DISSERTATION

RELATIONAL AND TECHNOLOGICAL PROCESS CONCEPT UTILIZING A HUMAN-IN-THE-LOOP-CENTERED METHODOLOGY FOR USSOCOM

Submitted by

Kenneth Casselbury Corl

Department of Systems Engineering

In partial fulfillment of the requirements

For the Degree of Doctor of Engineering

Colorado State University

Fort Collins, Colorado

Fall 2024

Doctoral Committee:

Advisor: Erika Gallegos

Thomas Bradley
Steve Simske
Troy Mumford
Jerry “Clay” Crocker

ABSTRACT

RELATIONAL AND TECHNOLOGICAL PROCESS CONCEPT UTILIZING A HUMAN-IN-THE-LOOP-CENTERED METHODOLOGY FOR USSOCOM

The Department of Defense (DoD) employs broad human factors requirements across various applications, resulting in a universal application of the same standards to a multitude of DoD acquisition systems. In unconventional warfare, specifically within missions conducted by US Special Operations Command (USSOCOM), operators face intensified workloads and domain-specific challenges that current human factors considerations do not adequately address. The objective of this dissertation aims to introduce and validate the Relational and Technological Capstone (RTC), which expands upon existing human factors requirements through both architectural and behavioral diagrams in a well-defined set of methodology-driven process steps. In referencing the system lifecycles as defined by the Defense Acquisition University (DAU) and the International Council on Systems Engineering (INCOSE), the objective is to diversify and enhance the consideration of Human Systems Integration (HSI) requirements in USSOCOM platforms by addressing the unique challenges posed by intensified workloads and domain-specific ontologies. The RTC employs a methodology-driven approach utilizing architectural, behavioral, and parametric diagrams. It integrates with Model Based Systems Engineering (MBSE) and the Systems Modeling Language (SysML) to improve the design of human-system interactions, incorporating a Special Operations Task List and Performance Shaping Factors (PSFs) into aggregated performance values. The results of this dissertation demonstrate the efficacy of RTC within MBSE, showcasing its value through improved design processes and as a

foundation for new programs. The RTC can integrate existing models to further benefit customer needs through initiatives like Engineering Change Proposals (ECPs) as well as assist starter models for new programs and projects. The containment tree format aids in developing USSOCOM MBSE and opens possibilities for automation tools as well as an easily transferrable modeling package for future use on all complex systems. Continual use of RTC contributes to the maturity of MBSE models and diagrams, fostering the evolution of a federation-of-models and Program of Record standards. This not only benefits subsequent SOCOM programs and projects but also facilitates the emerging field and methodology of mission engineering to realize and forecast capability gaps before a system reaches the implementation and integration phase. The ultimate goal is to center the RTC around the operator, ensuring man-machine compatibility and optimization throughout special operation acquisitions.

ACKNOWLEDGEMENTS

I would like to thank my advisory committee Dr. Erika Gallegos, Dr. Thomas Bradley, Dr. Steve Simske, and Dr. Troy Mumford for both their mentorship during course instruction and support in my overall research efforts. An added thanks goes out to my primary advisor, Dr. Gallegos, who's encouragement and direction made this journey special from start to finish. I would also like to recognize my practicum sponsor, Jerry "Clay" Crocker, for his leadership guidance over the past 15 years and his enabling approach toward my professional goals. I am truly thankful to the Systems Engineering Department and Colorado State University (CSU) for its flexibility and willingness to both enable and engage distance students to pursue academic milestones of this caliber. This would not be possible without the coordination and guidance of Dr. Debra Dandaneau and Ms. Ingrid Bridge, who deserve much appreciation in navigating students toward success. Most importantly, I would like to thank my wife Lauren and my children Mickey and Mattingly for their sacrifice, backing, and love these last four, action-packed years.

TABLE OF CONTENTS

ABSTRACT ii
ACKNOWLEDGEMENTS iv
LIST OF TABLES vii
LIST OF FIGURES viii
LIST OF ACRONYMS x
CHAPTER 1.0 - INTRODUCTION 1
CHAPTER 2.0 BACKGROUND 7
2.1 Human Factors Engineering Origins and Adoption into Military 7
2.2 Modern HFE and the Link with MBSE 9
2.3 HFE Challenges in the Technical Process 18
CHAPTER 3.0 RESEARCH QUESTIONS AND TASKS 19
CHAPTER 4.0 THE RTC METHODOLOGY 23
4.1 Definition of the RTC Methodology 23
4.2 Development of an MBSE Model from a Set of UUV Requirements 33
CHAPTER 5.0 RESEARCH QUESTION 1 45
5.0 RTC Phase 1 [RQ1] Introduction 45
5.1 Insertion of Actor into Architectural Framework 45
5.2 Development of Behavioral Diagrams and Functional Flows with Actor Swim Lanes 52
5.2.1 Use Case Diagram [Propulsion Module Subsystem] 52
5.2.2 Activity Diagram [Control Module Subsystem] 58
5.2.3 Sequence Diagram [Battery Module Subsystem] 64
5.3 Translation of Behavioral Diagrams into HSI Requirements 71
5.3.1 Use Case Diagram Requirements [Propulsion Module Subsystem] 72
5.3.2 Activity Diagram Requirements [Control Module Subsystem] 74
5.3.3 Sequence Diagram Requirements [Battery Module Subsystem] 76
5.4 Compiled List of RTC Phase 1 HSI Requirements 79
5.5 RTC Phase I [RQ1] Conclusion 84
CHAPTER 6.0 RESEARCH QUESTION 2 86
6.0 SOCOM Task List [RQ2] Introduction 86
6.1 Review of UNTL for SOCOM-Related Tasks 86

6.2 Performance Shaping Factors 89
6.2.1 Operational Availability 92
6.2.2 SOCOM Task List PSF Formulas 95
6.3 Development of SOCOM Task List 98
6.4 SOCOM Task List [RQ2] Conclusion 103
CHAPTER 7.0 RESEARCH QUESTION 3 105
7.0 RTC Phase 2 [RQ3] Introduction 105
7.1 Organization of SOCOM Tasks with PSF Assignment by Block Actor 105
7.2 Transition of Task-Based BDDs into Aggregated Performance Metrics 108
7.3 Translation of Task-Based BDDs into HSI Requirements 117
7.4 RTC Phase 2 [RQ3] Conclusion 119
CHAPTER 8.0 RESEARCH VALIDATION 120
8.1 Research Survey 120
8.2 Research Question 1 Validation [RTC Phase 1] 123
8.3 Research Question 2 Validation [SOCOM Task List] 128
8.4 Research Question 3 Validation [RTC Phase 2] 133
8.5 RTC Summary 138
CHAPTER 9.0 RESEARCH CONTRIBUTIONS 142
9.1 Dissemination of Research Findings 144
CHAPTER 10.0 CONCLUSION 146
REFERENCES 148
APPENDIX A: Quantitative Survey Data 156
APPENDIX B: Qualitative Survey Data 159
APPENDIX C: SOCOM Task List 161

LIST OF TABLES

Table 1: Example of a Tiered Hierarchy 1
Table 2: Human Engineering Design Documentation for DoD (18) 9
Table 3: UUV Performance Specification Summary (34) 40
Table 4: UUV HSI Requirements (34) 40
Table 5: Compiled List of T03 Functional Requirements for Evaluation 80
Table 6: UNTL Special Warfare Task (29) 88
Table 7: PSF References and their Associations (40) (49) 90
Table 8: RTC Performance Shaping Factors and Rating Descriptions 91
Table 9: SOCOM Task List Specification Summary (38) (37) 99
Table 10: Job Titles for SOCOM Research Subjects 121
Table 11: Additional Experience for SOCOM Research Subjects 122

LIST OF FIGURES

Figure 1: DoD Technical Process with RTC (V-Diagram) (12) ... 5
Figure 2: HSUV Use Case Diagram (24) ... 11
Figure 3: HSUV Block Definition Diagram (24) ... 12
Figure 4: HSUV Internal Block Diagram (24) ... 13
Figure 5: HSUV Sequence Diagram (24) ... 14
Figure 6: UUV Use Case Diagram - Deployed System ... 15
Figure 7: UUV Use Case Diagram 2 – System Maintenance ... 16
Figure 8: UUV Block Definition Diagram - Domain Architecture ... 17
Figure 9: DoD Technical Process with RTC (V-Diagram) (12) ... 24
Figure 10: INCOSE Technical Process with RTC (1) ... 25
Figure 11: RTC Phase 1 ... 26
Figure 12: RTC Phase 2 ... 28
Figure 13: Relationship Between RTC Phase Steps and the Mission Engineering Methodology (13) ... 30
Figure 14: Decomposition Hierarchy ... 34
Figure 15: RTC Containment Tree ... 36
Figure 16: T02_03 Logical Requirement Decomposition ... 38
Figure 17: T02_02 Requirements Package Diagram (34) ... 39
Figure 18: 03 Stakeholders/Actors Package ... 43
Figure 19: UUV Operator Actor Block ... 46
Figure 20: UUV System Architecture ... 47
Figure 21: UUV System Architecture with Block Actor ... 48
Figure 22: Propulsion Module Subsystem Functional Requirements [derived] ... 52
Figure 23: Associated Relationship between UUV Operator and Propulsion Module Subsystem Requirements ... 54
Figure 24: UUV Operator and Propulsion Module Subsystem Use Cases ... 56
Figure 25: Control Module Subsystem Functional Requirements [derived] ... 58
Figure 26: Associated Relationship between UUV Operator and Control Module Subsystem Requirements ... 59
Figure 27: UUV Operator and Control Module Subsystem Activity – receiving status reports from UUV Swarm ... 61
Figure 28: Battery Module Subsystem Functional Requirements [derived] ... 65
Figure 29: Associated Relationship between UUV Operator and Battery Module Subsystem Requirements ... 66
Figure 30: UUV Operator and Battery Module Subsystem Sequence 01 – Startup and Shutdown of the UUV using a remote or alternate external switch ... 68
Figure 31: UUV Operator and Battery Module Subsystem Sequence 02 – Startup and Shutdown of the UUV [Referenced] in a plugged and unplugged state ... 69
Figure 32: Trace Relationship between UUV Operator and New Propulsion Module Subsystem Requirements ... 72

Figure 33: Trace Relationship between UUV Operator and New Control Module Subsystem Requirements 74
Figure 34: Trace Relationship between UUV Operator and New Battery Module Subsystem Requirements 76
Figure 35: Workflow for SOCOM Task List Development 99
Figure 36: SOCOM Task List Package 101
Figure 37: UUV System Architecture with Block Actor and Tasks 106
Figure 38: P_{RTC} Aggregated Formula in Python for SOTN 2.1.2.9 110
Figure 39: P_{RTC} Aggregated Formula in Python for SOTN 2.1.2.9 [Computed with Simulation Toolkit] 111
Figure 40: UUV System Architecture with Block Actor and Task Hierarchy with P_{RTC} Parallel Constraint Block Applied 112
Figure 41: P_{RTC} Aggregated Diagram for the UUV Operator 113
Figure 42: P_{RTC} Aggregated Diagram for the UUV Operator [Computed with Simulation Toolkit] 114
Figure 43: P_{RTC} Aggregated Output Computed with Simulation Toolkit.................................. 115
Figure 44: Trace Relationship between UUV Operator and New P_{RTC} Performance Requirements 117
Figure 45: Survey Mean and Standard Deviation for Research Question 1 123
Figure 46: Survey Mean and Standard Deviation for Research Question 2 128
Figure 47: Survey Mean and Standard Deviation for Research Question 3 133
Figure 48: Survey Mean and Standard Deviation for All Research Questions 138

LIST OF ACRONYMS

AAO	Actions at the Objective
ACT	Activity Diagram
ALDT	Administrative and Logistics Delay Time
Ao	Operational Availability
AFTL	Air Force Task List
ASTM	American Society for Testing and Materials
ATHEANA	A Technique for Human Error Analysis
BDD	Block Definition Diagram
C_A	Fully unrestricted task value (Capacity)
CDU	Computer Display Unit
C_O	Task rated PSFs (Commitment)
CSU	Colorado State University
DAU	Defense Acquisition University
DBSE	Document Based Systems Engineering
DI-HFAC	Data Items – Human Factors
DoD	Department of Defense
DOE	Department of Energy
DoDAF	DoD Architecture Framework
ECP	Engineering Change Proposal
EP	Emergency Procedure
ESOH	Environmental Safety and Occupational Health

etc	et cetera
EXFIL	Exfiltrate
FY	Fiscal Year
HCSE	Human-Centered Systems Engineering
HF	High Frequency
HFE	Human Factors Engineering
HFES	Human Factors and Ergonomics Society
HMI	Human Machine Interface
HQ	Headquarters
HRA	Human Reliability Analysis
HSI	Human Systems Integration
HSUV	Hybrid Sport Utility Vehicle
IBD	Internal Block Diagram
INCOSE	International Council on Systems Engineering
INFIL	Infiltrate
IOT	In order to
IRB	Institutional Review Board
JSOU	Joint Special Operations University
KSA	Key System Attributes
LF	Low Frequency
MANPRINT	U.S. Manpower and Personnel Integration
Max	Maximum

MBSE	Model Based Systems Engineering
MCMT	Mean Corrective Maintenance Time
ME	Mission Engineering
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
Min	Minimum
Misc.	Miscellaneous
MS	Mission Specialist (Submersible)
MTBF	Mean Time Between Failures
NASA	National Aeronautics and Space Administration
NAV	Navigator (Submersible)
NSW	Naval Special Warfare
NSWC PCD	Naval Surface Warfare Center Panama City Division
NTA	Navy Tactical Task
O-level	Organizational-Level
OCSMP	OMG-Certified SysML Professional
OMG	Object Management Group
OOSEM	Object-Oriented Systems Engineering Method
OPM	Office of Personnel Management
OT	Operational Time
OP	Operating Procedure
PEO	Program Executive Office

PLT	Pilot (Submersible)
PM	Project/Program Manager
PMS	Project/Program Manager, Ship
PoR	Program of Record
P_{RTC}	Performance Value / Fully realized task
PSF	Performance Shaping Factor
PU2B	Product Utility Usability Business
Q#	Question number (e.g. Q3, Q4, etc.)
REQ	Requirements Diagram
ReqEng	Requirements Engineering
RFP	Request for Proposal
RSS	Root Sum Square
RTC	Relational and Technological Capstone
RQ	Research Question
SATCOM	Satellite Communication
SBIR	Small Business Innovative Research
SD	Sequence Diagram
SD	Standard Deviation
SE	Systems Engineering
SEAL	Sea, Air, and Land (Naval Special Operator)
SME	Subject Matter Expert
SOCOM	Special Operations Command

SOTN	Special Operations Task Number
SPAR-H	Standardized Plant Analysis Risk HRA
SRS	System Requirements Specification
ST	Standby Time
SysML	Systems Modeling Language
TALDT	Total Administrative and Logistics Delay Time
TALOS	Tactical Assault Light Operator Suit
TCM	Total Corrective Maintenance
THERP	Technique for Human Error Rate Prediction
TPM	Total Preventative Maintenance
TT	Total Time
UAF	Unified Modeling Language
UC	Use Case Diagram
UNTL	Universal Naval Task List
USSOCOM	United States Special Operations Command
UTIC	Undersea Technology Innovation Consortium
UUV	Unmanned Undersea Vehicle or Unmanned Underwater Vehicle

CHAPTER 1.0 - INTRODUCTION

In the Department of Defense (DoD), a complex system (also termed in this paper as simply a system, or platform) is in place to satisfy stakeholder needs based on operational concepts and defined environments as shown in Table 1 with a simplified example utilizing a tiered hierarchy (1).

Table 1: Example of a Tiered Hierarchy

Hierarchy Category	Tier Level	Stakeholder Needs and Requirements
Operational Concept and Defined Environment	Tier 0	To launch from a maritime host platform and transit in the undersea domain to an objective.
Stakeholder Needs	Tier 1	As the stakeholder, I would like the ability to move a small team of special operators in an expeditious, clandestine manner to an objective.
System Description	Tier 2	The non-pressurized submersible shall be capable of holding a minimum of four operators.
Subsystem Description	Tier 3	The air subsystem shall provide two breathing sources for each operator.

When integrating human-in-the-loop characteristics into a DoD system, a 2021 definition from ScienceDirect of this integration is, "the interaction between human and technology, which is designed in such a way that needs and abilities of the human are appropriately implemented in the system design" (2). In addressing system design, modern efforts bring into the fold digital engineering, which has become an important strategy in the defense domain for a comprehensive, more efficient systems engineering process toward new and existing platforms (3). In certain industries such as automotive, space, and DoD, digital engineering becomes centered around Model Based Systems Engineering (MBSE) and the Systems Modeling

Language (SysML) language, which is intended to supply the building blocks for systems and the human (or actors) involved versus the more traditional Document Based Systems Engineering (DBSE) approach. However, the common building blocks of system design in DoD center around traditional disciplines like mechanical, electrical, and software, but not on the actors, except as a siloed, disconnected source for requirements, or as an external block. With that, the referenced concept of Human-Centered Systems Engineering (HCSE) seeks to address this potential shortfall.

In the DoD acquisition landscape, MBSE-related methodologies such as the International Council on Systems Engineering's (INCOSE's) Object-Oriented Systems Engineering Method (OOSEM), or the internal DoD Architecture Framework (DoDAF) and Unified Architecture Framework (UAF) are often leveraged, both as strict direction and loose guidance, to Programs of Record (PoR) in support of system development (1) (4). These system assets can exist within a stand-alone platform and are employed in a "servicemember enables the system" means to satisfy a unique mission or set of missions. Common examples of this include aircraft and surface vessels where the platform asset itself is integral during all phases of mission execution (e.g., Infiltrate (INFIL), Actions at the Objective (AAO), and Exfiltrate (EXFIL)). However, in circumstances such as U.S. Special Operations Command (USSOCOM, or just SOCOM), the asset shifts over to the human and the employment is flipped into a "platform enables the servicemember" premise. An example of this is where a platform or system may simply assist with INFIL and EXFIL, and the warfighters are performing the AAO independently. In both circumstances, MBSE methodologies have continually evolved to meet DoD needs, but do not abundantly represent the participation and mission behaviors of humans such as the warfighters rooted in SOCOM. While some modeling methodologies are looking closer and accounting for the human-in-the-loop domain such as in a Product Utility Usability Business (PU2B) model, the MBSE focus remains strictly at the platform/product level with minimal injections of human factors criteria to account for the servicemember (5). In the case of SOCOM, this results in needs and capabilities that go undefined, when put to practice, due to the exclusion of the warfighter attributes, mental acuity, and physical characteristics. Ancillary platforms or equipment that make up a fully burdened operator, and the inclusion of all operational reference missions are also omitted. Additionally, considerations for architecture-wide, aggregated, human factors parametrics with respect to cognitive workload, for example, are overlooked and prevent the design of a progressively evolving, user-friendly platform. These defined parametrics are typically a platform afterthought, or altogether absent, and the consequence is unnecessary, overcomplex stressors applied to an already high risk, stressful mission environment. It is fair to say human factors is not well represented in MBSE methodologies and requirements engineering, and for a community like SOCOM, it is essential to fully define those complexities in order for the human and the technology to be optimized in system design.

While USSOCOM is considered to be more effective at acquisitions than the larger U.S. military departments, they are generally still held to the same statutory and regulatory acquisition requirements as the much bigger military departments (or branches-of-service) (6). Moreover, SOCOM's acquisition performance primarily stems from a much smaller product of scale (6). Although the size of the SOCOM community, focus areas of its acquisitions, and program size are the basis of SOCOM's advantage, they still utilize the same processes and regulatory frameworks as well as training and education venues as those larger branches of service (6). By mirroring the system design of larger branches-of-service acquisition landscapes described in the prior paragraph, the ability to place focus on an operator's capabilities can be easily lost or stripped from serious consideration. In 2013, SOCOM introduced a Tactical Assault Light Operator Suit (TALOS), which immediately dealt with inadequate power and energy constraints, most notably duration and weight, since the suit could only leverage DoD authorized battery options (7). This created a host of human-in-the-loop challenges such as heads-up display latency, overall weight of the suit, and freedom-of-movement difficulties, which resulted in TALOS being cancelled in 2019 for infeasibility. In 2011, SOCOM executed a non-pressurized submersible program, which comprised of less than 30 Human Systems Integration (HSI) requirements (out of almost 450 system level requirements in total) with many tied to outdated DoD Military Standards (MIL-STDs) and Handbooks (MIL-HDBKs) that apply to environments unrelated to the undersea domain (8) (9) (10). For a human-centric project of this magnitude, this is a small and inconsequential proportion of human factors requirements. This led to cost and schedule overruns due to HSI issues in drivability, operator fitment, and several anthropometric traits that were either not captured in the requirements or were altogether ignored in favor of the system. Most recently, a pressurized submersible program was recently awarded based on approximately 170 requirement statements with only nine requirements tied to training and zero HSI requirements. In all three programs, the system design challenges are larger DoD program regulations and frameworks, which are accepted by SOCOM without human-in-the-loop considerations. The former acquisition executive at SOCOM, Mr. James Smith, has made a key point in stating, “The operator is our platform” (11). However, by replicating DoD’s way of doing acquisition, SOCOM continues to put the bulk of their attention on the platform and not on the warfighter.

On the basis of the above reflections regarding HSI requirements engineering, we can understand there is a need for three key improvements with regards to human-in-the-loop centered system designs. The first is a comprehensive representation of human factors engineering architecture throughout an MBSE model that is paralleled with other disciplines such as mechanical, electrical, and software engineering. The second is an all-inclusive and deliberate behavioral methodology that accounts for mission participation of the human, both independently and integrated with the system. The third is defining those human complexities through parametrics across both the architectural diagrams, behavioral diagrams, and elements within MBSE. The product is a Human-Centered Systems Engineering (HCSE) process and capability labeled the Relational and Technological Capstone (RTC). As depicted in the figure below, the RTC is a non-invasive option to notable, existing systems engineering lifecycles.

