions, the vessel is to be capable of communicating distress signals to surrounding vessels	The vessel is to operate based on principles of COLREGs the vessel is to be capable of communicating distress signals to surrounding vessels	Requirement	(ABS 2021), COLREGS

6	Mitigate Environmental Impacts	The vessel is to be MARPOL compliant and therefore requires adherence to all measures defined in MARPOL and respective Flag or Port State requirements.	Requirement	(ABS 2021)
7	Monitoring	Vessel Monitoring is to be provided for remote supervision and autonomous decision-making support. The vessel is also to be provided with necessary perception and situational awareness. The following areas are to have integrated monitoring systems:	Requirement	(ABS 2021)
7.1	Power and Propulsion	The USV shall provide power and propulsion monitoring	Requirement	(ABS 2021)
7.2	Safety / Damage Control	The USV shall provide Safety / Damage Control monitoring	Requirement	(ABS 2021)
7.3	Stability and Ballast Control (Intact and Damaged)	The USV shall provide Stability and Ballast Control (Intact and Damaged) monitoring	Requirement	(ABS 2021)

7.4	Structural Integrity and Health	The USV shall provide Structural Integrity and Health monitoring	Requirement	(ABS 2021)
7.5	Navigation and position (Geolocation)	The USV shall provide Navigation and position (Geolocation) monitoring	Requirement	(ABS 2021)
7.6	Environmental Regulatory Reporting	The USV shall provide Environmental Regulatory Reporting monitoring	Requirement	(ABS 2021)
7.7	Normal Operations and Restorative Actions	The USV shall provide Normal Operations and Restorative Actions monitoring	Requirement	(ABS 2021)
7.8	Cybersecurity	The USV shall provide Cybersecurity monitoring	Requirement	(ABS 2021)
7.9	Voyage data	The USV shall provide power and propulsion monitoring	Requirement	(ABS 2021)
8	Maintain Communication with Shore Control Station	For vessel supervision and safety management, it is critical for the vessel to maintain communication with the shore control station. Additionally, the vessel is to be capable of	Requirement	(ABS 2021)

		communication with the following:		
8.1	Communicate with Other vessel traffic	The USV shall Communicate with Other vessel traffic	Requirement	(ABS 2021)
8.2	Communicate with Pilot/ Harbor Control	The USV shall Communicate with Pilot/ Harbor Control	Requirement	(ABS 2021)
8.3	Communicate witg Riding Crews/Transport Team	The USV shall Communicate witg Riding Crews/Transport Team	Requirement	(ABS 2021)
9	Collect Data and Intelligence- NTA 2.2	To gather data, information, and previously produced intelligence from all sources to satisfy the identified requirements. Collection involves mission planning, positioning of assets to locations that are favorable to satisfying collection objectives, data collection, reporting of acquired information, and continuous gathering of relevant	Requirement	DOD UNTL 2007

		information and intelligence from sources that are already on-hand or that are available from other intelligence organizations.		
9.1	Collect Target Information - NTA 2.2.1	To acquire information that supports the detection, identification, location, and operational profile of enemy targets in sufficient detail to permit attack by friendly weapons. Activities include searching for, detecting, and locating targets; and then tracking to include information such as range, bearing, altitude/depth, latitude/ longitude, grid, and course and speed of the target. It also includes conducting post-attack battle damage	Requirement	DOD UNTL 2007

		assessment (BDA) and identifying follow-on targets. This task includes optimizing the use of organic collection assets to provide bomb hit assessment (BHA) in search of (ISO) BDA for targeting cycle and re-strike assessment.		
9.2	Detect Contacts-NTA 2.2.1.1	To detect contacts.	Requirement	DOD UNTL 2007
9.3	Track Contacts - NTA 2.2.1.2	To provide cueing, early warning, or other initial data to assist in detecting targets.	Requirement	DOD UNTL 2007
9.4	Classify Contacts - NTA 2.2.1.3	To determine the classification of a contact such as whether a surface or air contact should be designated a target; or an underwater contact is a possible submarine; or a mine-like object is, in fact, a mine.	Requirement	DOD UNTL 2007
9.5	Identify Contacts -NTA 2.2.1.4	To determine the identity of a contact.	Requirement	DOD UNTL 2007