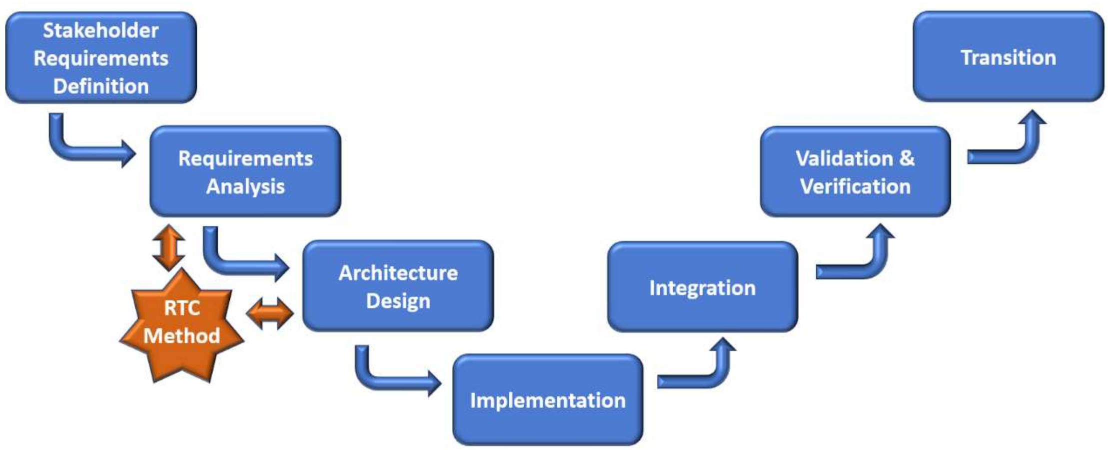

Figure 1: DoD Technical Process with RTC (V-Diagram) (12)

While this paper centers on the fields of systems engineering and human factors engineering, an up-and-coming technical field in the DoD deserving of acknowledgement is Mission Engineering (ME). The Mission Engineering Guide and Defense Acquisition Guidebook define ME as the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired warfighting mission effectiveness (13). Within ME is an approach and methodology where a problem statement and mission characterization are identified. By simply replacing mission characterization with system characterization, the RTC can directly fulfill the ME consumer, informing acquisition requirements before a system begins the implementation and integration phases (13). From there, RTC closely emulates the remaining four ME methodology steps with continued emphasis on the conceptual system versus an established system within operational scenarios.

CHAPTER 2.0 BACKGROUND

2.1 Human Factors Engineering Origins and Adoption into Military

Regardless if human factors reside as a sub-discipline under systems engineering, industrial engineering, or stands independent within an organization or institution, its roots remain the same. Under the direction of design engineers, architects, industrial hygienists, medical personnel, psychologists, physiologists, anatomists, and other interested specialties with respect to advancing human performance, an assembly was formed in Oxford, England back in the late 1940s. This cluster of diverse minds collaborated on this emerging field, which they coined as ergonomics (14). With the Greek words 'ergos' and 'nomos' in place (meaning work and natural laws, respectively), the benefit of this title was its universality where no discipline could stake ownership or conform ergonomics to its standards and culture. With this, the United Kingdom began the Ergonomics Research Society. Later on and in similar fashion, the United States coined the term 'human factors', which lead to the establishment of the Human Factors and Ergonomics Society (HFES) in the late 1950s in Southern California (14) (15).

While this research and overall initiative seeks to improve upon military system design with respect to human factors, it is important in noting the military are widely considered to be farther along and more developed than the civilian industry in this area. The "down-range" environmental conditions and risk-to-life, coupled with the demographics such as fitness standards of servicemembers has inspired military leadership to take a targeted effort in ensuring system design accounts for the human-in-the-loop. These considerations place emphasis on, but are not limited to:

- Human factors engineering

- Personnel
- Habitability
- Manpower
- Training
- Environmental Safety and Occupational Health (ESOH)
- Survivability

The value placed on each of these sub-domains are highly interconnected, so any trade-offs may have both positive and negative consequences on all other sub-domains in some fashion (16).

Three decades after the formation of HFES in the 1950s, the US Army saw the emerging need to tackle the relationship between soldiers and their platforms and equipment. This had to be achieved during the early design phases of defense acquisition programs. This need gave rise to the launch of the U.S. Manpower and Personnel Integration (MANPRINT) program in the 1980s (17). MANPRINT's charge was to develop a methodology to integrate systems with both the soldier and any ancillary equipment comprising of small arms weapons, optics, and layered apparel for hazardous environments such as extreme cold conditions, to name a few. This novel approach by the US Army was later adopted by the UKs Ministry of Defense to support their Human Factors Integration program (17).

2.2 Modern HFE and the Link with MBSE

Whether a SOCOM program or a larger DoD program, the implementation of human factors engineering requirements, or more appropriately termed HSI requirements, share similar themes. The most notable are requirements that call out human engineering design standards through MIL-STD and MIL-HDBK documentation. These documents capture best practices across common human-machine interfaces including control panels, button-ology, knobology, and anthropometric measurements to support human fitment, and much more. Below is a list of current military design criteria documents commonly leveraged during requirements development (18).

Table 2: Human Engineering Design Documentation for DoD (18)

Document Number	Title
MIL-STD-882	Standard Practice for System Safety
MIL-STD-1472	Human Engineering
MIL-STD-1474	Noise Limits
MIL-STD-1477	Symbols for Army Systems Displays
MIL-STD-1787	Aircraft Display Symbology
DOD-HDBK-743	Anthropometry of U.S. Military Personnel
MIL-HDBK-759	Human Engineering Design Guidelines
MIL-HDBK-767	Design Guidance for Interior Noise Reduction in Light-Armored Tracked Vehicles
MIL-HDBK-1473	Color and Marking of Army Materiel
MIL-HDBK-1908	Definitions of Human Factors Terms
MIL-HDBK-46855	Human Engineering Program Process and Procedures
DI-HFAC-80742	Human Engineering Simulation Concept
DI-HFAC-80746	Human Engineering Design Approach Document - Operator
DI-HFAC-80747	Human Engineering Design Approach Document - Maintainer
DI-HFAC-81399	Critical Task Analysis Report
	Handbook of Perception and Human Performance Vol I – Sensory Processes and Perception Vol II – Cognitive Processes and Performance
	Engineering Data Compendium: Human Perception and Performance
DOE-HDBK-1140	Human Factors/Ergonomics Handbook for the Design for Ease of Maintenance

Many of these documents have overlapping content and may not necessarily align directly to the future system-to-be, especially if the system contains unconventional characteristics typically seen in communities like SOCOM or the National Aeronautics and Space Administration (NASA). DoD will also leverage non-government standards and outside sources when they potentially apply to the system of interest. Overall, these documents, whether government or non-government, serve as best practice guidelines for a contractor to perform an end-to-end review for appliable standards and may not line up the man-machine implementation and integration.

The implementation of HSI in an MBSE model is generally limited to typical diagrams and is consistent across methodologies. The basis of this is through the inclusion of actor elements within diagrams that can cover external actors (operators, drivers, etc.), internal actors (system engineers, mechanical engineer, or anyone who is responsible or accountable to the model and overall program/project), and in some cases non-actors (shareholders, competitors, etc.). As illustrated and covered below, actor elements can be conveyed as a stick-man actor, an actor as a block (“block actor”), a lifeline, or as a swim lane. While the focus of this dissertation will center around an Unmanned Undersea Vehicle (UUV) system, this section will cover both a Hybrid Sport Utility Vehicle (HSUV) and the UUV to prove similitudes in actor usages. In using Cameo Systems Modeler, the following diagrams are redeveloped from a HSUV package provided as a training resource for three of the four SysML Object Management Group (OMG) exams, commonly referred to as OMG-Certified SysML Professional (OCSMP) certifications (19) (20) (21). As OCSMP certifications serve as a multi-industry standard, especially within DoD, the HSUV diagrams containing actors both illustrate and support the point of typical usages of actors on diagrams regardless of methodology.

The first and most common use of actors is with Use Case (UC) diagrams. A use case is a black box of a system where actors invoke or participate in identified services with the system, which is typically labeled as a block (22). Put another way, a use case describes the functionality of a system in terms of how it is used to achieve its goals with actors who interface with the system (23). After stakeholders and their respective needs or concerns are identified, use cases tend to be one of the first diagrams built in MBSE as it is a good starting point to capture needs and concerns into requirements via use cases with associated actors.

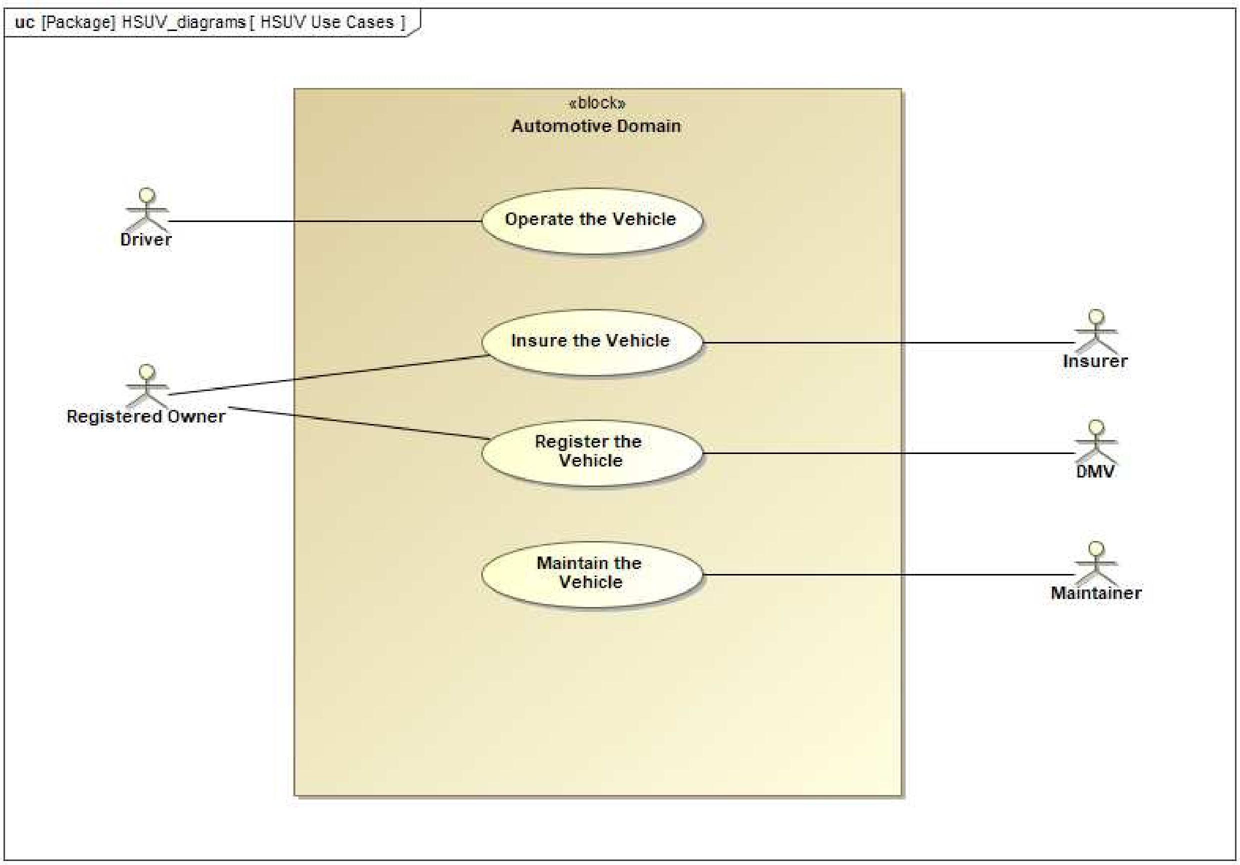

Figure 2: HSUV Use Case Diagram (24)

Another common use of actors is in Block Definition Diagrams (BDD). However, it is less common to see actors in BDDs, except when portrayed at the system domain level, or the

Tier 0 level (operational concept and defined environment) as covered in the introduction. As with use cases, these "to-be" system domain BDDs are typically built once stakeholder needs and concerns have been identified and are also a black box representation of the system.

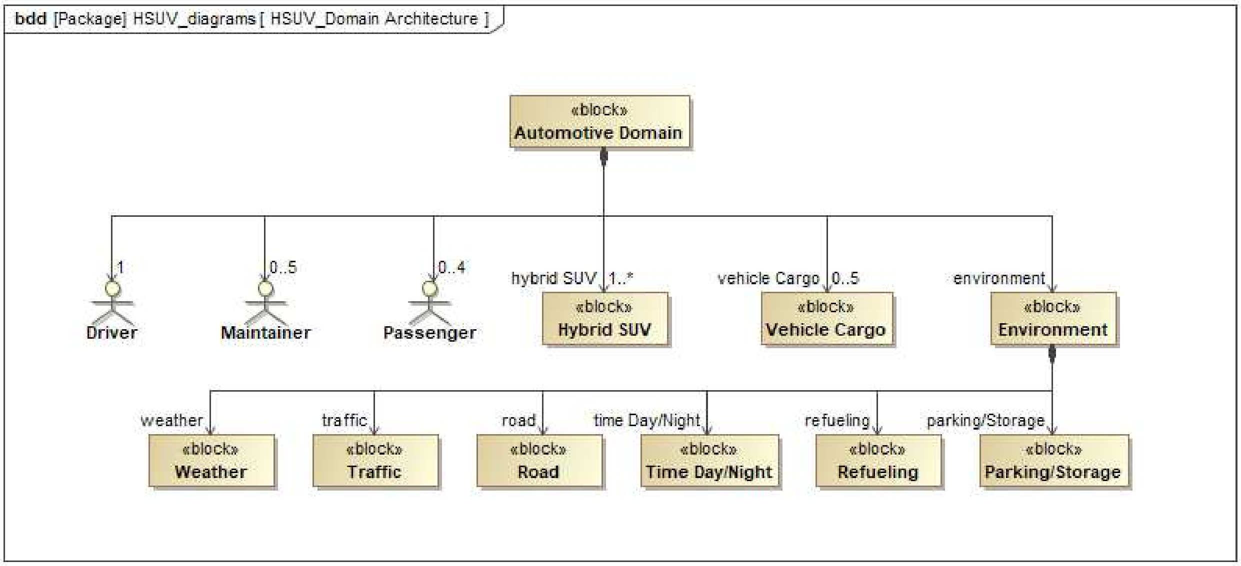

Figure 3: HSUV Block Definition Diagram (24)

Although far less common, the HSUV domain diagram examples can provide a complementary Internal Block Diagram (IBD) based on the above BDD. Just like the HSUV BDD, the HSUV IBD is also portrayed as a black box, which generally contradicts the use of an IBD as they are designed to specify the internal structure of a block and almost never contains actors since it's better equipped to show connections between part properties and reference properties as well as the matter, energy, or data that flow across the connections (22) (23).

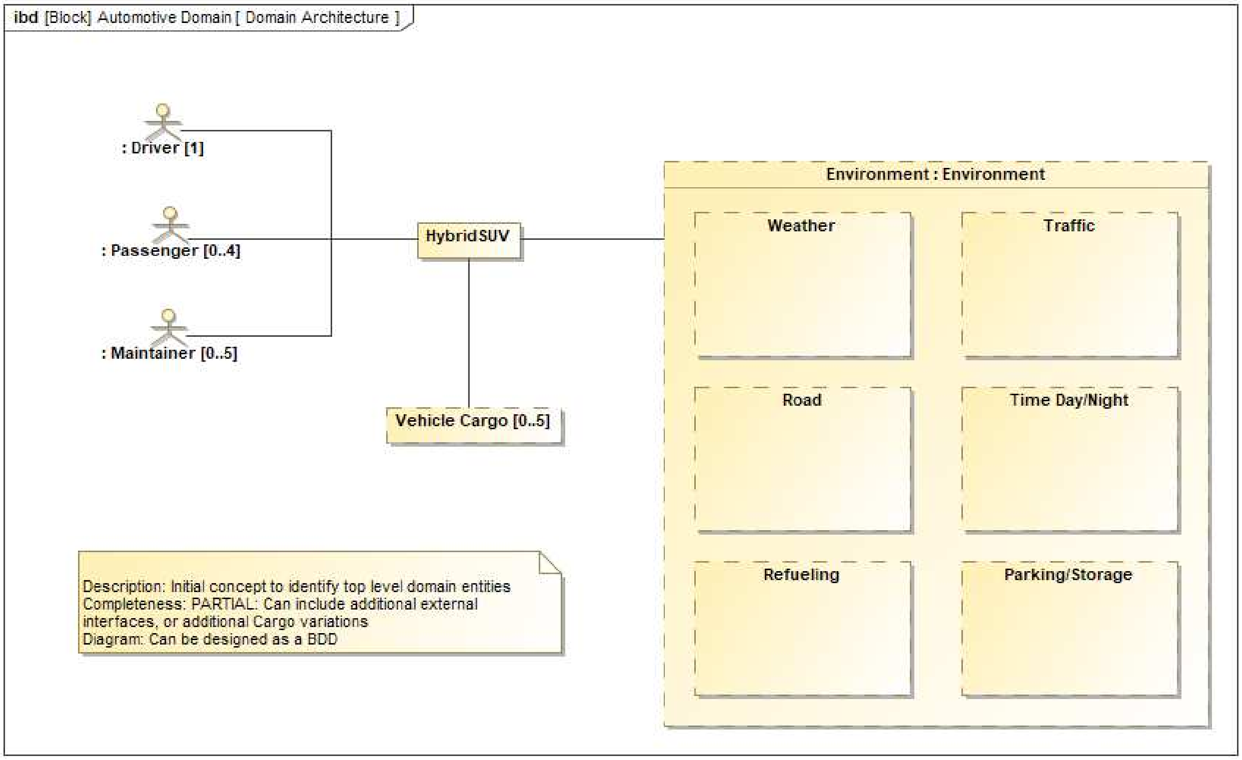

Figure 4: HSUV Internal Block Diagram (24)

Another common use of actors is seen across a behavior diagram. Specifically, activity (ACT) diagrams and sequence diagrams (SD). In the case of activity diagrams, actors are represented by activity partitions (commonly termed as swim lanes) where specific activities or actions are performed by the actor, or group of actors, represented as the swim lane. There can be additional swim lanes represented by other actors or the system, which help to complete the overall activity using object flows and control flows. The goal of an activity diagram is to dynamically describe how the activities and actions execute and transform its inputs to outputs (23). Many methodologies begin the development of activity diagrams to provide a more graphical and sequential description of use cases to stakeholders (22). Although the HSUV package does not contain an activity diagram with actors represented, it does have a sequence diagram example. Instead of swim lanes, sequence diagrams show actors (in this case, the driver) as lifelines and how they interact with the system to show a dynamic behavior in a step-by-step fashion (22). As with activity diagrams, sequence diagrams can expand the behavioral understanding of the stakeholders early in architectural, post-use case stages. Additionally, sequence diagrams have proven to be a widespread practice as test cases to be executed through test plans and procedures.

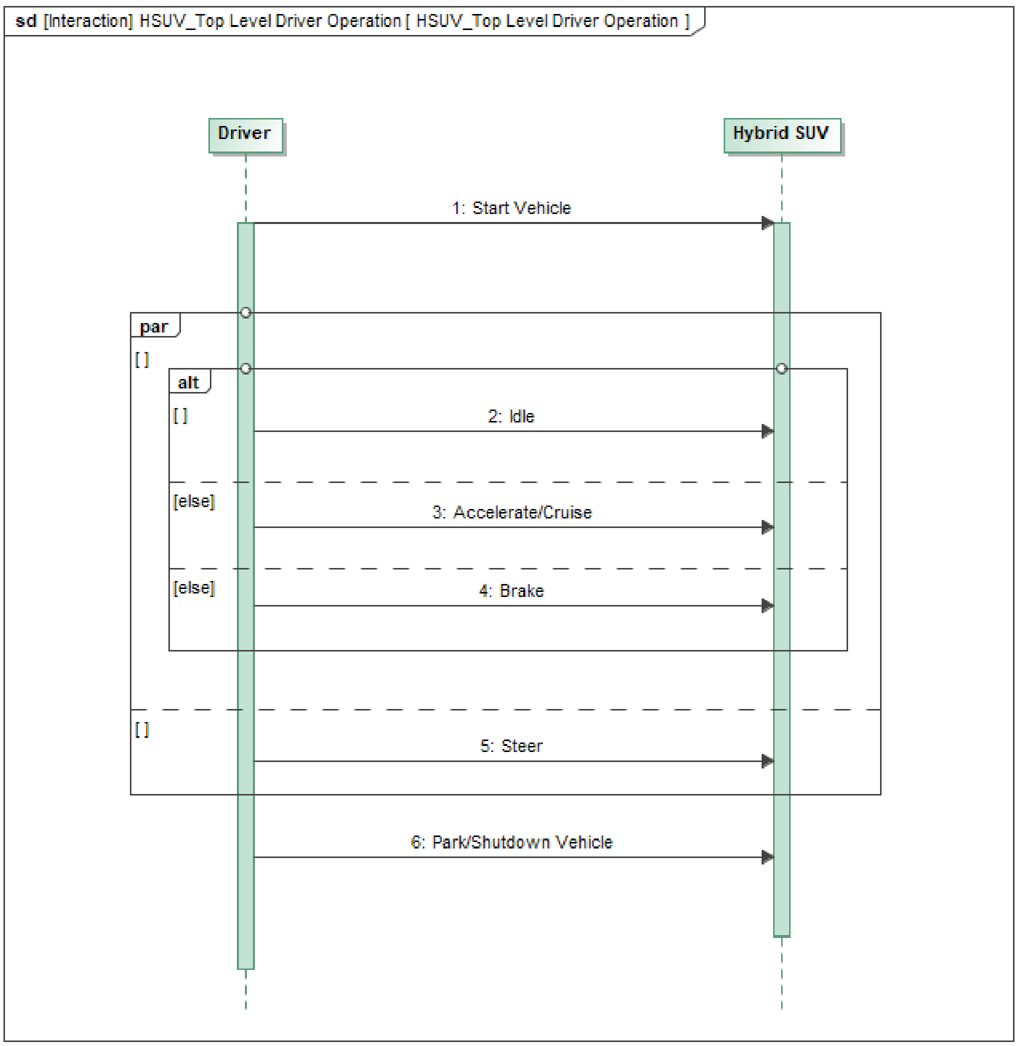

Figure 5: HSUV Sequence Diagram (24)

To show resemblances between actor usages across different systems and industries, the below UUV diagrams are provided. These diagrams were developed in the proposal stage of a UUV program where use cases and domain architectures are commonly built. The first use case centers around a UUV operator utilizing a deployed system. Like the HSUV use case containing five actors, the UUV operator is external to the system and is connected to the UUV use cases through an association relationship with include relationships.

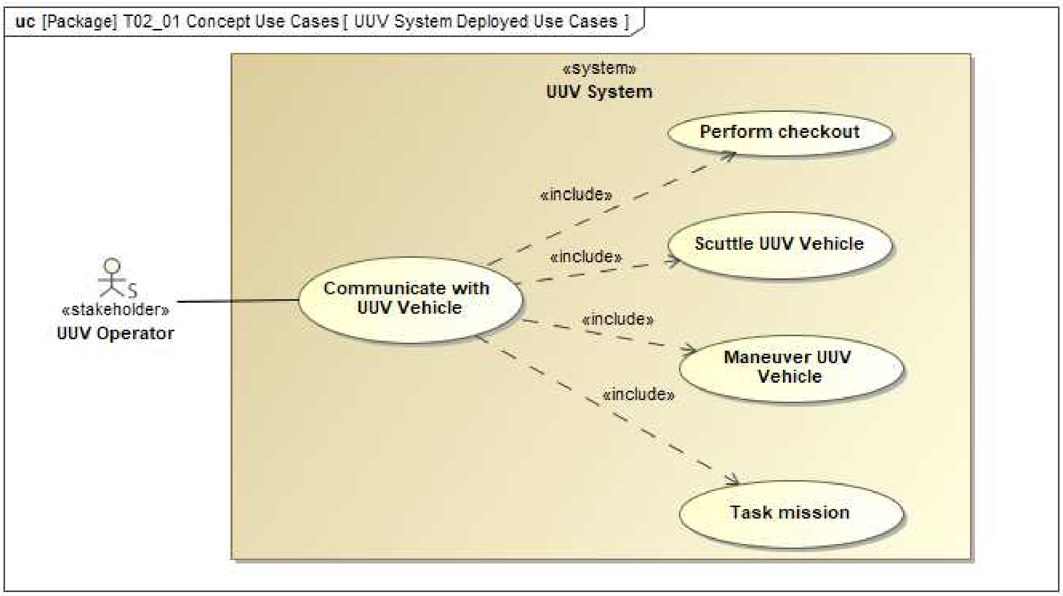

Figure 6: UUV Use Case Diagram - Deployed System

The next UUV use case diagram is for the technician and although the role of the actor has changed, it remains as an external element to the system. In this figure, the UUV technician is associated with eight separate use cases from the UUV operator, all via association.

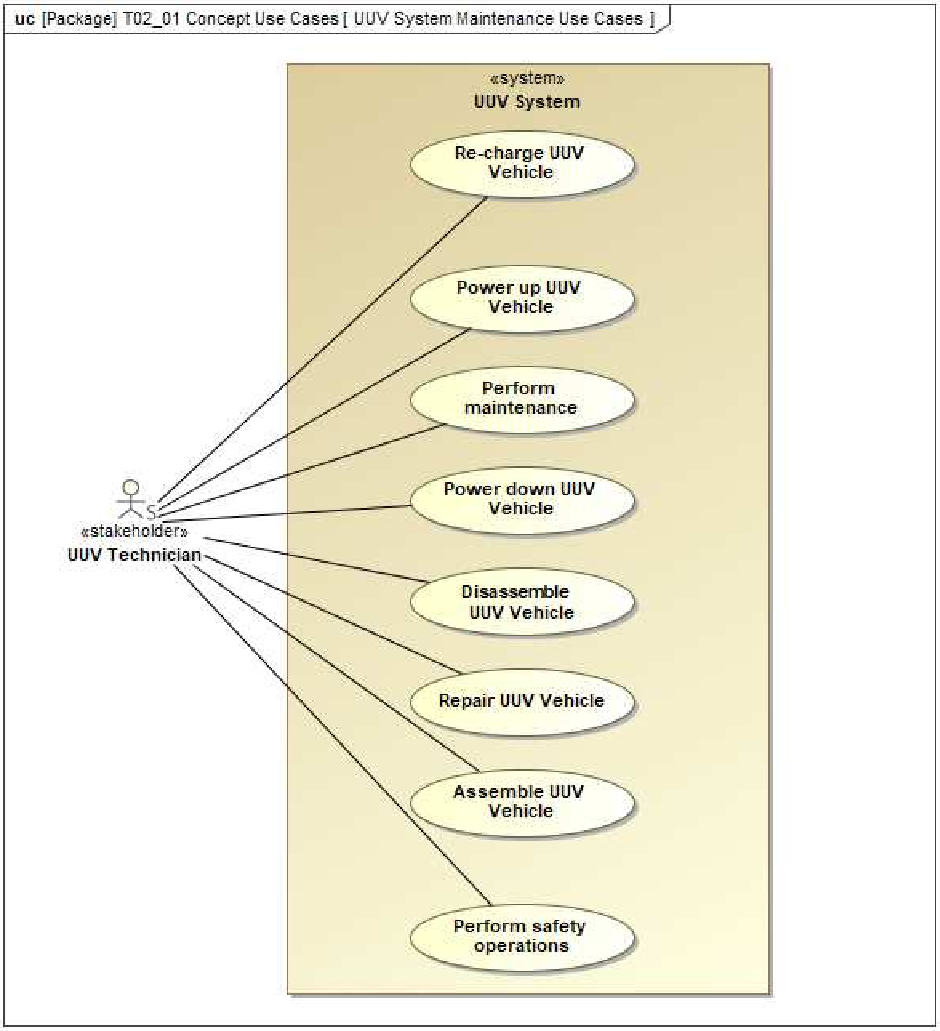

Figure 7: UUV Use Case Diagram 2 – System Maintenance

Leveraging a similar methodology as seen in the HSUV package, the UUV diagram follows use cases with a "to-be" system domain BDD. And analogous to the HSUV domain architecture, the UUV domain architecture is related to the actors using composite associations. Additionally, every actor, from UUV operator to host platform support operators, also relate to the UUV system externally, but with associations.

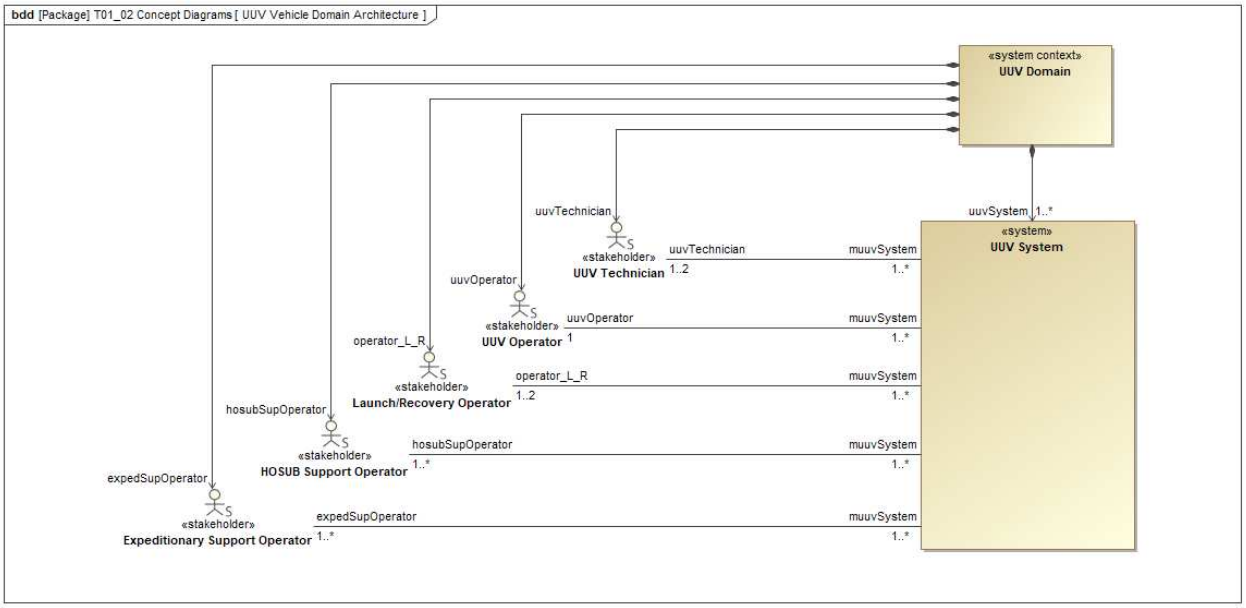

Figure 8: UUV Block Definition Diagram - Domain Architecture

While the diagrams for both the HSUV and UUV are strong examples of actor representation, the following section will explore the challenges and shortfalls seen in the Human Factors Engineering (HFE) technical process and HSI requirement development.

2.3 HFE Challenges in the Technical Process

Whether an engineering team or division adheres to INCOSE, the defense acquisition lifecycle, or the SE V-Model, there is a general technical process being undertaken. Many cases in industry like modern space exploration down to household appliances have resulted in highly successful HFE products and platforms. However, with human factors and the military, there are identified challenges across most PoRs, from Small Business Innovative Research (SBIR) to a major system acquisition. These identified challenges are:

- *Organizationally*, in order to maintain a cost-effective program, skilled staff may be limited to the core disciplines needed to build a complex system such as mechanical, electrical, and software engineering.
- *Conceptually*, visualizing how the operator or human-in-the-loop will behave and perform with the system is generally more removed and incomplete than with other components and subsystems. As shown above in the HSUV and UUV diagrams in the 'Modern HFE and the Link with MBSE' section, the actors involved are positioned externally to the system, making them less integrated than other elements contained in the system.
- *Contractually*, satisfying requirements and meeting acceptance criteria in human systems integration can become difficult due to the ambiguity of clear, quantifiable measures. Many requirements across programs simply reference the same MIL-STD documents, which provides a "one size fits all" design guidelines.
- *Traditionally*, the user feedback from servicemembers provides legacy recommendations where the human factors design ideas regress to prior system designs instead of novel design ideas.

CHAPTER 3.0 RESEARCH QUESTIONS AND TASKS

Research Question 1 (RQ1) Aim: Development and Validation of RTC Phase 1.

- **RQ1.1:** Can an MBSE model, developed from an architectural and behavioral framework that includes an internal actor block at the subsystem level (Tier 3), address human-in-the loop functional requirement shortfalls during requirements generation through a supplemental process for SOCOM?
- **RQ1.2:** Will functional requirements of a human-in-the-loop centered model supplement the needs of modern SOCOM systems?
- **RQ1.3:** How can the characteristics of a human-in-the-loop centered model and resulting functional requirements be validated for SOCOM acquisition?

Task 1.1 (RQ1 - 1.1): Investigate and inspect SOCOM, or larger DoD MBSE and DBSE conceptual models and requirements from existing undersea systems to determine the current level of human factors and human-related architecture within the model, as well as the quantity and hierarchy of each element and relationship. SOCOM MBSE and DBSE models will have to be requested and accessed from an acquisition program office within SOCOM, SOFWERX, or an applicable DoD program.

Task 1.2 (RQ1 - 1.2): Using one of the MBSE or DBSE models from existing undersea systems in Task 1.1, design and construct new architectural and behavioral diagrams with a human-in-the-loop centered modeling approach. These new architectures and flows will result in an expanded list of HSI functional requirements.

Task 1.3 (RQ1 - 1.3): Leveraging SOCOM and Subject Matter Expert (SME) representation with respect to the models from Task 1.2, evaluate the overall quality and effectiveness of the human-in-the-loop centered model and resulting HSI functional requirements using custom, evaluation and assessment questions derived from multiple MBSE adoption surveys (25) (26) (27). Each SME evaluation will be conducted through a formal review and structured walkthrough (28).

Research Question 2 (RQ2) Aim: Development and validation of a SOCOM Task List.

- **RQ2.1:** Could the SOCOM community utilize an independent task list, similar to the Air Force Task List (AFTL) or the Universal Naval Task List (UNTL), which encompasses Navy, Marine Corps, and Coast Guard tasks, to catalogue and organize at the tactical level to be translated into an inventory of operator performance attributes to be aligned into quantitative metrics (29) (30)?
- **RQ2.2:** How can SOCOM-related human-in-the-loop performance metrics help to further define the Human System Integration (HSI) requirements for an architectural model?
- **RQ2.3:** How can the characteristics of a SOCOM Task List be validated for SOCOM acquisition?

Task 2.1 (RQ2 - 2.1): Investigate and inspect existing SOCOM-applicable columns from UNTL, specifically at the tactical level. Leverage the SOCOM-related tasks from the UNTL and generate an all-encompassing, tactical task list from the undersea SOCOM domain to construct an initial list of performance attributes needed for SOCOM undersea operations (29).

Task 2.2 (RQ2 - 2.2): Using Performance Shaping Factors (PSFs) similar to values published in the Technique for Human Error Rate Prediction (THERP) and the Engineering Data Compendium – Human Perception and Performance, develop PSFs using prior experience estimations for all SOCOM-related attributes identified across each undersea task in the SOCOM Task List (31) (32) (33).

Task 2.3 (RQ2 - 2.3): Leveraging SOCOM and SME representation with respect to the task list developed in Task 2.1 and the quantitative PSFs within that list from Task 2.2, evaluate the SOCOM Task List for collaboration potential and system design consideration based on PSF scoring.

Research Question 3 (RQ3) Aim: Development and validation of RTC Phase 2.

- **RQ3.1:** Utilizing a human-in-the-loop centered modeling architecture from RQ1 and the task list performance metrics from RQ2, does combining these into a parametric architecture to address human-in-the-loop performance requirements improve how SOCOM executes on acquisition programs?
- **RQ3.2:** How can the characteristics of a parametric architecture and resulting performance requirements be validated for SOCOM acquisition?
- **RQ3.3:** Overall, does this new methodology strengthen or weaken existing human factors requirements commonly applied to programs?

Task 3.1 (RQ3 - 3.1): Re-design, modify and construct new MBSE architectures, along with corresponding logic and behaviors based on a human-in-the-loop centered task modeling approach, with the measures from the SOCOM Task List as stated in Task 1.2 and Task 2.2, respectively. From this updated model, construct parametric architectures to aggregate task elements. Derive and generate a comprehensive set of human factors requirements, which fully encompasses the RTC.

Task 3.2 (RQ3 - 3.2): Using the architectural and parametric models from Task 3.1, compute P_{RTC} values using a simulation toolkit plugin. These new architectures and flows will result in an expanded list of HSI performance requirements. Evaluate the overall quality and effectiveness of the aggregated P_{RTC} scoring and resulting performance requirements.

Task 3.3 (RQ3 - 3.3): Leveraging SOCOM and SME representation with respect to the models from Task 3.1 and 3.2, determine if the overall RTC process for developing requirements provides a positive or negative impact toward SOCOM acquisition using custom, evaluation and assessment questions derived from multiple MBSE adoption surveys (25) (26) (27). Each SME evaluation will be conducted through a formal review and structured walkthrough (28).

CHAPTER 4.0 THE RTC METHODOLOGY

4.1 Definition of the RTC Methodology

Based on the bullets provided in the HFE Challenges in the Technical Process section (Section 2.3), the organizational, conceptual, contractual, and traditional challenges can be mitigated by adding an amendment or addition to a typical SE process. In many instances, skilled staff limitations and user feedback are viewed as resource constraints that can be remedied with program-specific hiring and scheduled interactions with end users. However, treating actors more expansively across a system and providing less ambiguity in HSI requirements may be improved with the RTC. The general principles behind incorporating the RTC are threefold:

1. To provide the RTC as an all-encompassing, "á la carte" addition to an SE process. This is to ensure there are no alterations to any existing SE processes with either phase of the RTC.
2. To supplement, while not altering, any traditional or existing HSI requirement generation such as the use of MIL-STDs, MIL-HDBKs, or operational recommendations. To date, HSI requirements that have been used in the past have been helpful toward system development and should not be subtracted.
3. To allow the RTC to exist across all SE processes. For this to be effective, RTC must be a stand-alone process that can seamlessly inject itself into any process as shown below with both the DoD and INCOSE processes.

With these three principles defined, the following two figures portray where the RTC fits into the DoD process as captured from the Defense Acquisition University (DAU) as well as in the INCOSE process. For the remainder of this research, the INCOSE process will be employed in support of the RTC steps (12) (1).

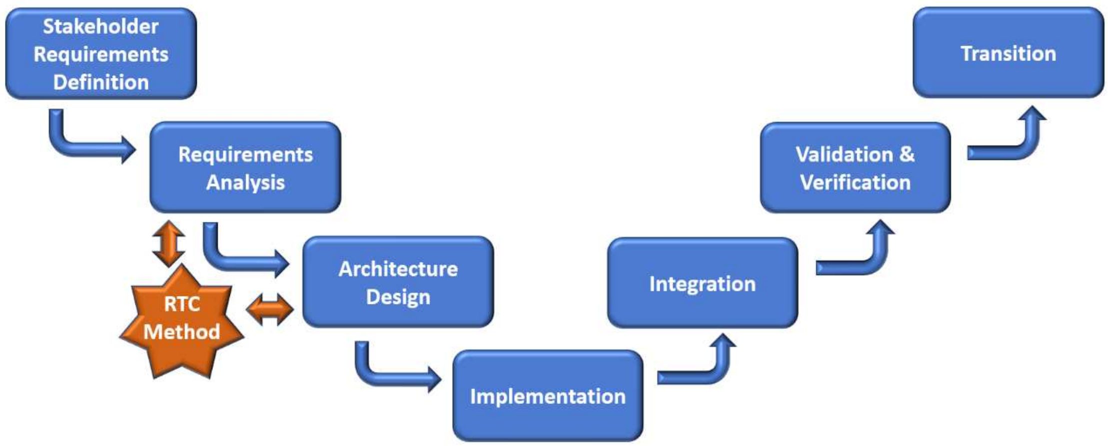

Figure 9: DoD Technical Process with RTC (V-Diagram) (12)

While the figure above shows the entirety of the DoD process, the INCOSE process below shows a zoomed in portrayal where the RTC places adjoining focus in the architecture definition and the System Requirements Specification (SRS) document. As mentioned above, the below image will be the reference standard and serve as the benchmark for the RTC two-phase sequence of steps as part of an overall objective of answering the research questions in the previous section.

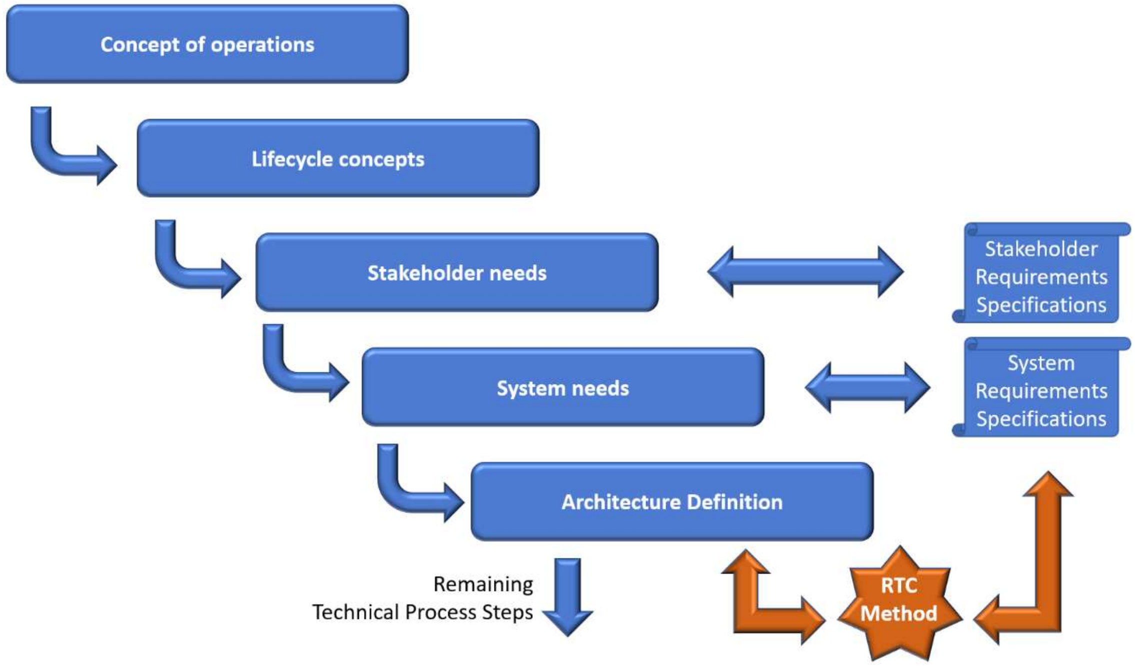

Figure 10: INCOSE Technical Process with RTC (1)

The key aspect prior to defining the steps within the RTC is where to properly inject the RTC into an existing systems engineering process. As shown in the above two figures, the RTC requires a conceptual architecture definition of a proposed system. While program constraints such as cost and schedule may dictate how much architecture definition is reasonable, a suggested minimum level to execute the RTC is a partial subsystem architecture definition to be completed prior to beginning the RTC. Explained in more detail when considering a system architecture, the next level or hierarchy below a system are the subsystems. In the case of the RTC, so long as a systems engineer develops a portion of the subsystems needed for HSI requirements development, the RTC can be executed. Depending on the system design lifecycle, there could be additional opportunity to add further layers and detail to the architecture definition, such as components, to perform additional iterations of the RTC. Using the more detailed, zoomed-in INCOSE Technical Process figure, the architecture definition step must be completed prior to commencing with the RTC. Now that the RTC has been aligned to the INCOSE process, the next action is defining the specifics of the RTC in detail. With that, the RTC begins with Phase 1 and described in the figure below:

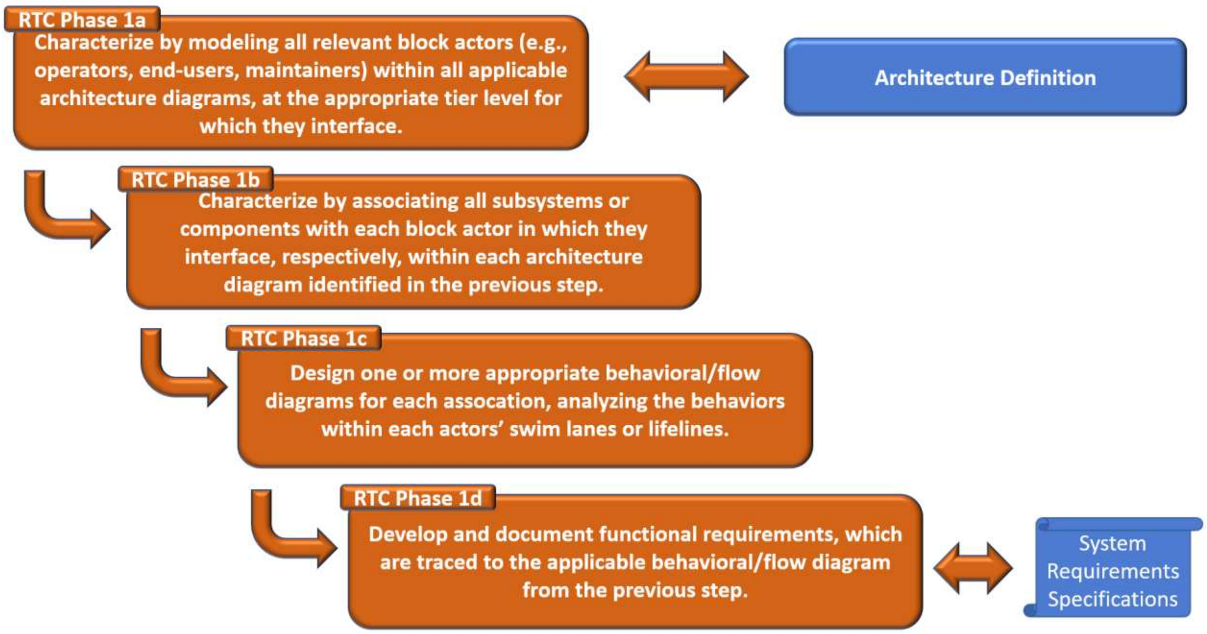

Figure 11: RTC Phase 1

The RTC Phase 1 is broken up into four steps labeled 1a, 1b, 1c, and 1d, and shows which specific steps a relationship exists with an architecture definition and the System Requirements Specifications (SRS). Each step is described in further detail as follows:

- RTC Phase 1a: Insert all relevant block actors at the highest tier levels for which they interface with, respectively, within all applicable concept and logical architecture packages. Within reasonable scope of the program, each architecture should be considered for the RTC in order to maximize HSI requirement potential.