9.6	Localize Contacts- NTA 2.2.1.5	To determine a contact's position by reducing the general area of contact to a fixed point.	Requirement	DOD UNTL 2007
10	Collect Tactical Intelligence on Situation -NTA 2.2.2	To obtain information that affects a commander's possible courses of action. Considerations include the characteristics of the area of operations and the enemy situation. Information includes threat, physical environment, health standards/ endemic disease, and social/political/ economic factors. This task also includes the reporting and locating of isolated or captured personnel.	Requirement	DOD UNTL 2007

11	Perform Tactical Reconnaissance and Surveillance-NTA 2.2.3	To obtain, by various detection methods, information about the activities of an enemy or potential enemy or tactical area of operations. This task uses surveillance to systematically observe the area of operations by visual, aural, electronic, photographic, or other means. This includes development and execution of search plans. Also called "Scouting."	Requirement	DOD UNTL 2007
11.1	Search Assigned Areas- NTA 2.2.3.1	To conduct a search/ localization plan utilizing ordered search modes/ arcs.	Requirement	DOD UNTL 2007
11.1.1	Provide Cueing-NTA 2.2.3.1.1	To provide cueing, early warning, or other initial data to assist in detecting targets.	Requirement	DOD UNTL 2007
11.2	Perform Tactical Reconnaissance-NTA 2.2.3.2	To obtain by visual observation or other detection methods, information about the	Requirement	DOD UNTL 2007

		activities and resources of an enemy or potential enemy or about the meteorological, hydrographic, or geographic characteristics of a particular tactical area of operations.		
11.3	Perform Zone Reconnaissance-NTA 2.2.3.3	To conduct a directed effort to obtain detailed information concerning all routes, obstacles (to include chemical or radiological contamination), terrain, and enemy forces within a zone defined by boundaries. A zone reconnaissance normally is assigned when the enemy situation is vague or when information concerning cross-country trafficability is desired.	Requirement	DOD UNTL 2007
11.4	Perform Area Reconnaissance-NTA 2.2.3.4	To conduct a form of reconnaissance that is a directed effort to obtain detailed information	Requirement	DOD UNTL 2007

		concerning the terrain or enemy activity within a prescribed area, such as a town, ridgeline, woods, or other feature critical to operations.		
12	Assess Tactical Environment- NTA 2.2.4	To utilize organic and non-organic sensors to detect combat threats, environmental conditions, geographic constraints and background shipping.	Requirement	DOD UNTL 2007
13	Conduct Perception Management- NTA 6.1.2	To convey and/ or deny selected information and indicators to foreign audiences to influence their emotions, motives, and objective reasoning. To convey and/or deny selected information and indicators to intelligence systems and leaders at all levels to influence official estimates, ultimately resulting in foreign behaviors and official actions favorable to the	Requirement	DOD UNTL 2007

		originator's objectives. In various ways, perception management combines truth projection, operations security, cover and deception, and psychological operations.		

APPENDIX B

Appendix B provides a full listing of all METS and UNTLs with a mapping to the Critical Systems. Adapted from DOD (2007).

Requirement/Statement		Satisfied by		
Number	**Name**	**Class**	**Number**	**Name**
1	Maintain Steering and Propulsion			
1.1	Continuity of propulsion power	Asset	C1.5	Main Engines
1.2	Continuity of electrical power	Asset	C1.5	Main Engines
1.3	Continuity of position / course	Asset	C1.5	Main Engines
2	Safety of Vessel & Security			
2.1	Maintain continuity of electrical power	Asset	C1.6	Electrical Generation & distribution
2.2	Manage fire risk	Asset	C1.3	Autonomous Vessels Navigation
2.3	Maintain the machinery management system	Asset	C1.6	Electrical Generation & distribution
2.4	Prevent cyber security intrusions	Asset	C1.2	C4ISR
2.5	Detect and contain flooding	Asset	C1.3	Autonomous Vessels Navigation
2.6	Mitigate risks from hazardous cargo	Asset	C1.1	Hull
3	Protection against Flooding & Maintaining Stability	Asset	C1.1	Hull
3.1	Correct operation of bilge system	Asset	C1.3	Autonomous Vessels Navigation