- RTC Phase 1b: Associate all relevant architectural blocks (in the case of this research, the subsystem level) with each block actor in which they interface with, respectively, within each concept and logical architecture package identified in the previous step. This step is where the RTC deviates from typical SE process as the actors are included directly into the system design like any other subsystem. While subsystems are specifically called out in this research, Phase 1b can also apply at the component or sub-component level, where appropriate. In the same manner of maximizing HSI requirements by leveraging as many architectures as practical, associating as many relevant actors to architectures will also serve to maximize HSI requirements. Examples of relevant actors include operators, maintainers, passengers, etc.
- RTC Phase 1c: For each association, construct an appropriate behavioral/flow diagram, highlighting typical behaviors within each actors' swim lanes. While swim lanes are called out and are related to activity diagrams, the use of use cases or sequence diagrams, which relate actors to lifelines, may be preferential. In designing behavioral diagrams, working with SMEs can help provide Concept of Operations (CONOPS), coupled with the functional requirement metrics.
- RTC Phase 1d: Develop functional requirements, which are verified through each behavior within each block actors' swim lanes or lifelines. By using the behavioral/flow diagrams, requirements are worded around the specific actions or messages developed in the activity or behavioral diagrams, respectively. Once the HSI functional requirements are written, they are to be incorporated into the SRS, or equivalent document.

Whether the RTC Phase 1 is completed or not, the RTC Phase 2 can proceed. Unlike the Phase 1, the Phase 2 does not depend on Architecture packages or diagrams to be completed. However, it does require the development of a block actor BDD, with the applicable information contained in a DoD task list. The use of pertinent tasks from a task list, or task list subset is to be properly organized and tiered into a BDD, so long as the tasks are enabled by, or related to the proposed system. For example, a SOCOM operator represented by a block actor would not include skydiving-related tasks as it pertains to undersea, submersible system missions or operations. With that, the RTC can begin or conclude with Phase 2 as explained in the figure below:

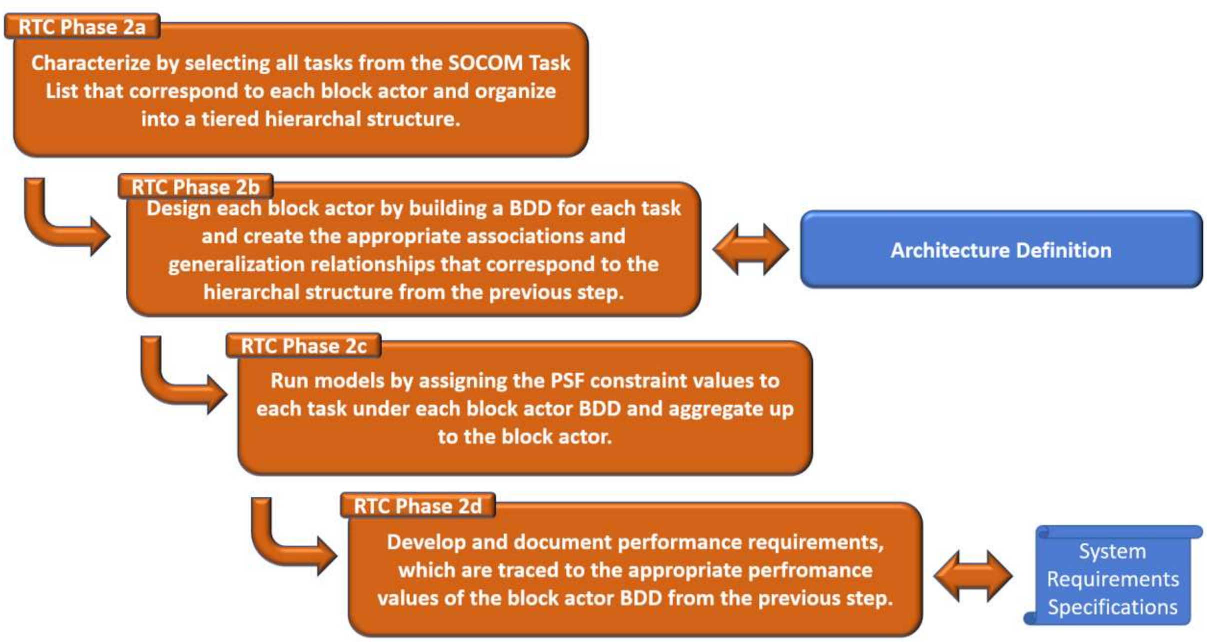

Figure 12: RTC Phase 2

Like with Phase 1, the RTC steps for Phase 2 are broken up into four steps labeled 2a, 2b, 2c, and 2d, and shows which specific steps a relationship exists with the architecture definition and the SRS. Each step is described in further detail below.

- RTC Phase 2a: Select all tasks from the SOCOM Task List that correspond to each block actor and organize into primary, secondary, tertiary, and quaternary tasks. This requires a detailed inspection of the task list to ensure each OP and EP is accounted for based on every evolution, whether mission, training, or maintenance to name a few, identified by the proposed system.
- RTC Phase 2b: Under each block actor, build a BDD for primary tasks, and create the appropriate associations and generalization relationships for each secondary, tertiary, and quaternary tasks. The SysML model architect must inspect each task within the task list to determine the tasks parent and child relationships to be incorporated into the BDD. This portion may require SME input to help ensure the BDD is properly constructed based on end user applications.
- RTC Phase 2c: Assign the PSF constraint values to each task within each block actor BDD and aggregate up to the block actor. The constraint values will be dependent on the data pulled from the BDD. Some data may be aggregated utilizing a Reliability Block Diagram (RBD)-style series or parallel format, whereas other data may be aggregated using different calculations. The constraint values are the preference of the SysML model architect with the support of SME input.
- RTC Phase 2d: Develop performance requirements, which are traced to each aggregated value of a block actor. Based on the analysis of the aggregated values from the parametrics applied to the BDD, requirements are generated to place consideration toward system

design as it relates to HSI. For example, if the aggregated value at the block actor level reveals an excessive level of mental acuity carried by the actor, the resulting HSI performance requirements may expand upon how much additional simplicity can be applied by the proposed system (e.g. assuming the system GUI displays complex information, thus requiring a simplification of the GUI for ease-of-understanding for the actor).

The RTC Phase 1 and RTC Phase 2 were developed to be closely related to the Mission Engineering Guide's ME approach and methodology, as shown in the below figure.

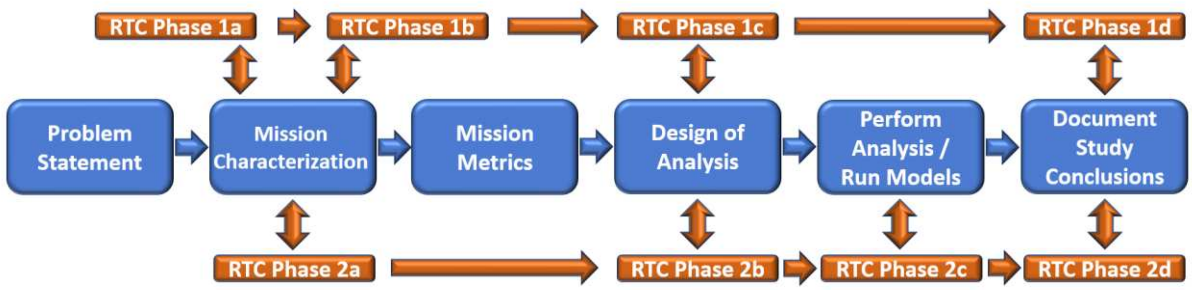

Figure 13: Relationship Between RTC Phase Steps and the Mission Engineering Methodology (13)

The RTC Phase 1a and 1b characterize the actor with the system in the same manner as a mission is characterized by including the needed elements into a diagram. RTC Phase 1c designs behavioral diagrams similarly to how a mission is designed using alternative models and architectures, which represent a different view from a relatable diagram. RTC Phase 1d documents requirements into an SRS, or equivalent document, just like the mission study is typically documented in a report or briefing (13). The RTC Phase 2a characterize the actor with the necessary SOCOM tasks in the same fashion as a mission is characterized by including the necessary assets and interfaces. RTC Phase 2b designs the tasks into the actor block into an alternative architecture similarly to how a mission is designed using alternative operational scenarios. RTC Phase 2c runs parametric models as a mission would run a Monte-Carlo or simulation application. Just like with RTC Phase 1d, RTC Phase 2d documents the new requirements into an SRS, or equivalent document, just like the mission study is typically documented in a report or briefing (13).

With the RTC defined, the identification of a system of interest to use for this research must account for varying factors to comprehensively exercise each step in the RTC process for evaluation.

1. As targeted throughout this research, the system of interest must account for its use in the USSOCOM community due to their operator-centric mission sets.
2. The system of interest requires a human-in-the-loop set of tasks that can place emphasis on operator performance.
3. The system of interest must have artifacts established up to and including the architecture definition as called out in the INCOSE Technical Process with RTC figure in section 4.1. This includes the following steps:
    a. Concept of Operations
    b. Lifecycle Concepts
    c. Stakeholder Needs
    d. System Needs
    e. Architecture Definition

Given the completeness and availability of this information, any formal set of requirements that accompany these three factors will suffice in order to proceed with the RTC.

4.2 Development of an MBSE Model from a Set of UUV Requirements

With the RTC now defined, the next major step is to lay the groundwork for an MBSE model with the development of conceptual and logical views to fully characterize the process in the following sections. These views will primarily account for the concept of operations, system needs, and architecture definition steps as defined in the INCOSE Technical Process with RTC figure.

Before this is possible, the identification of a system of interest needs to be finalized. In discussions with a Naval Special Warfare (NSW) program office director in Washington D.C., an acquisition representative at USSOCOM headquarters in Tampa, FL, and government engineers at Naval Surface Warfare Center Panama City Division (NSWC PCD), the identification of a UUV system has been recommended. UUVs are utilized by SOCOM as an extension of their undersea operations. While the RTC can be implemented for any system with a human-machine interface, the manner in which they deploy, recover, and utilize a UUV is much more dynamic and operator centric than typical UUV deployment. The dynamic use of the UUV will be through a non-pressurized manned submersible platform in a clandestine, undersea environment. The government engineers at NSWC PCD support NSW research and development efforts and are frequently exposed to a variety of NSW undersea systems and projects, including both UUVs and manned submersibles, making them an ideal group to hold research discussions.

The following information was provided on the UUV system, which presents an all-inclusive starting point to demonstrate the RTC (34) (35).

- 370 requirements provided via a UUV Performance Specification and categorized in the upcoming figures below (34).

- Subsystem architecture via a Technical Volume derived from a commercial UUV system and converted to a BDD in the upcoming figures below (35).

With the RTC requiring an architecture to proceed, a baseline model can be developed with this information. To accommodate those who review this research, the remainder of this section will briefly describe the model containment and tier hierarchy. The tier hierarchy is illustrated below and follows a Tier 00 to Tier 04 decomposition and alignment with a typical system breakdown.

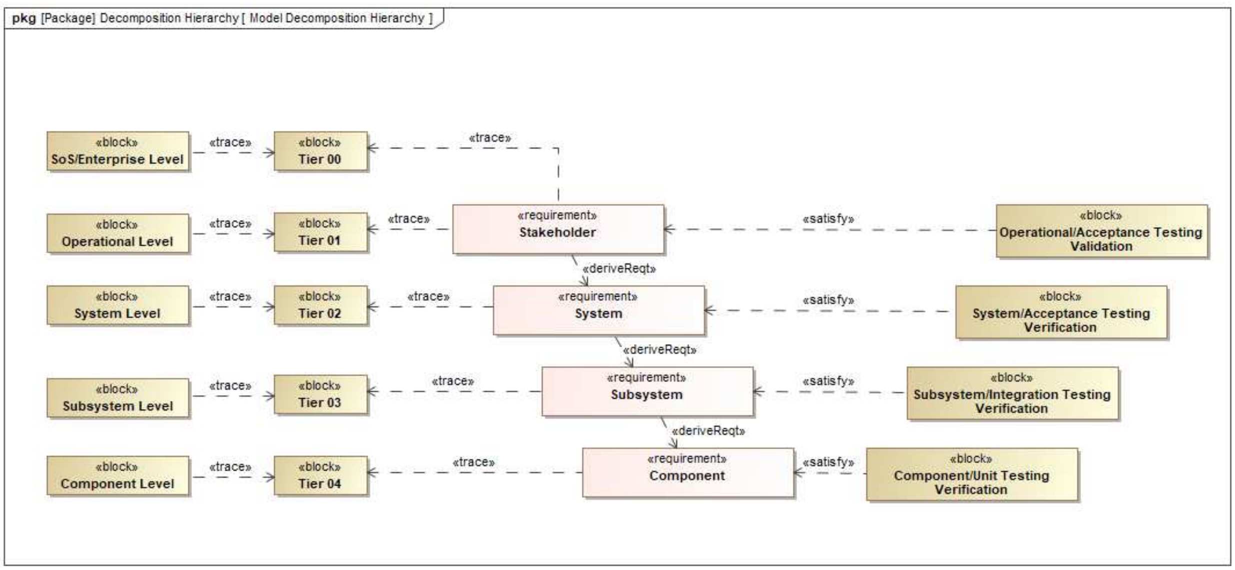

Figure 14: Decomposition Hierarchy

Based on the decomposition hierarchy, a containment tree is assembled that places emphasis on a tiered organization. The main modeling packages are broken into:

- Misc: This package serves as a “catch-all” for additional modeling.
- RTC_01 Common Libraries: Acronym lists, Glossaries, etc.

- RTC_02 Concept/Proposal Model: This package supports the proposal effort where conceptual models and stakeholder use cases are developed in order to satisfy technical sections of a proposal.
- RTC_03 Logical/ReqEng Model: Once a proposal is awarded or prior to award, the requirements engineering model supports the logical development of derived use cases, functional flows and behavioral diagrams to generate new requirements or derive existing requirements.
- RTC_04 Physical Model: Upon completion of the logical model, the operational model is developed to capture the relevant stakeholders and the physical, behavioral, and procedural characteristics of the platform as well as test cases to verify and validate the design. Element types such as constraint, signal, and value types are also located in this package.

The RTC_02, RTC_03, and RTC_04 packages are further decomposed into a tiered organizational package structure to differentiate between hierarchies. For example, the requirements listed in the logical model can be separated by system level (T02), subsystem level (T03), and component level (T04). The containment tree in the figure below conveys the bulleted RTC items and their respective placement within the model.

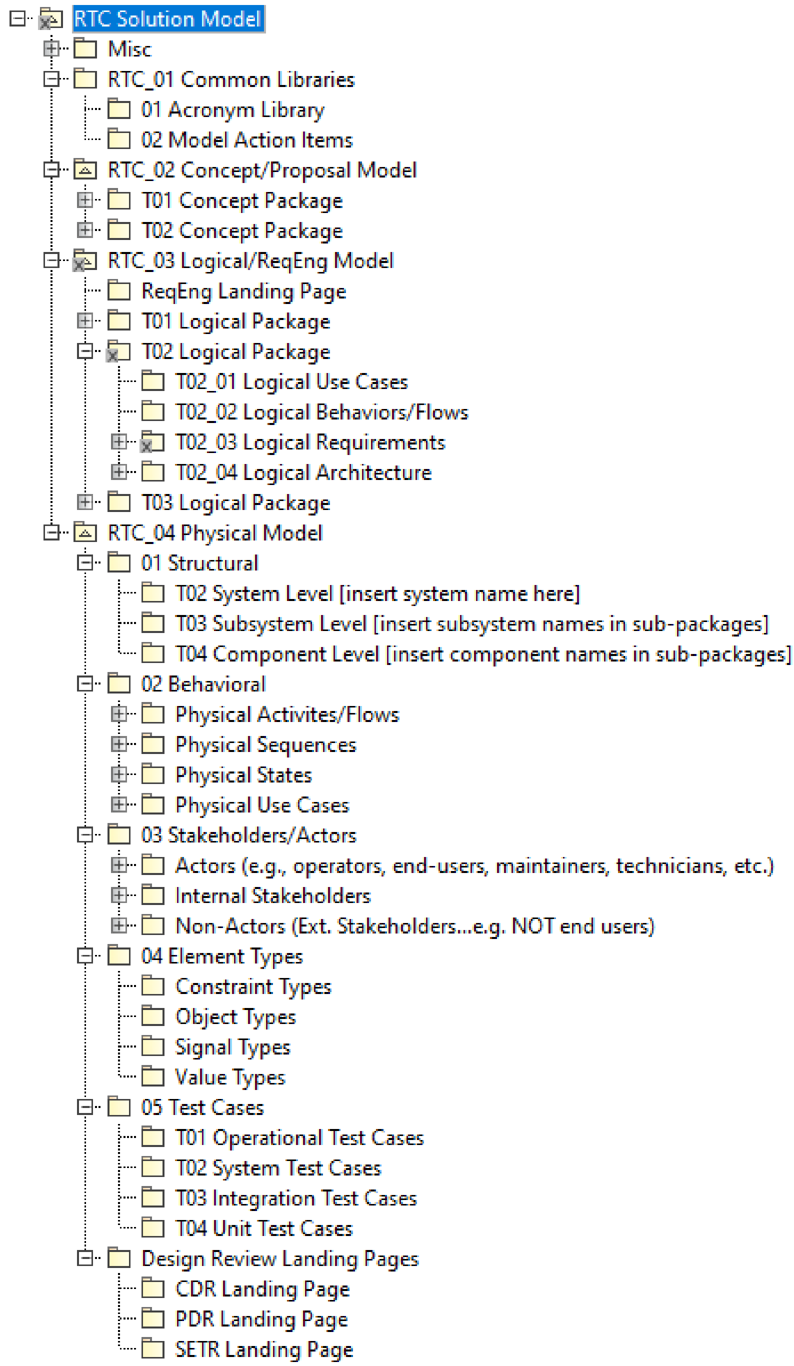

Figure 15: RTC Containment Tree

Looking closer into the containment tree and in reference to the decomposition hierarchy that aligns platform levels to a tiered structure, the UUV system requirements reside entirely in

T02_03 Logical Requirements package. As all the requirements are written at the system level, there are no additional requirements in any other tiers. Expanding the T02_03 Logical Requirements package, the following top-level, organizational packages are shown in the below figure. These include:

- 3.1 Vehicle Design Characteristics: Contains the Weight, Vehicle Dimensions, Depth, and Modularity sub-packages (34).
- 3.2 Functionality Characteristics: Contains the Intelligence Preparation of the Operating Environment, Mine Countermeasures, Endurance, Propulsion and Maneuverability, Energy and Power, Navigation, Obstacle and Threat Avoidance, Command and Control, Communications, Autonomy, Data Management, Monitoring and Assessment, Abnormal Operations, Flasher/Strobe, Operator Console, Launch and Recovery Operations sub-packages (34).
- 3.3 External System Interfaces: Contains the Common Control System and Host Platform Interfaces sub-packages (34).
- 3.4 Design and Construction Standards: Contains the Implodable Volumes, Corrosion, Materials, Workmanship, and Nameplate and Product Marking sub-packages (34).
- 3.5 Operational Environmental Conditions: Contains the Salinity, Sea State, Atmospheric Pressure, Operational Temperature, Temperature Shock, Shock, Operational Vibration, Operational Electromagnetic Environments sub-packages (34).
- 3.6 System Safety and Loss Mitigation: Contains the System Safety, Program Protection, Cybersecurity, and Signatures sub-packages (34).

- 3.7 Suitability: Contains the Package, Handling, Storage, & Transportation, Reliability, Maintainability, & Availability, Maintenance & Turnaround, and Human Systems Integration sub-packages (34).

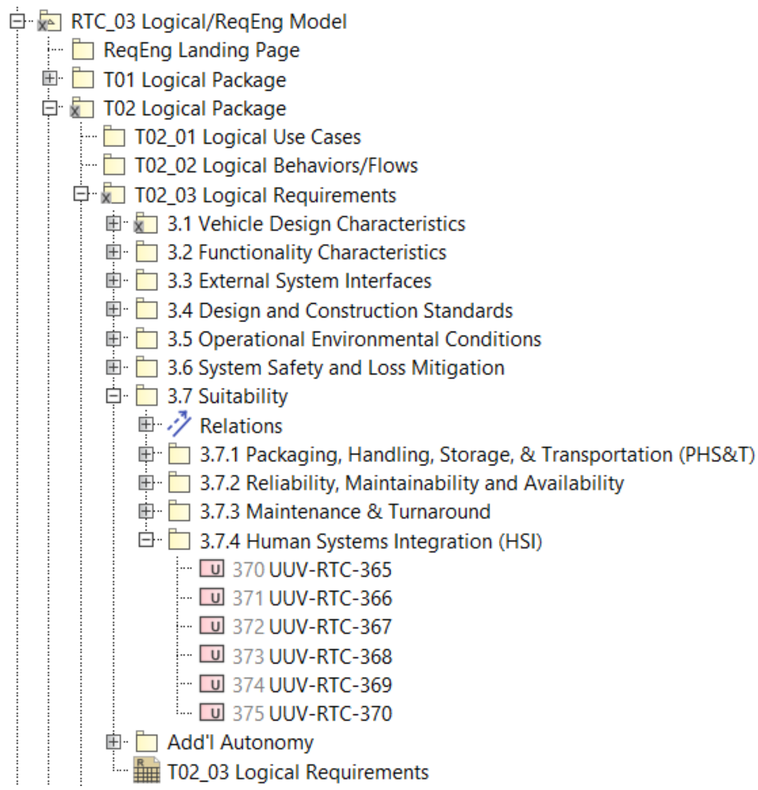

Figure 16: T02_03 Logical Requirement Decomposition

There are additional packages at a further sub-level as seen in the requirements package diagram below, but the bulleted summary above provides a clear understanding of what garners the majority of attention from a requirement development standpoint by leveraging the RTC.

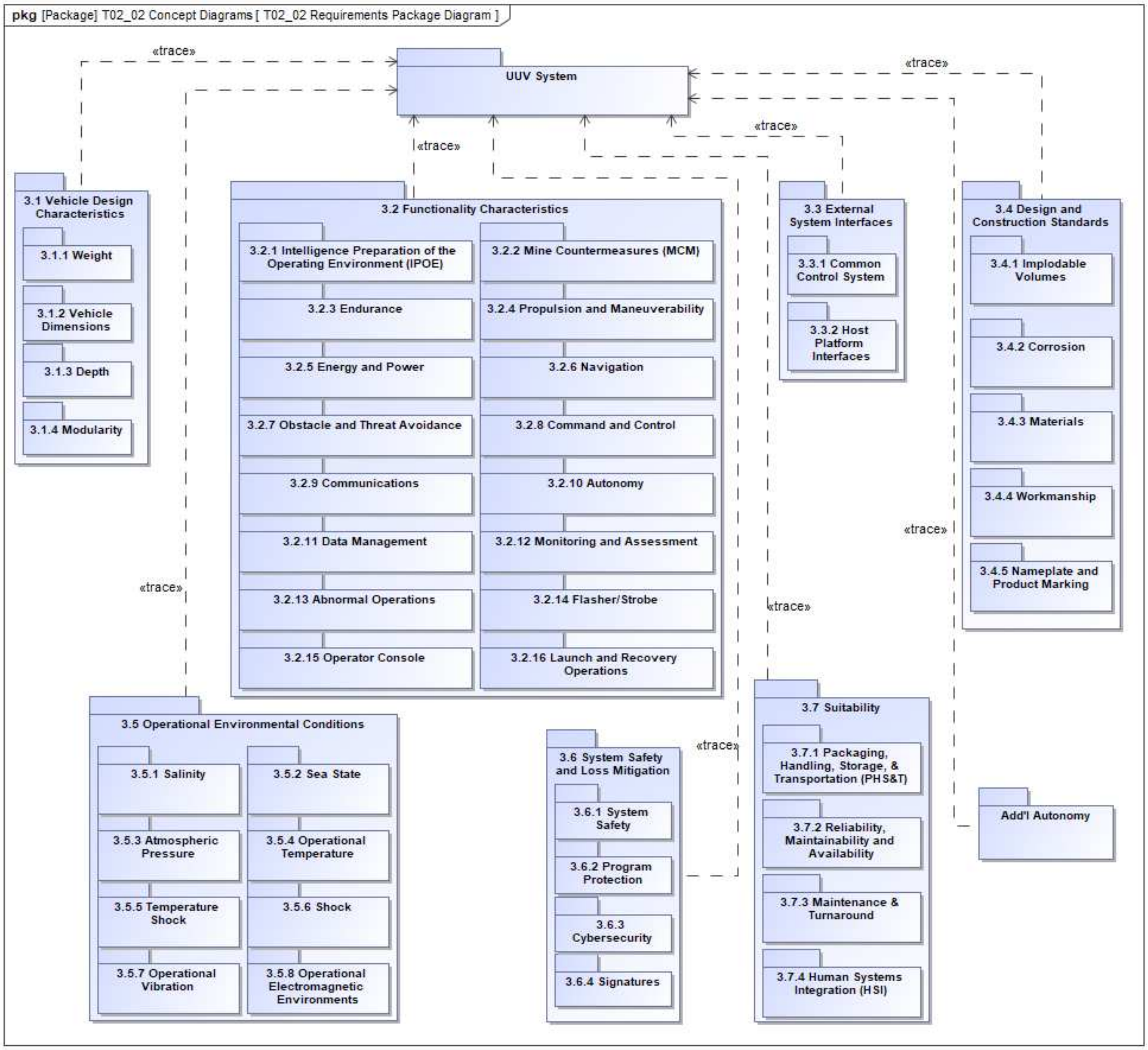

Figure 17: T02_02 Requirements Package Diagram (34)

While the Logical Requirement Decomposition provides an organizational picture of the requirements, the below table places basic sum total values to the key information that is pertinent to this research including a closer look at the HSI requirements.

Table 3: UUV Performance Specification Summary (34)

Performance Specification Summary Type	Specification Value
Date of Release	FY2021
Number of Requirements	370
Number of HSI Requirements	6
Number of Identified Missions within Document	11
Number of Human-In-The-Loop centric Missions	1
Number of Requirement Sections	61

The key ratio is the number of requirements to the number of HSI requirements. While most requirements can compare differently to each other with respect to characteristics such as importance and scope, the UUV System only assigns 1.6% of its requirements toward HSI and one out of eleven (9.1%) of its mission sets toward a human-in-the-loop centric mission. Looking at the HSI requirements in more detail, the below table lists the wording from UUV-365 to UUV-370.

Table 4: UUV HSI Requirements (34)

Requirement #	HSI Requirement
UUV-365	The UUV system shall be designed with proper Human Factors Engineering practices in accordance with the approach and guidance from MIL-STD-46855 (Human Engineering Requirements for Military Systems, Equipment, And Facilities), with specific detailed design guidance from MIL-STD-1472 (Human Engineering), and ASTM F1166-07 (Human Engineering Design for Marine Systems, Equipment, and Facilities) where applicable.
UUV-366	The UUV's auxiliary equipment single package module shall be designed to be “person-portable” as guidance defined in Section 5.8.6.3 of MIL-STD-1472, with a preference for items that are 1- or 2-person portable, and should be able to be readily transported through U.S. Naval surface ship’s hatches and passageways.

UUV-367	The UUV system maintenance software and Human-Machine Interfaces (HMIs) shall be designed with proper user-computer interface requirements per Sections 5.2 and 5.2.2.5 of MIL-STD-1472 (Human Engineering) and the Microsoft Windows User Experience Interaction Guidelines (https://docs.microsoft.com/en-us/windows/win32/uxguide/guidelines).
UUV-368	All UUV system user interfaces shall be readable and useable under varying ambient light conditions ranging from bright sunlight to total darkness.
UUV-369	The UUV system components and operator-machine interfaces shall be designed to enable users to operate all components during the full sortie cycle, while wearing foul-weather gear including gloves (thick cold-weather and/or thick neoprene), heavy clothing and outerwear, goggles and face coverings, etc.
UUV-370	The UUV system components shall be designed to support applicable O-level maintenance, charging, and replenishment task requirements and task performance in the expeditionary deployment, staging, and system maintenance environment(s).

Looking at each requirement in more detail, the following summaries are made based on the wording. Overall, the HSI requirements place the majority of emphasis on broad considerations that can be derived down to military standards and commercial guidance.

- UUV-365: This requirement relies on overarching, all-platforms-applicable military standards and commercial guidance (e.g. MIL-STD-46855, MIL-STD-1472, ASTM-F1166-07), which is applied to most contracts where HSI requirements are present.
- UUV-366: This requirement references a specific section within MIL-STD-1472 that can be considered as a more critical need than the document as a whole.
- UUV-367: In the same fashion as 366, this requirement references specific sections within MIL-STD-1472 as well as an overarching reference toward the Microsoft Guide on user experience.

- UUV-368: This user interface need is the first non-referenced requirement that addresses varying environmental conditions with respect to visibility. While this requirement does not call out a specific military standard or guideline, applicable information is provided within MIL-STD-1472 and other DoD human factors documentation.
- UUV-369: This user interface need is the second non-referenced requirement that address varying environmental conditions with respect to potential weather extremes. While this requirement does not call out a specific military standard or guideline, applicable information is provided within MIL-STD-1472 and other DoD human factors documentation.
- UUV-370: This user interface need is the third non-referenced requirement that addresses varying environmental conditions with respect to host platform interfaces needed for UUV mission sets.

The last view of the RTC model is the various actors identified based on the UUV performance specification. Within the RTC model, actors are broken up into three categories within the 03 Stakeholders/Actors package under the RTC_04 Physical Model.

- Actors: Those who are involved with the UUV at the operational level such as UUV operators, maintainers, and host platform support.
- Internal Stakeholders: Those who are involved with the UUV at the acquisition lifecycle level such as program managers, engineers, and logisticians.
- Non-Actors: Those who are involved with the platform from a vested interest level such as stakeholders, competitors, and foreign allies.

For the sake of this research, the two RTC phases place the entirety of its focus toward the actor package due to their exposure with the operational UUV in the mission environment. As mentioned in the Definition of the RTC Methodology, all end users in the actors' package are redesigned as actor block elements, as opposed to actor elements commonly seen in use cases and shown in the containment tree diagram below:

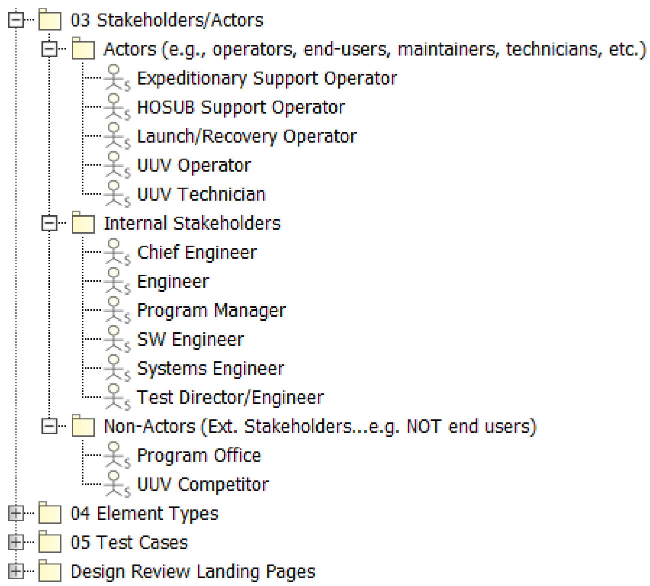

Figure 18: 03 Stakeholders/Actors Package

As Research Question 1 is investigated, an actor will be down selected to use as a sample to support the RTC. The actor will be refactored into an actor block for three reasons. The first is to better incorporate into a BDD. While the UUV example provides a fairly straightforward system-to-subsystem architectural hierarchy, more complex systems may require an actor block versus an actor due to the varying relationships. The second reason is the need to translate the SOCOM Task List into an actor hierarchy where relationships exist below the actor subsystem level. The third and final reason is the use of parameterization to aggregate and quantify task measures associated with each task that is applicable to the sampled actor.

With the groundwork laid in the methodology section, the RTC can commence by placing focus on Research Question 1, where the actor is inserted into the architectural framework. From there, behavioral diagrams are developed to qualify the relationships between the actor and system elements. This results in the interpretation and translation of each diagram into HSI requirements by the human factors engineer.

CHAPTER 5.0 RESEARCH QUESTION 1

RTC PHASE 1

5.0 RTC Phase 1 [RQ1] Introduction

Chapter 5.0 is going to present the development and validation of RTC Phase 1 applied to a UUV platform. Summarized from the Research Questions and Tasks in Chapter 3.0, the RQ1 tasks include finding a suitable undersea system to be leveraged by SOCOM, constructing new architectural and behavioral diagrams with a human-in-the-loop centered modeling to generate new requirements, and evaluating the overall quality and effectiveness of the human-in-the-loop centered model and resulting functional requirements. Evaluation of RQ1 also takes place in Chapter 8.0, specifically in the RTC Phase 1 subsection.

5.1 Insertion of Actor into Architectural Framework

As introduced in the previous section, the RTC will focus on a UUV system being utilized through an NSW non-pressurized manned submersible. Since the submersible is non-pressurized, the human-in-the-loop will exist in the water column in a diving status. Because of the vital environmental potential along with the human-on-the-loop focus, the actor to be sampled for this research will be the UUV Operator within the submersible. In this mission environment, the UUV Operator will be responsible for both the operation of the UUV, the operation of the manned submersible (in concert with the rest of the submersible crew), and the operation of their diving and ancillary equipment (36) (37). In refactoring the UUV Operator actor element into a block actor, the actor package within the RTC containment tree is redesigned as follows:

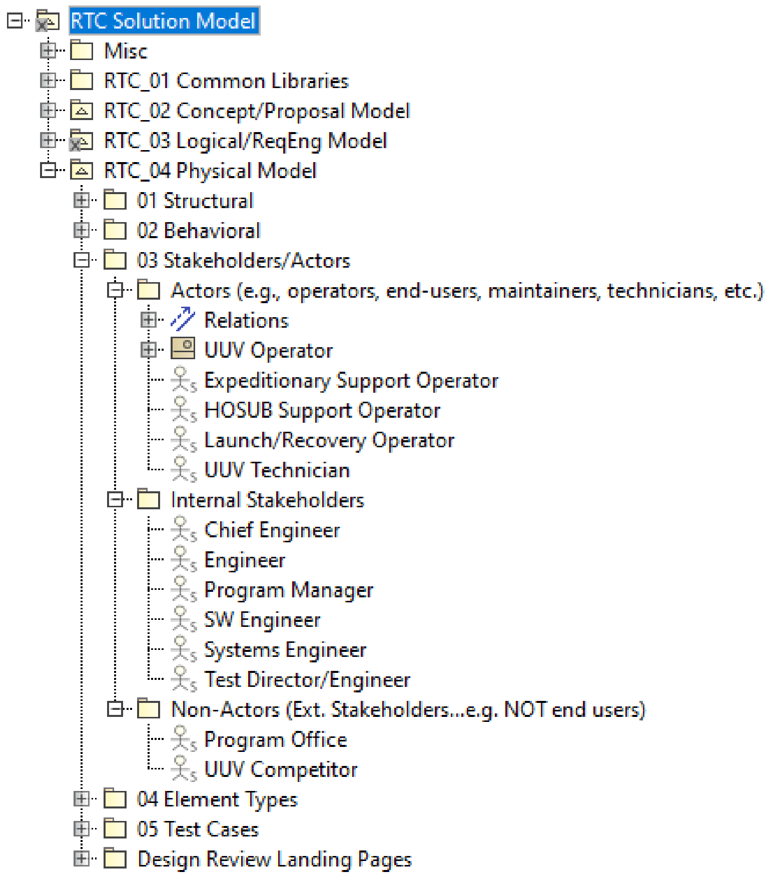

Figure 19: UUV Operator Actor Block

The highlighted element represents the UUV Operator block actor as a block within the actor package. The UUV Operator is the preferred choice for this research since the actor has a diverse set of human-in-the-loop responsibilities in a dynamic, undersea SOCOM environment. The dynamic and specific tasks of the UUV Operator will be specified during Research Question 2 when a SOCOM Task List is developed around operating and emergency procedures (36) (38) (37).

With the UUV Operator selected, the next step is to identify the conceptual architecture. While this can be proactively completed during the system needs phase, the more appropriate phase is during the architectural definition as identified in section 4.1 of the INCOSE Technical Process in section 4.1 of this paper (1). If the RTC is to be completed by the same organization that generates the requirements identified in section 4.2 of the INCOSE Technical Process, a recommendation from this research is to expand the government's responsibility to include a conceptual architecture definition prior to releasing a Request for Proposal (RFP) to the defense industry (1) (35). The RTC can also be leveraged by the defense industry to show a comprehensive derivation of both subsystem and HSI system requirements provided as part of an RFP (35).

For the sake of this research, the architecture definition is provided in the contractor phase during the bidding process of this particular RFP. The architecture captured in the below figure is based on the overall content and interpretation of the 370 requirements (34).

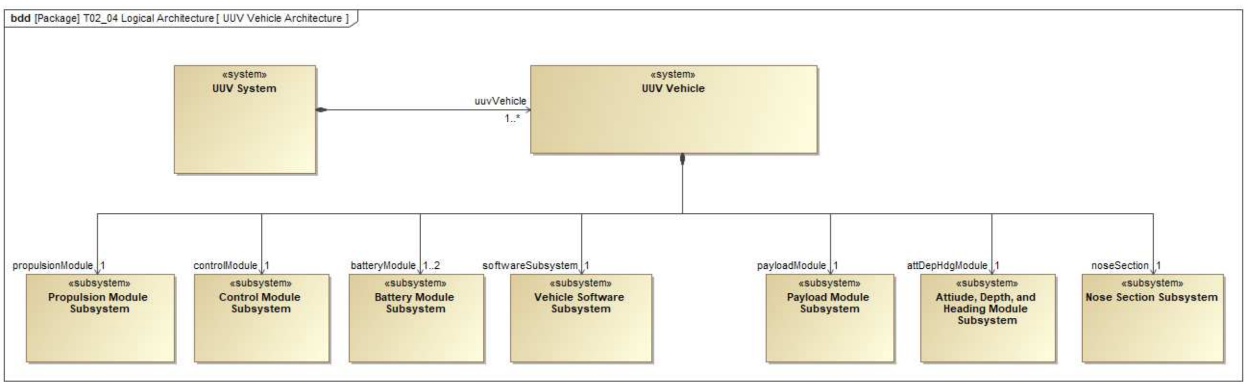

Figure 20: UUV System Architecture

While only a conceptual model, the UUV system architecture comprises of seven subsystems listed below and all represent a composite association of the overall UUV.

- Propulsion Module Subsystem
- Control Module Subsystem
- Battery Module Subsystem

- Vehicle Software Subsystem
- Payload Module Subsystem
- Attitude, Depth, and Heading Module Subsystem
- Nose Section Subsystem

A sample set of these subsystems will be investigated in more detail as the UUV Operator is included as a subsystem through an RTC sub-process that places focus on HSI priorities against a set of requirements that are directly linked to each subsystem. Using associations to link the block actor to each UUV subsystem, the following BDD shows the relationship of the UUV Operator to the system.

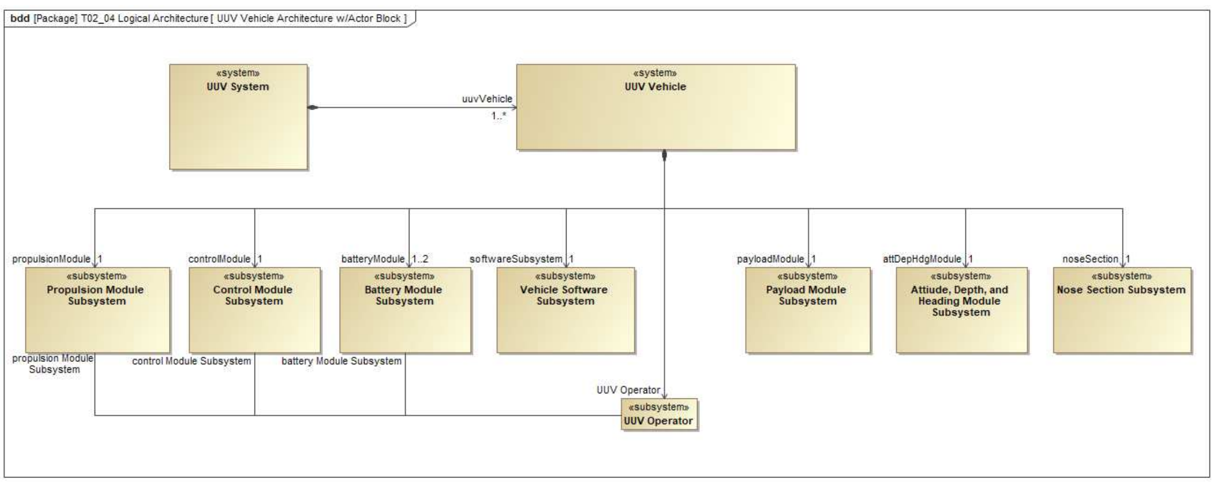

Figure 21: UUV System Architecture with Block Actor

The associations between the block actor subsystem and the remaining subsystems are of importance in the event this process becomes an automated plugin or application that supports MBSE data. It also documents a relationship within the RTC model for ease of containment tree navigation within a modeling application.