Requirement/Statement		Satisfied by		
3.2	Correct operation of sea valves	Asset	C1.3	Autonomous Vessels Navigation
3.3	Correct operation of Ventilation openings	Asset	C1.3	Autonomous Vessels Navigation
3.4	Damage Stability management	Asset	C1.3	Autonomous Vessels Navigation
3.5	Correct operation of Watertight doors and automated closures	Asset	C1.3	Autonomous Vessels Navigation
4	Safety of Navigation			
4.1	Maintaining Steering Capability	Asset	C1.3	Autonomous Vessels Navigation
4.2	Communicating with surrounding vessels	Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
4.3	Communicating distress to surrounding vessels	Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
4.4	Weather monitoring and routing	Asset	C1.3	Autonomous Vessels Navigation
4.5	Notice to Mariners and Navigation reference	Asset	C1.3	Autonomous Vessels Navigation
4.6	Law of the Seas compliance	Asset	C1.3	Autonomous Vessels Navigation
4.7	Port Interaction			
4.7.1	Arrival and departure notification	Asset	C1.3	Autonomous Vessels Navigation
4.7.2	Pilot interaction (entering port waters)	Asset	C1.3	Autonomous Vessels Navigation

Requirement/Statement		Satisfied by		
4.7.3	Docking	Asset	C1.3	Autonomous Vessels Navigation
4.7.4	Cargo Handling	Asset	C1.3	Autonomous Vessels Navigation
5	Communicate Distress			
5.1	In the event of distress or emergency conditions, the vessel is to be capable of communicating distress signals to shore control station	Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
5.2	In the event of distress or emergency conditions, the vessel is to be capable of communicating distress signals to surrounding vessels	Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
6	Mitigate Environmental Impacts	Asset	C1.3	Autonomous Vessels Navigation
7	Monitoring			
7.1	Power and Propulsion	Asset	C1.3	Autonomous Vessels Navigation
7.2	Safety / Damage Control	Asset	C1.3	Autonomous Vessels Navigation
7.3	Stability and Ballast Control (Intact and Damaged)	Asset	C1.3	Autonomous Vessels Navigation
7.4	Structural Integrity and Health	Asset	C1.3	Autonomous Vessels Navigation
7.5	Navigation and position (Geolocation)	Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications

Requirement/Statement		Satisfied by		
7.6	Environmental Regulatory Reporting	Asset	C1.3	Autonomous Vessels Navigation
7.7	Normal Operations and Restorative Actions	Asset	C1.3	Autonomous Vessels Navigation
7.8	Cybersecurity	Asset	C1.3	Autonomous Vessels Navigation
7.9	Voyage data	Asset	C1.3	Autonomous Vessels Navigation
8	Maintain Communication with Shore Control Station			
8.1	Communicate with Other vessel traffic	Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
8.2	Communicate with Pilot/Harbor Control	Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
8.3	Communicate with Riding Crews/ Transport Team	Asset	C1.3	Autonomous Vessels Navigation
9	Collect Data and Intelligence- NTA 2.2			
9.1	Collect Target Information -NTA 2.2.1	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
9.2	Detect Contacts- NTA 2.2.1.1			

Requirement/Statement		Satisfied by		
9.3	Track Contacts - NTA 2.2.1.2	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
9.4	Classify Contacts - NTA 2.2.1.3	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
9.5	Identify Contacts -NTA 2.2.1.4	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
9.6	Localize Contacts- NTA 2.2.1.5	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
10	Collect Tactical Intelligence on Situation -NTA 2.2.2	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11	Perform Tactical Reconnaissance and Surveillance- NTA 2.2.3	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications

Requirement/Statement		Satisfied by		
11.1	Search Assigned Areas- NTA 2.2.3.1	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.1.1	Provide Cueing- NTA 2.2.3.1.1	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.2	Perform Tactical Reconnaissance- NTA 2.2.3.2	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.3	Perform Zone Reconnaissance- NTA 2.2.3.3	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
11.4	Perform Area Reconnaissance- NTA 2.2.3.4	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications
12	Assess Tactical Environment- NTA 2.2.4	Asset	C1.2	C4ISR

Requirement/Statement		Satisfied by		
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C4	C2 Platform
13	Conduct Perception Management- NTA 6.1.2	Asset	C1.2	C4ISR
		Asset	C1.3	Autonomous Vessels Navigation
		Asset	C1.4	Communications

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