With the block actor included in the subsystem design, and before the investigation and integration with the remaining subsystems, HSI priorities need to be identified and prioritized to support both a standard to be considered for relational applications and requirements development. As the UUV Operator is associated with a given subsystem, it is to be reviewed by the human factors engineer against all HSI domains to determine a stakeholder or operational need. The INCOSE Handbook lists a set of HSI Domains that are in no particular order with summarized descriptions below (1):

- Manpower: Number and type of personnel
- Personnel: Experience and aptitude
- Training: Instruction and resources
- Human Factors Engineering: Understanding and integration of human capabilities
- Environment: External considerations
- Safety: Minimize the risk of mishaps or accidents
- Occupational Health: Minimize the risk of illness or injury
- Habitability: Characteristics of system living and working conditions
- Survivability: Reduce susceptibility of total mission failure, loss of life, or system loss

Based on the list of INCOSE HSI domains listed above, and after a review of HSI domains from additional sources, the following five HSI domains were down-selected with consideration toward SOCOM operations and are used in the RTC throughout this paper (39) (40) (41) (1):

1) Safety, Health, and Survivability: Subsystem considerations to minimize risk to the UUV Operator

2) Manpower: Subsystem considerations for specialties needed by UUV Operator, or additional number of personnel
3) Personnel: Subsystem considerations for UUV Operator knowledge, skills, abilities (KSAs), and experience
4) Environment: Subsystem considerations based on undersea environment
5) Human Factors Engineering: Subsystem considerations for UUV Operator performance to include effectiveness, efficiency, and usability

While training and habitability are key considerations when looking at the full spectrum of HSI considerations, these domains will be omitted given their close relationship with the personnel and environment domains, respectively. In proceeding through RQ1, these five domains will be abbreviated for ease of reference as: the HSI safety domain, the HSI manpower domain, the HSI personnel domain, the HSI environmental domain, and the HSI HFE domain.

To limit the repetitiveness and unnecessary research length of the RTC requirements development exercise in RQ1, a sample set of UUV subsystems will be run through the RTC Phase 1 process. While each of the seven subsystems have promise to deliver HSI requirements through the RTC, three subsystems were down-selected due to the direct traceability with a specific requirements package within the 3.2 Functionality Characteristics package and the "at first glance" potential to result in valuable HSI requirements in the undersea domain (34). Each subsystem will commence with one, or multiple UUV Operator use cases, which begin by highlighting the respective HSI domain(s) that justify the UUV Operator needs or preferences. The down-selected three subsystems of the UUV Vehicle include:

- Propulsion Module Subsystem
- Control Module Subsystem

- Battery Module Subsystem

The use case will then be further refined through functional flows or behavioral diagrams, where appropriate, in order to identify the necessary subsystem requirement(s). Through all modeling figures, the UUV Operator will be present in each diagram as either a swim lane, a lifeline, or directly referenced within a use case to properly convey the actor relationship with the respective subsystem.

5.2 Development of Behavioral Diagrams and Functional Flows with Actor Swim Lanes

5.2.1 Use Case Diagram [Propulsion Module Subsystem]

Beginning with the propulsion module subsystem, this research selected five requirements listed in section 3.2.4, the Propulsion and Maneuverability requirements package, within the parent 3.2 Functional Characteristics package. These five requirements are listed below and derived into the applicable propulsion module subsystem as commonly seen during requirements engineering decomposition practice in industry.

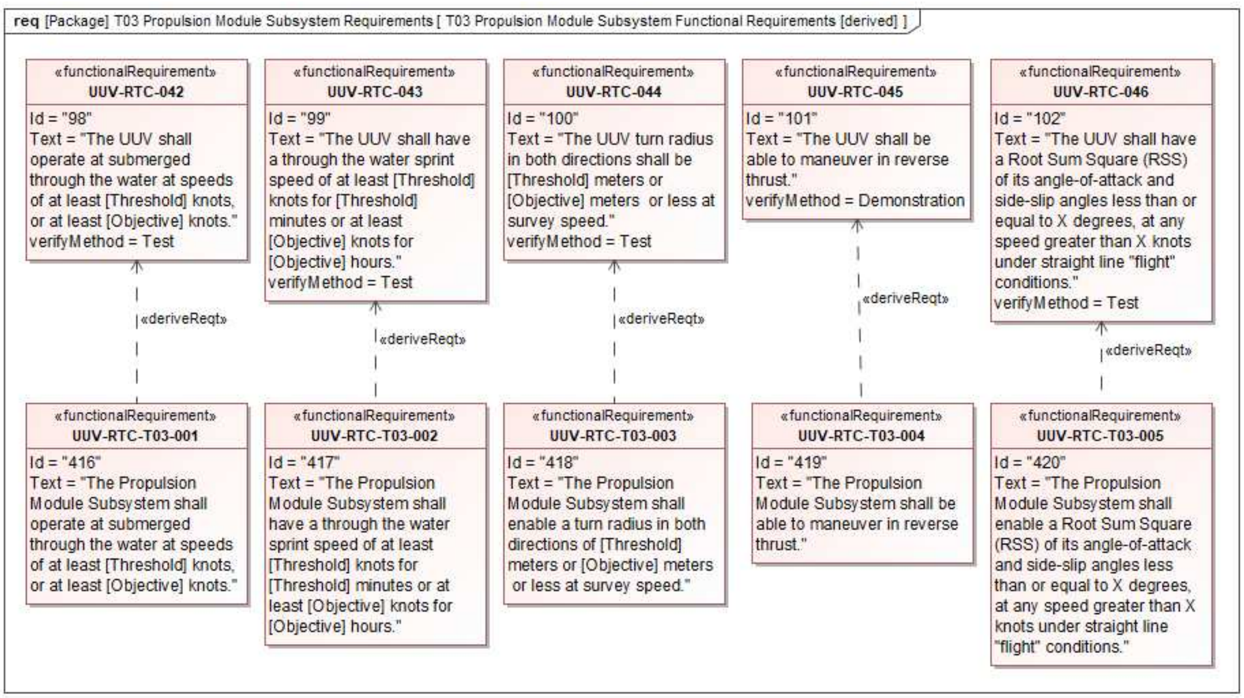

Figure 22: Propulsion Module Subsystem Functional Requirements [derived]

In looking at the functional detail within each requirement text throughout this research, the operational specifications have been altered or omitted to avoid the misinterpretation of sensitive information as shown in the requirements text in the above figure. For example, in requirement UUV-RTC-042, the UUV speed is not provided and listed as “[threshold] knots” and “[objective] knots” to avoid any interpretation of real-world, UUV capabilities. With the 3.2.4 Propulsion and Maneuverability package restated to align to the propulsion module subsystem, the following diagram highlights both the satisfy relationship to each of the subsystem requirements and as part of the RTC phase, associated the requirements to the UUV Operator block actor. For the purpose of this research, the goal of this diagram is to bridge the relationship between the subsystem requirements and the UUV Operator block actor.

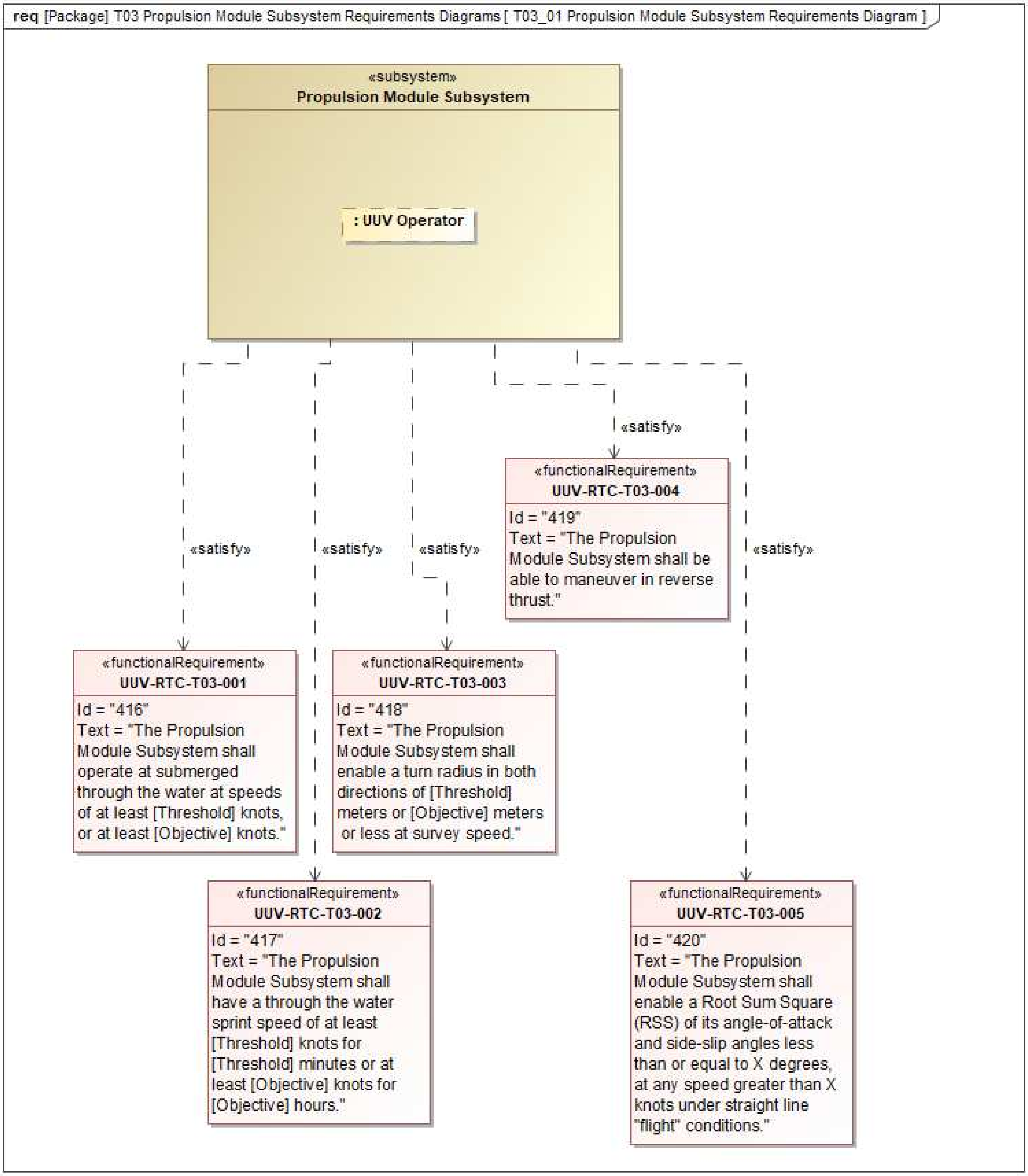

Figure 23: Associated Relationship between UUV Operator and Propulsion Module Subsystem Requirements

MBSE provides a host of different behavioral diagrams to further support the UUV Operator relationship with the requirements that make up each subsystem. In using a use case diagram, a human factors engineer can develop a series of use cases that place emphasis on the five HSI domains listed in section 5.1 (Safety, Manpower, Personnel, Environment, and HFE). If the use case is straightforward in content, this can be directly translated into one or several requirements, as is the instances of the verbalizations throughout the below figure. With that, below are five use cases that leverage several of the HSI domains surrounding the propulsion module subsystem.

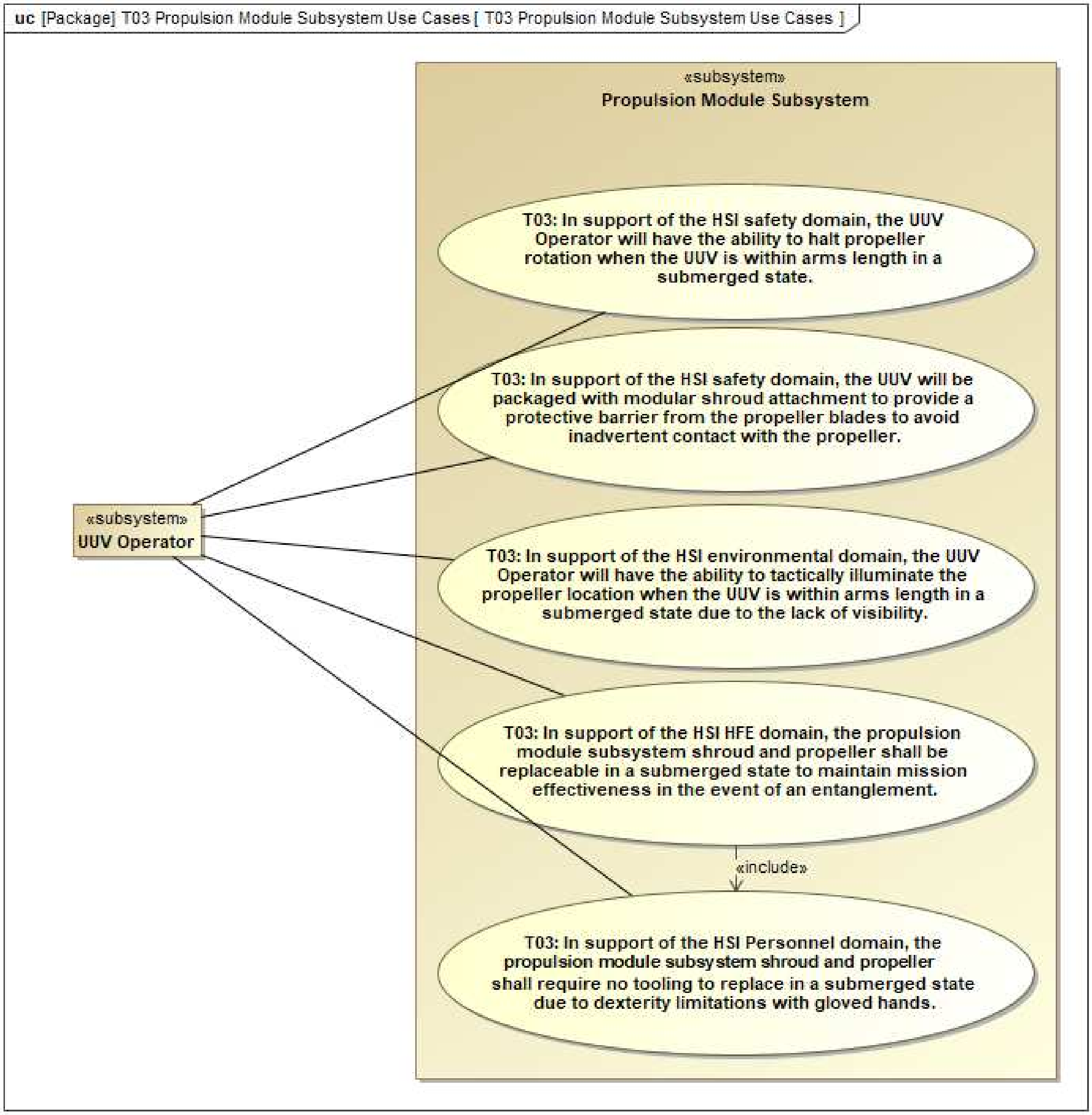

Figure 24: UUV Operator and Propulsion Module Subsystem Use Cases

With a defined set of five use cases explained from the HSI domains listed in section 5.1, the ability to interpret and convert each use case into a requirement becomes relatively easy for either the human factors engineer, or systems engineer. This is partially due to the user story format in the above figure to build use cases. These functional requirements will include relationships between both the use cases and the UUV Operator in order to convey the benefit of the RTC. This will be captured in section 5.3 Translation of Behavioral Diagrams into HSI Requirements. More specifically, section 5.3.2 will place focus on the propulsion module subsystem.

5.2.2 Activity Diagram [Control Module Subsystem]

Looking now at the control module subsystem, four requirements are pulled out in section 3.2.8, the Command and Control requirements package, within the parent 3.2 Functional Characteristics package. As managed in the previous section, these four requirements are listed below and derived into the applicable control module subsystem as commonly seen during requirements engineering decomposition practice in industry.

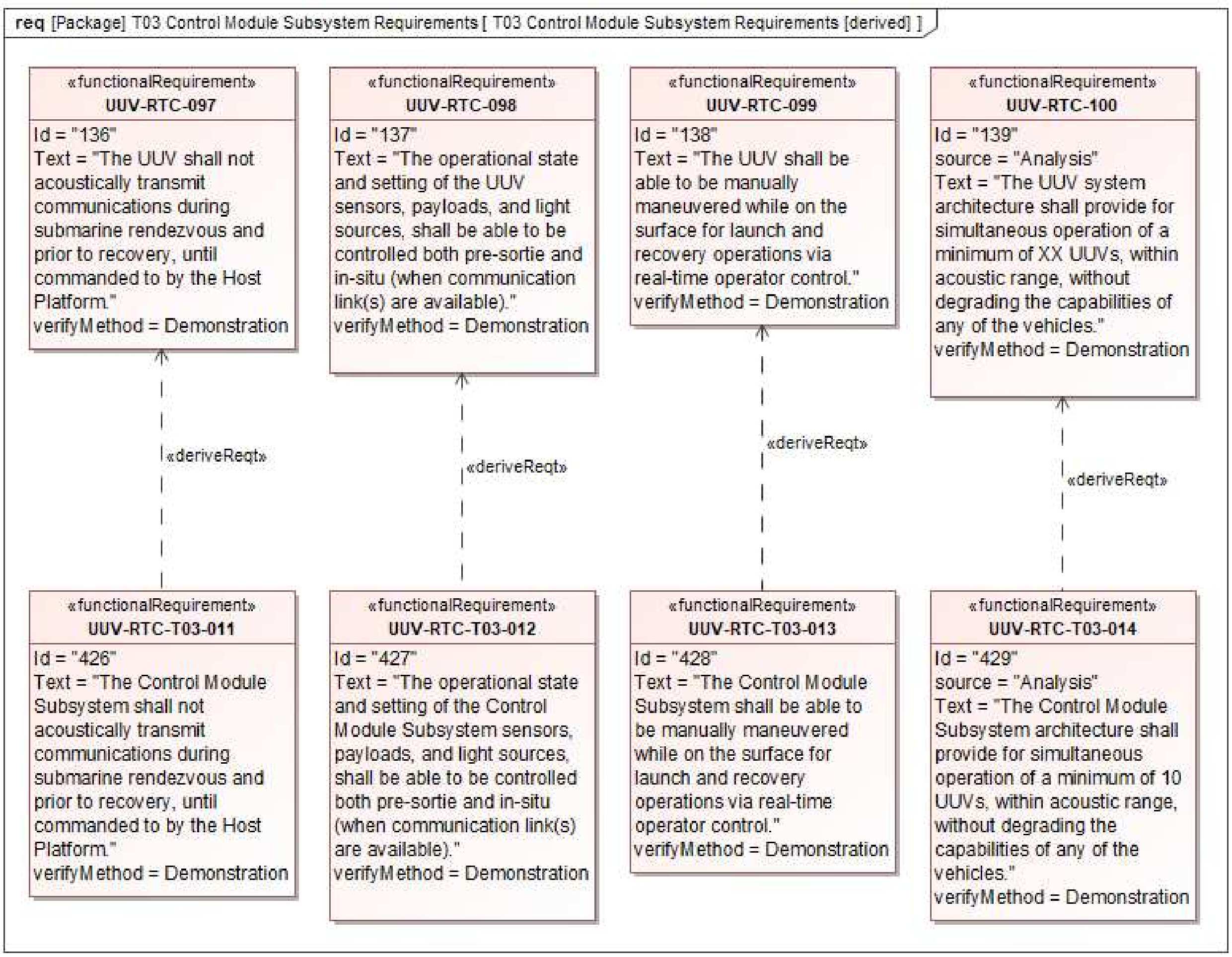

Figure 25: Control Module Subsystem Functional Requirements [derived]

Similar in process as the propulsion module subsystem, the 3.2.8 Command and Control package is now aligned to the control module subsystem. This provides the following diagram highlighting both the satisfy relationship to each of the subsystem requirements, and as part of the RTC phase, associated the requirements to the UUV Operator block actor. As emphasized in the wording of the previous requirements, operational specifications have been altered to avoid the disclosure of sensitive information. For example, in requirements UUV-RTC-100 and UUV-RTC-T03-014, the minimum number of UUVs capable of simultaneous operation is listed as "X" to avoid any interpretation of real-world, UUV capabilities.

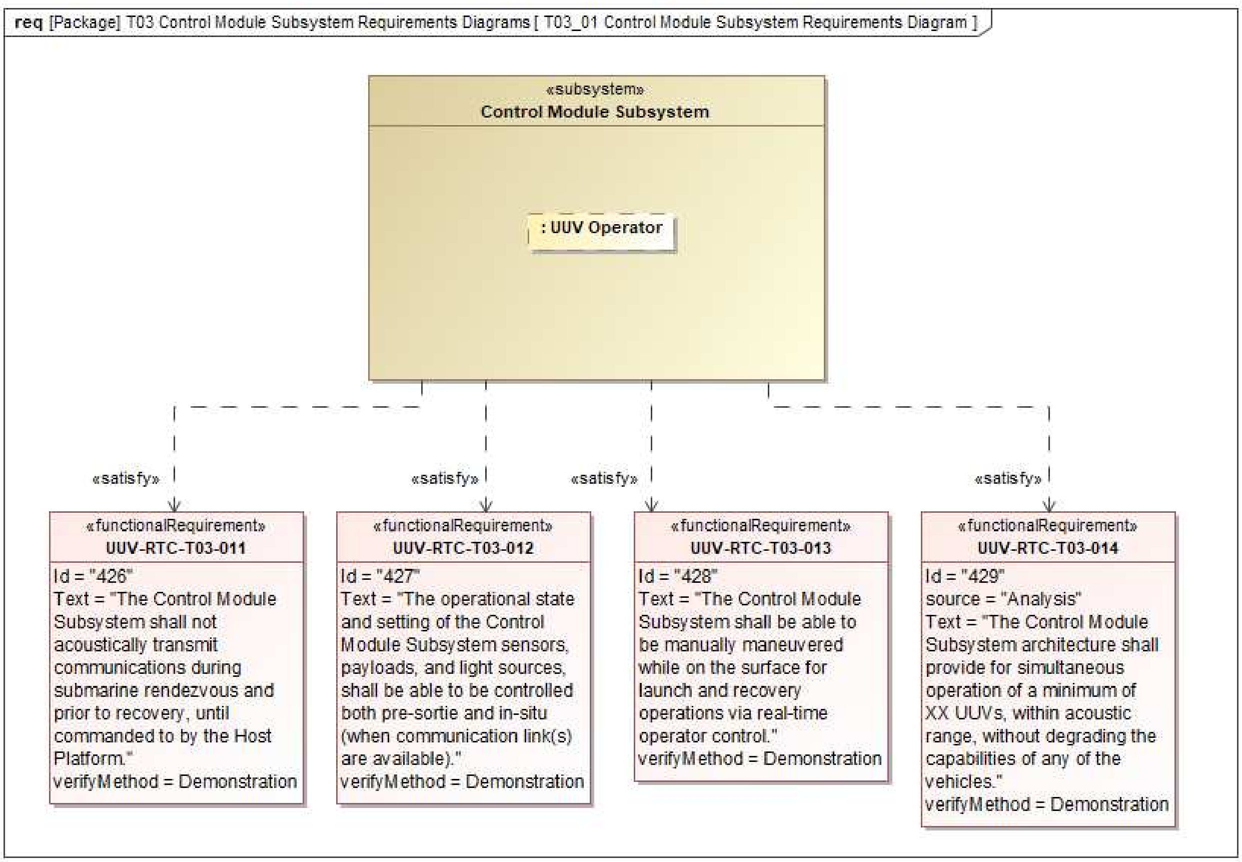

Figure 26: Associated Relationship between UUV Operator and Control Module Subsystem Requirements

In reviewing the derived control module subsystem requirements above, and with operational consideration given toward a submerged UUV Operator working with a submersible, the following use case is generated as a kickoff point.

- In support of the HSI environmental and HFE domains, the UUV operator will simultaneously operate a minimum of X UUVs, within acoustic range, in a submerged state.

Following the user story format seen in 5.2.1, this use case is written to account for two of the five HSI domains identified in section 5.1. However, while it points to some of the key capabilities embedded and derived from the four selected control module subsystem requirements, further detail and refinement is needed to properly extrapolate requirements in support of undersea SOCOM operations. While a use case describes the behavior of a system based on the needs and requests of an actor or stakeholder, an activity diagram will provide a more dynamic, step-by-step view of the system along with the role the actor will play in supporting the execution of the activity (1) (22). This allows a human factors engineer to develop a logical and conceptual series of actions that would have to be performed to satisfy the use case. In many instances, the human factors engineer would rely on subject matter expertise, which in this case could be a UUV Operator as well as a submersible operator. The activity diagram below shows the steps that may be required for a UUV Operator to receive a status update from a swarm of UUVs.

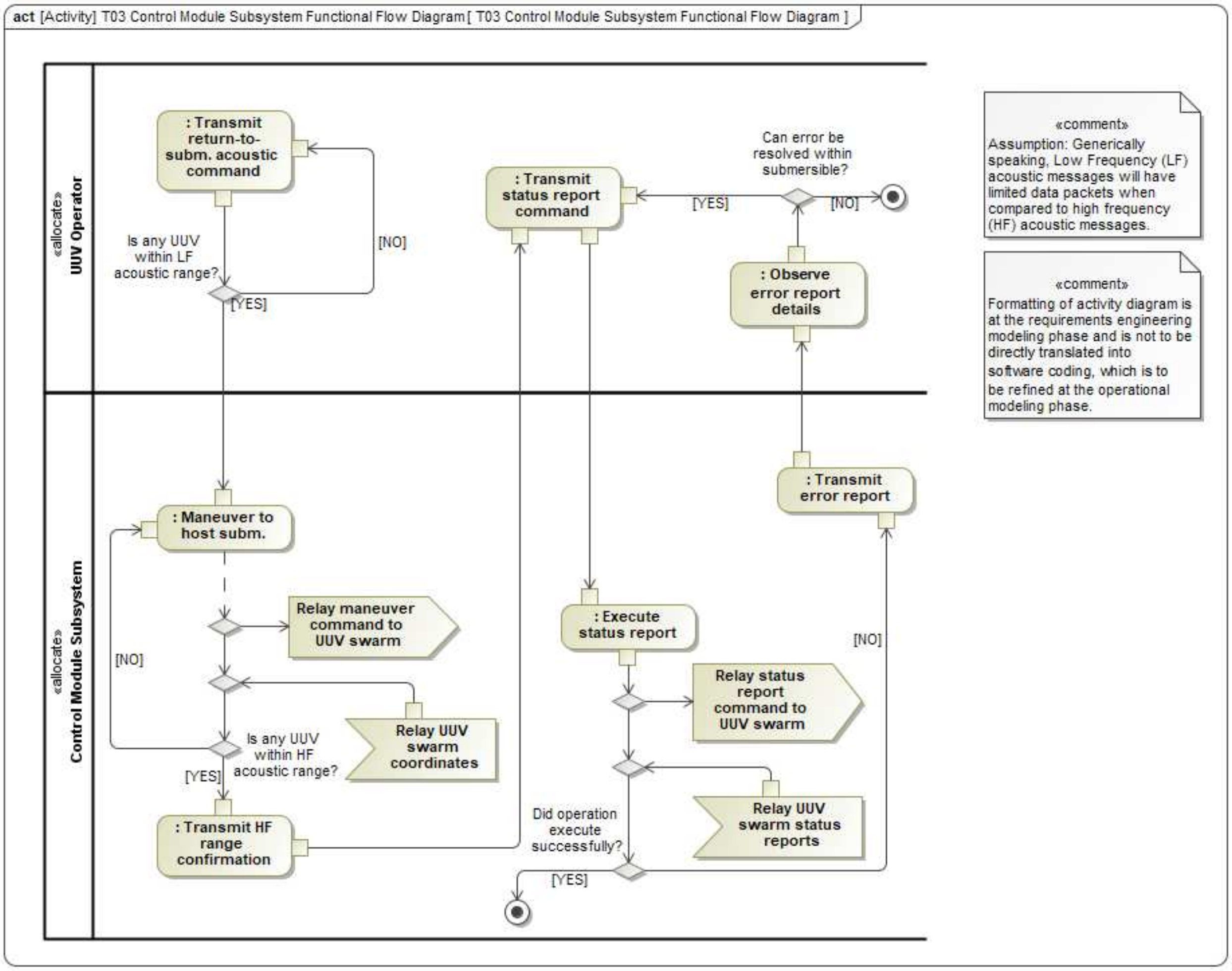

Figure 27: UUV Operator and Control Module Subsystem Activity – receiving status reports from UUV Swarm

In the above activity, the UUV Operator initiates the functional flow by transmitting a return-to-submersible acoustic command from the submersible. The assumption being made is based on the amount and detail of data packets being sent through-water. Low Frequency (LF) acoustics have a longer range but lacks the content volume in the messaging. The data rate of underwater acoustics is generally inverse proportional to communicative distance due to the limits of signal bandwidth resulting in signal propagation issues (42) (43). Conversely, High Frequency (HF) acoustics result in a more limited range, but at nearby distances, can send and receive larger data packets. Based on this, the goal of the flow on the left-hand side is to establish communications with the UUV swarm, and command it to approach the submersible for HF acoustic messaging. Once the UUV swarm is confirmed within HF range, the UUV operator sends a status report command. This message must be received by all UUVs within the swarm. To avoid unnecessary collisions, the assumption is the UUVs stay at a safe distance from one another. This creates the need to depict send signal action elements and accept event action elements, which enables the UUVs to relay commands from the UUV operator to ensure each UUV transmits a status report. In the event there is an error among one or many UUVs, an error report is sent back to the UUV operator to determine corrective action. Based on the written summary of the activity diagram, this functional flow revealed a couple UUV Operator needs in the undersea environment. The first is the need to maneuver UUVs, both manually and remotely, and the second is the need for the UUVs to communicate with each other in an efficient manner in order to maintain a safe distance from other UUVs and the host platform. In the case of the above scenario, efficient communication is also needed to ensure a command is received by every UUV in the swarm. In designing each UUV to behave as a node, the potential for a wireless, acoustic mesh network can enable peer-to-peer UUV meshing to deliver data packets across the swarm in an efficient manner through self-organizing, self-forming, and self-healing each individual UUV with the collective swarm (44).

With the UUV Operator needs revealed in the activity diagram, and by referencing existing UUV system requirements for pertinent and consistent wording formats per the characteristics of sets of requirements as outlined and described in the INCOSE Guide to Writing Requirements and the Needs and Requirements Manual, the following new set of control module subsystem requirements can be generated into the model (45) (46) (47). These requirements are provided in section 5.3.2 and are to be added into an SRS in the appropriate section.

5.2.3 Sequence Diagram [Battery Module Subsystem]

Finally, in looking at the battery module subsystem, five requirements are pulled out in section 3.2.5, the Energy and Power requirements package within the parent 3.2 Functional Characteristics package. Due to the wording of these requirements, these five requirements are not only derived into the applicable battery module subsystem, but they are further derived to specifically address the submerged conditions. To provide a better understanding, UUV-RTC-050 is derived down to UUV-RTC-T03-019 to place focus on the battery module subsystem versus the UUV system. Additionally, UUV-RTC-T03-019 is then derived down to UUV-RTC-T03-023 to expand on a UUV Operator’s need to access the external manual power shut-off switch in both a surfaced and submerged setting. Recall T03 is imbedded in the alphanumeric title of the requirement to indicate a requirement at the subsystem level.

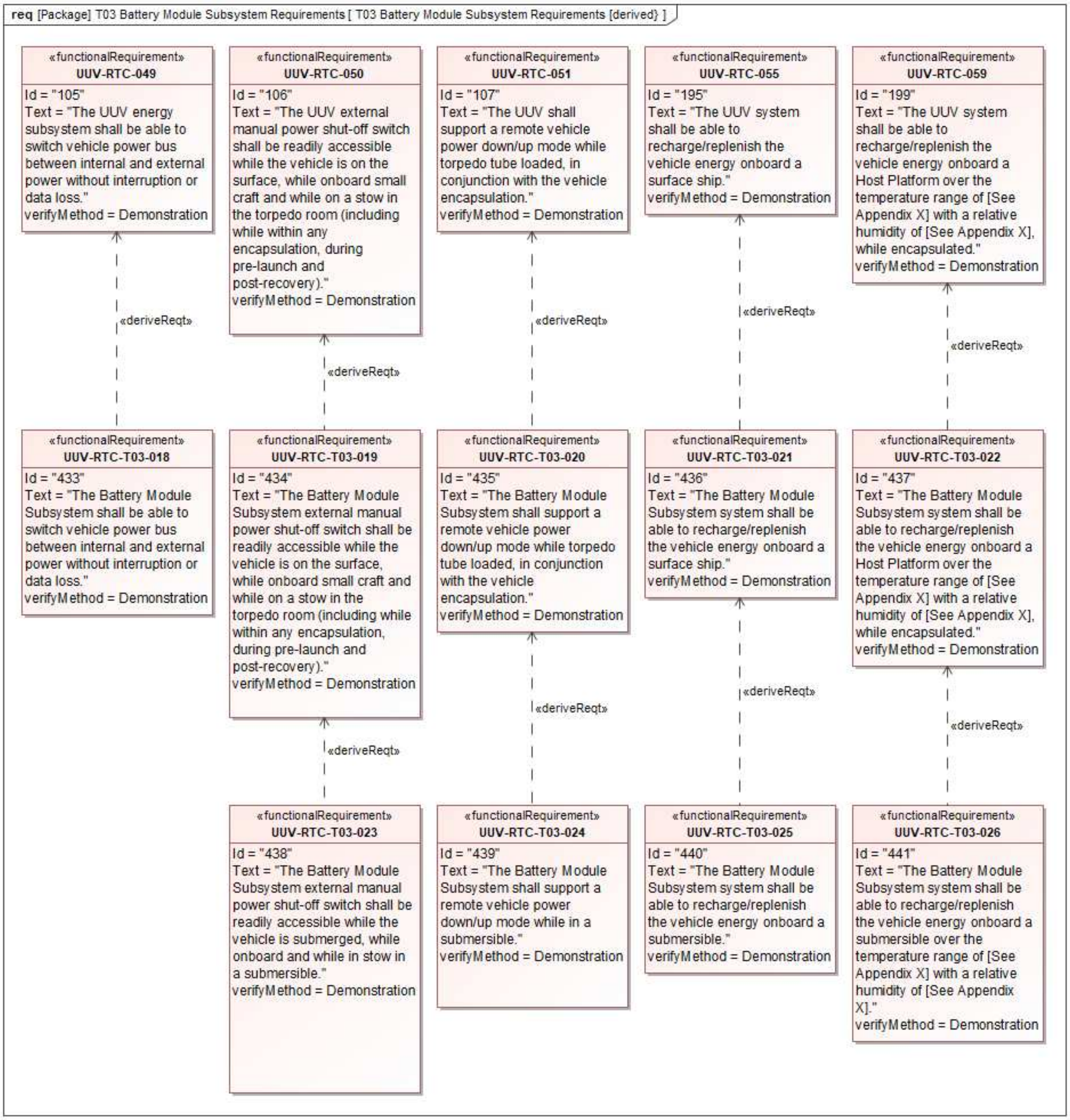

Figure 28: Battery Module Subsystem Functional Requirements [derived]

As demonstrated above with both the propulsion module subsystem and control module subsystem, the 3.2.5.1 Energy Replenishment package, in addition to the parent 3.2.5 Energy and Power package, is aligned to the battery module subsystem. This provides the following diagram that highlights both the satisfy relationship to each of the subsystem requirements and as part of the RTC phase, associated the requirements to the UUV Operator block actor. As called out in the two previous sections, operational specifications have been altered to avoid the disclosure of sensitive information.

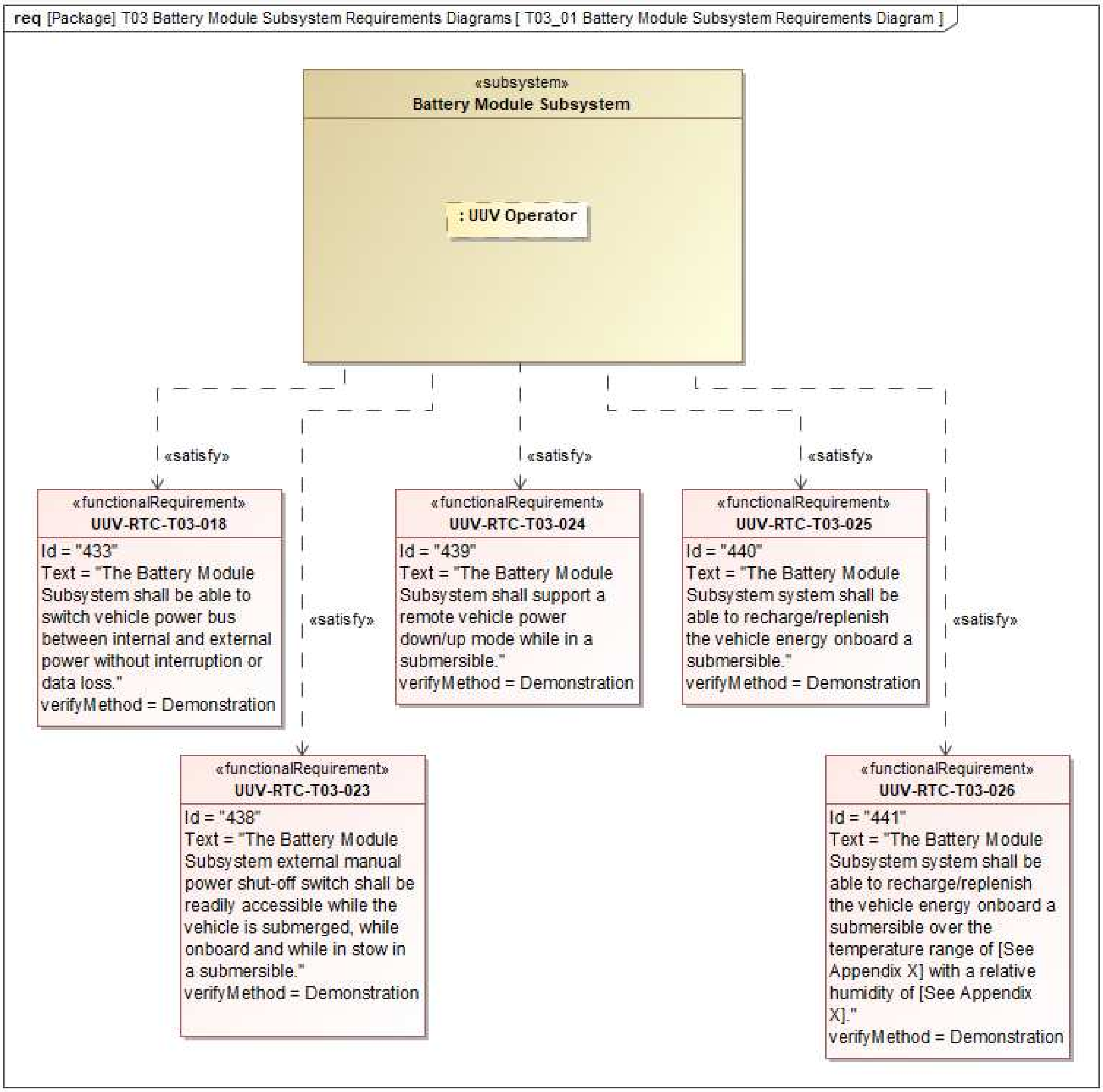

Figure 29: Associated Relationship between UUV Operator and Battery Module Subsystem Requirements

In reviewing the derived battery module subsystem requirements above, and with operational consideration given toward a submerged UUV Operator working with a submersible, the following use case is generated as a kickoff point in the same manner as the use case developed from the control module requirements.

- In support of the HSI environmental and HFE domains, the UUV Operator will have the ability to effectively startup, charge, and shutdown the UUV in a submerged state.

While this use case can be easily broken out into two or more child use cases, the decision was made to keep it as a single multi-part use case to maintain a more readable diagram in section 5.3.3

This use case is written to account for two of the five HSI domains that are identified in section 5.1. However, while it points to some of the key capabilities embedded and derived from the five control module subsystem requirements and four derived, undersea requirements, further detail and refinement is needed to properly extrapolate requirements in support of undersea SOCOM operations. While an activity diagram will provide a more dynamic, step-by-step view of the system and actor, a sequence diagram offers a more direct behavioral relationship between an actor and a system or subsystem (22) (1). This allows a human factors engineer to develop sequential calls and signals that would have to be performed to satisfy the use case. As with activity diagrams, the human factors engineer would rely on subject matter expertise, which in this case could be both a UUV Operator as well as a submersible operator. The sequence diagram below shows the messaging steps that may be required for a UUV Operator to interact with pertinent battery features effectively and safely in an undersea setting.

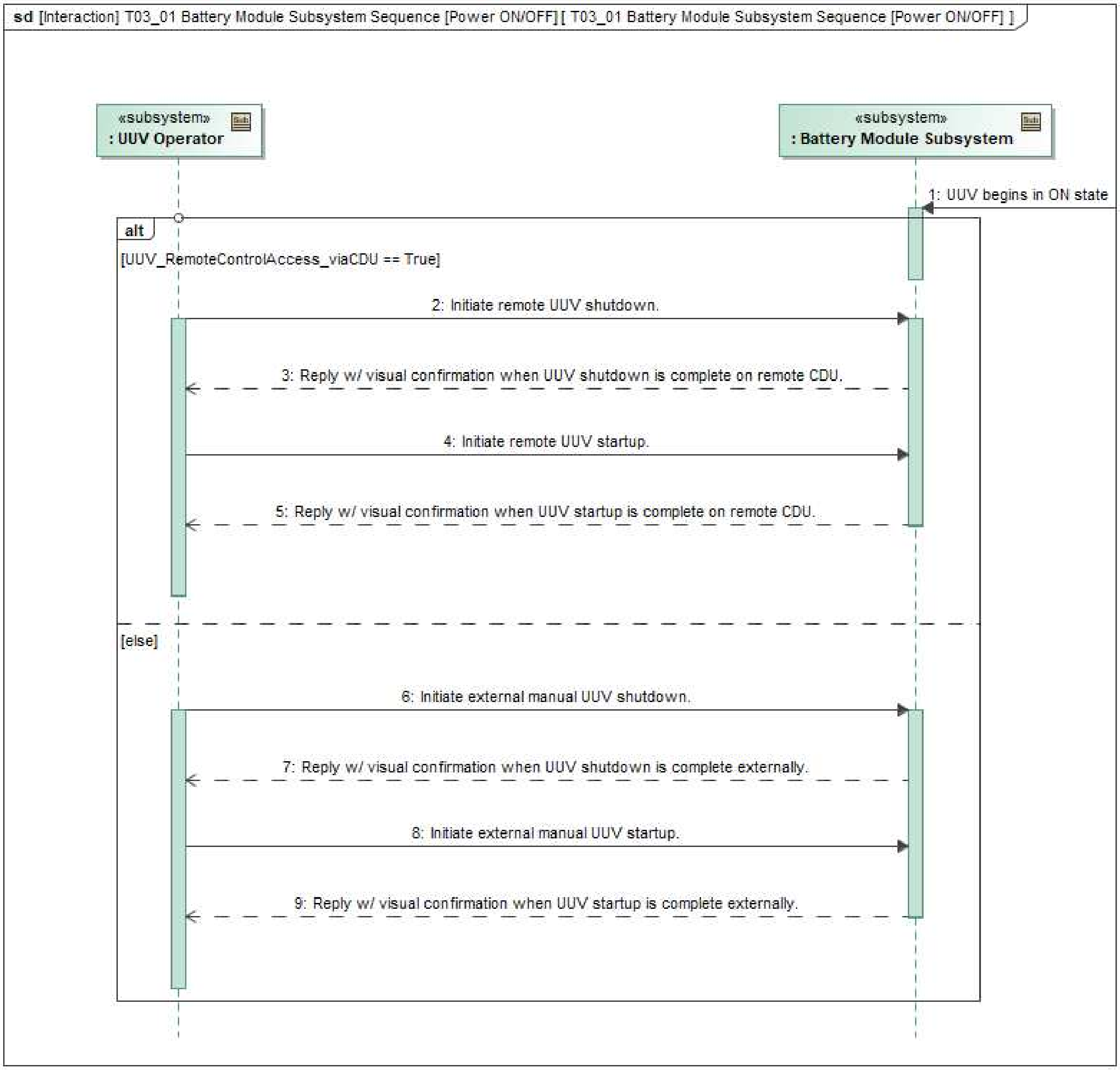

Figure 30: UUV Operator and Battery Module Subsystem Sequence 01 – Startup and Shutdown of the UUV using a remote or alternate external switch

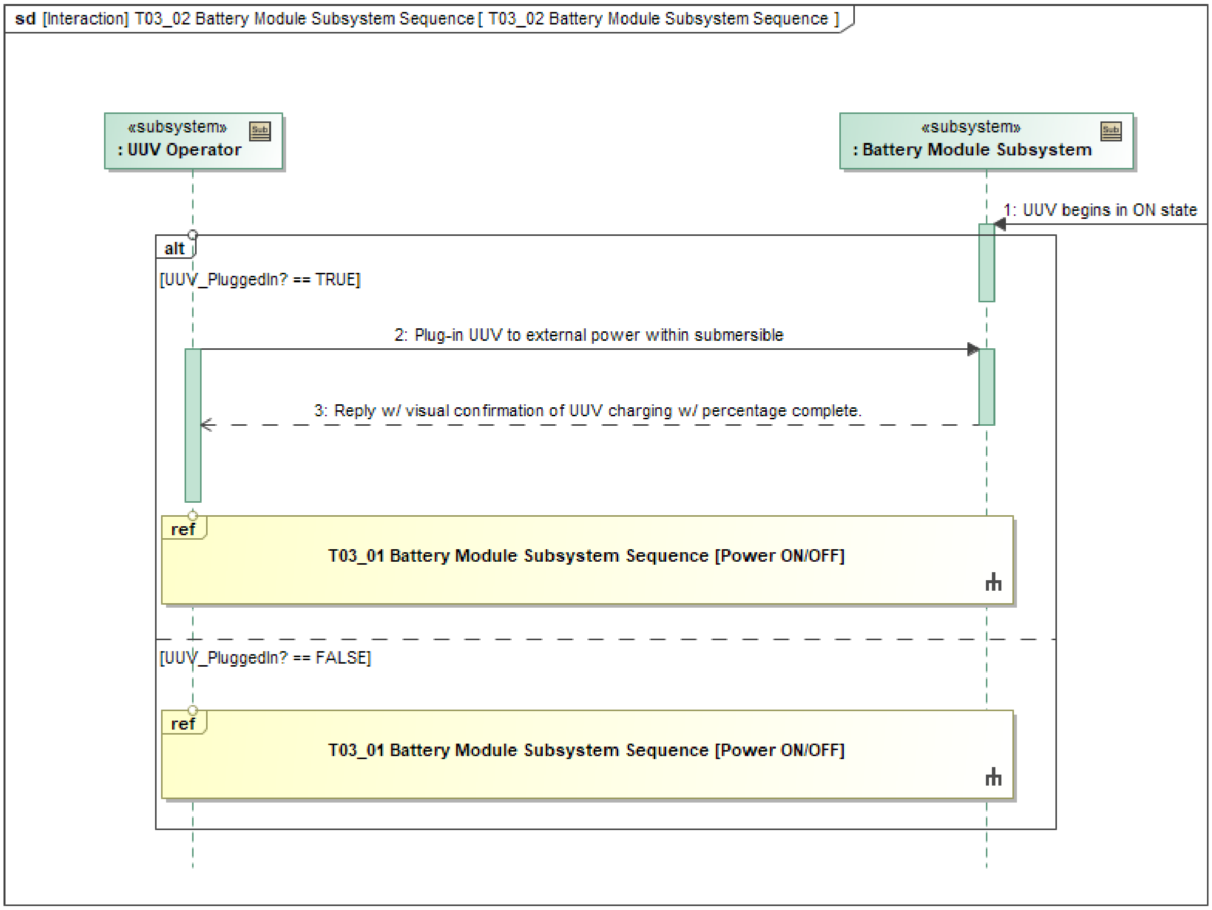

Figure 31: UUV Operator and Battery Module Subsystem Sequence 02 – Startup and Shutdown of the UUV [Referenced] in a plugged and unplugged state

In the above sequence, the UUV Operator initiates the first signal based on whether the CDU remote controller is available. Regardless of the alternative combined fragment, the UUV Operator and the UUV battery module subsystem sequentially shutdown the UUV, reply with a visual confirmation of the shutdown, startup the UUV, and reply with a visual confirmation the startup succeeded (22) (1). With the Power ON/OFF Sequence Diagram established, it is then used as a reference in a second alternative combined fragment sequence, except with the UUV battery module subsystem plugged in to external power from the submersible. Once plugged in, the battery module subsystem replies by providing a percentage complete visualization before beginning the first referenced Power ON/OFF Sequence Diagram. The alternative is the Power ON/OFF sequence without plugging in to external submersible power. These two sets of alternative combined fragments demonstrate every scenario based on the plugged-in state and using the CDU remote controller state.

With the UUV Operator needs revealed in the sequence diagram, and by referencing existing UUV system requirements for pertinent and consistent wording formats per the characteristics of sets of requirements as outlined and described in the INCOSE Guide to Writing Requirements and the Needs and Requirements Manual, the following new set of battery module subsystem requirements can be generated into the model (45) (46) (47). These requirements are provided in section 5.3.3 and are to be added into the SRS in the appropriate section.

5.3 Translation of Behavioral Diagrams into HSI Requirements

Before translating behavior diagrams into HSI requirements for all three sampled subsystems, two key points need to be made regarding the choice of wording within each requirement. The first point is defining whether each requirement is formalized and introduced at the system and subsystem level. The second point is whether each requirement will be categorized under the HSI requirements package, or the respective subsystem requirements package. While the decision for either point listed above can be justified, and given there may be a need for certain requirements to be categorized differently, this research will apply each requirement to the subsystem level and within the respective subsystem requirements package. The reason for this is to simply assist the reader with orientation and tracking of the RTC and requirements process throughout this paper.

Due to the UUV requirement format provided, the new and resulting set of propulsion, control, and battery module subsystem requirements are presented per the characteristics and rules for need and requirement statements to maintain consistency in overall syntax (45) (46) (47).

5.3.1 Use Case Diagram Requirements [Propulsion Module Subsystem]

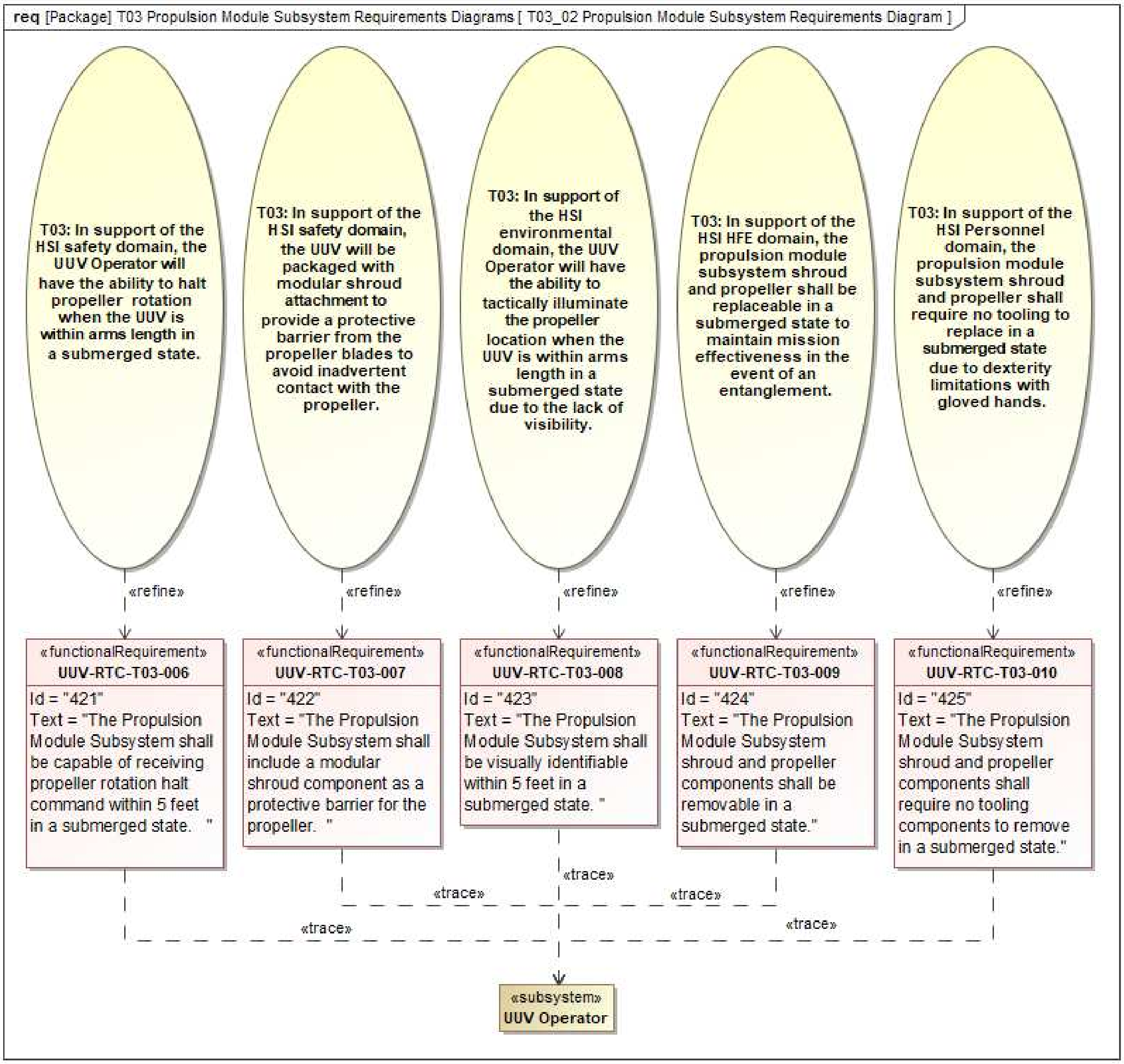

Figure 32: Trace Relationship between UUV Operator and New Propulsion Module Subsystem Requirements

Based on the process from section 5.2.1, the above requirements diagram is generated in support of the propulsion module subsystem. The use cases developed by the human factors engineer create a refine relationship to the new set of requirements. The bulleted list below represents the rationale behind the human factors engineer for generating each requirement. While this rationale is not all inclusive, it does provide justification behind the use case statements and resulting requirement statements.

- UUV-RTC-T03-006 HFE rationale: The halt command will enhance operator safety by stopping propeller rotation when in the vicinity of human contact.
- UUV-RTC-T03-007 HFE rationale: The modular shroud component will enhance operator and UUV safety by providing a protective barrier to avoid any foreign or human contact with an active propeller.
- UUV-RTC-T03-008 HFE rationale: The identification of the propulsion module will enhance operator awareness (for example: provide tactical illumination) so the operator knows where the active propeller is when water visibility is poor.
- UUV-RTC-T03-009 HFE rationale: The shroud and propeller will enhance operator efficiency by being removable in the event the propeller becomes fouled.
- UUV-RTC-T03-010 HFE rationale: The shroud and propeller will minimize the need for operator skills and abilities required to troubleshoot by eliminating the need for additional tooling equipment in the undersea domain.

The requirements are then traced to the UUV Operator. This allocation relationship was specifically selected based on the dependency relationship. While a weak relationship when compared to other requirement relationships such as derive or refine, a trace relationship can highlight downstream impact analysis (22) (1). If the UUV Operator’s responsibility were to adjust in the undersea domain, this may have an impact on the wording, or overall need on the set of propulsion module subsystem requirements.

5.3.2 Activity Diagram Requirements [Control Module Subsystem]

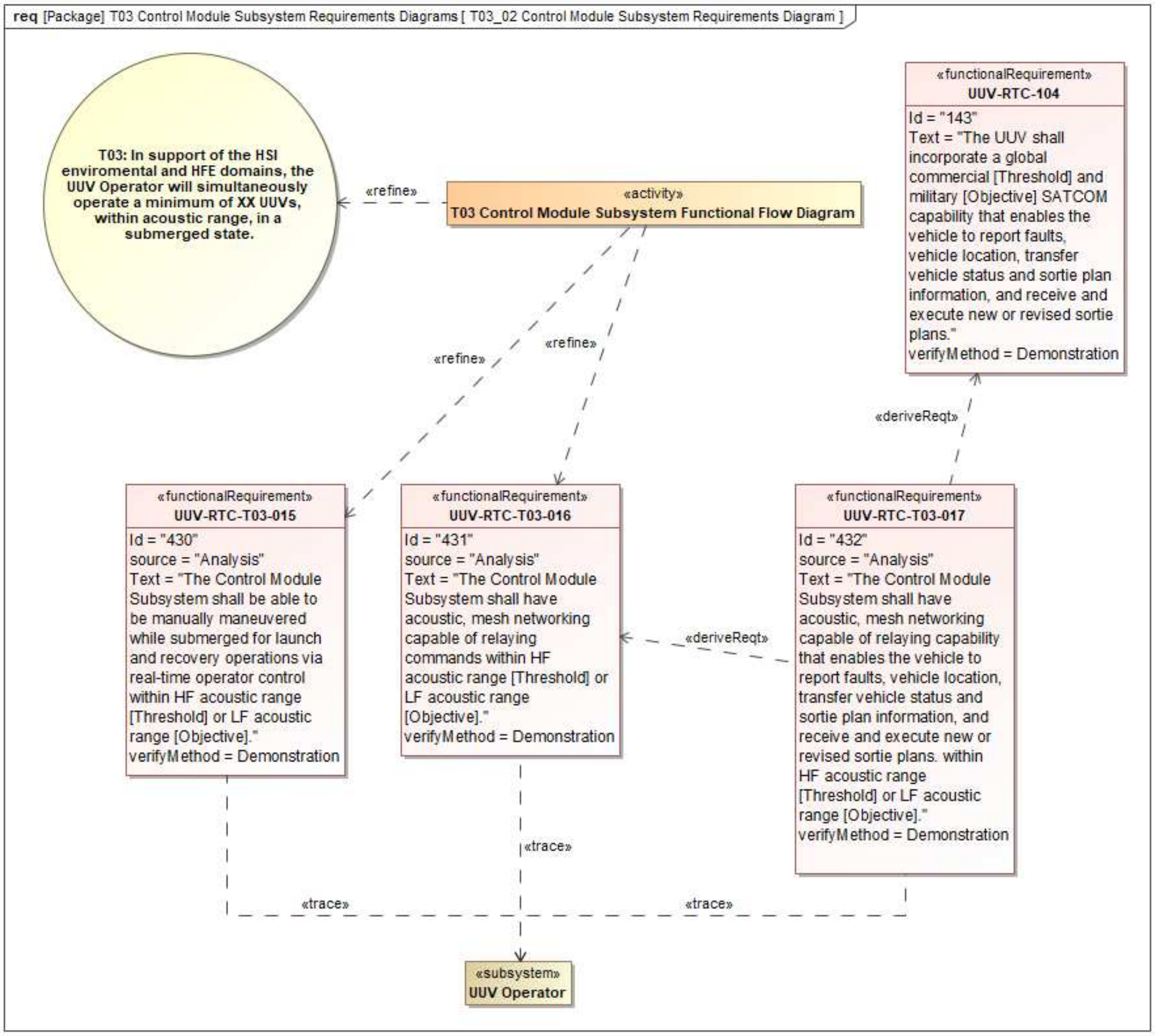

Figure 33: Trace Relationship between UUV Operator and New Control Module Subsystem Requirements

Based on the process from section 5.2.2, the above requirements diagram is generated in support of the control module subsystem. The functional flow diagram developed by the human factors engineer creates a refine relationship to both the new use case and two of the three requirements. The remaining requirement, UUV-RTC-T03-017, is created by a pair of derive requirement relationships from UUV-RTC-T03-017 and UUV-RTC-104. The bulleted list below represents the rationale behind the human factors engineer for generating each requirement. While this rationale is not all inclusive, it does provide justification behind the use case statement, the related activity diagram, and resulting requirement statements.

- UUV-RTC-T03-015 HFE rationale: The UUV controller will enhance operator efficiency and usability by providing an acoustic means to launch, maneuver, and recover a UUV to an undersea platform without surfacing.
- UUV-RTC-T03-016 HFE rationale: The UUV mesh network will enhance effectiveness and environmental capabilities by UUVs communicating and relaying commands to all UUVs from an undersea platform without surfacing.
- UUV-RTC-T03-017 HFE rationale: The UUV mesh network will enhance effectiveness and environmental capabilities by UUVs communicating and relaying status and data via mesh network to all UUVs from an undersea platform without surfacing.

Just like the propulsion module subsystem, the requirements are then traced to the UUV Operator. This allocation relationship was specifically selected based on the dependency relationship. While a weak relationship when compared to other requirement relationships such as satisfy or verify, a trace relationship can highlight downstream impact analysis (22) (1). If the UUV Operator's responsibility were to adjust in the undersea domain, this may have an impact on the wording, or overall need of the set of control module subsystem requirements.

5.3.3 Sequence Diagram Requirements [Battery Module Subsystem]

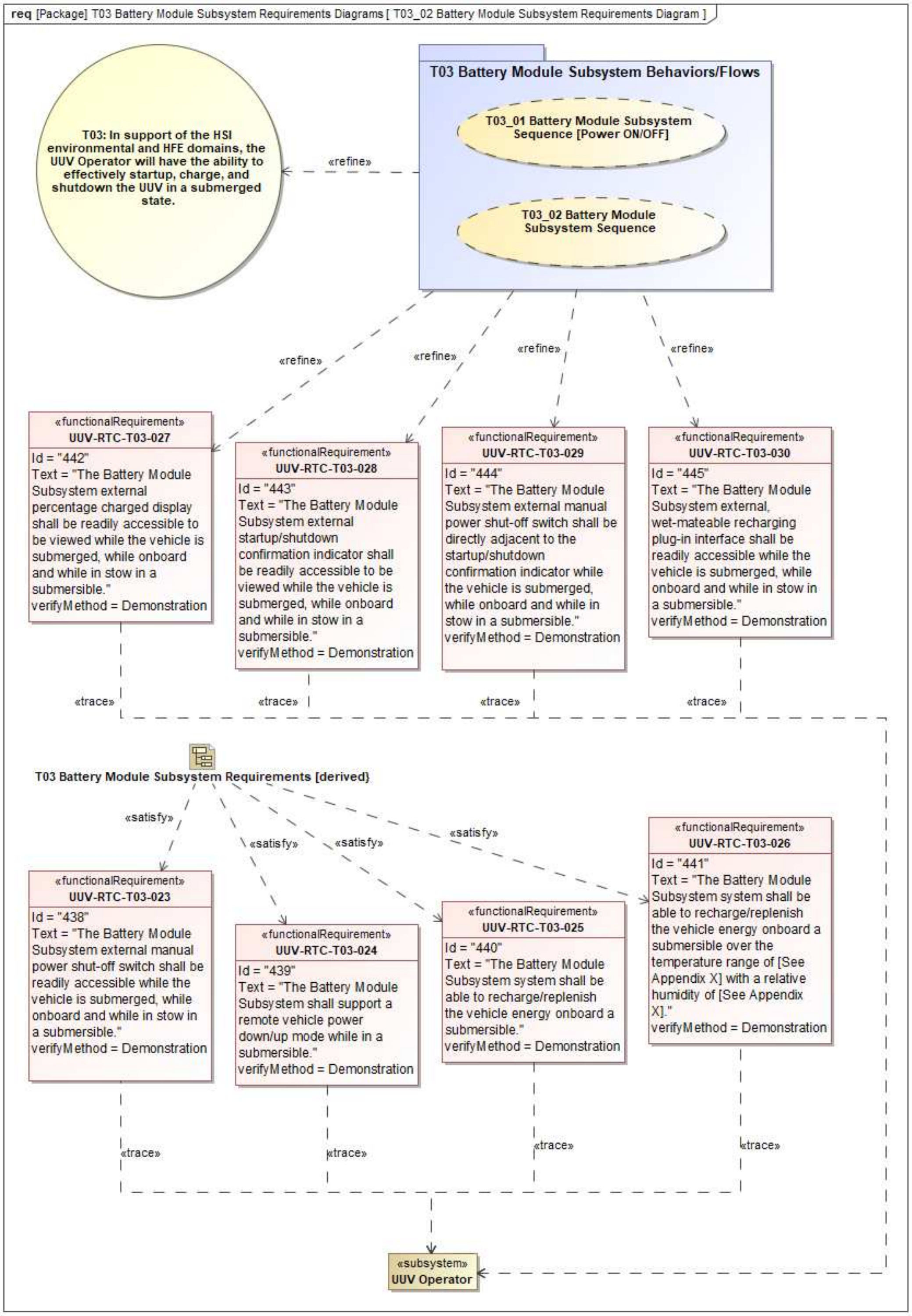

Figure 34: Trace Relationship between UUV Operator and New Battery Module Subsystem Requirements

Based on the process from section 5.2.3, the above requirements diagram is generated in support of the battery module subsystem. The two sequence diagrams developed by the human factors engineer create a refine relationship to both the new use case and the four requirements in the upper half of the diagram. The remaining four requirement on the lower half of the diagram, are created by derive requirement relationships from the T03 Battery Module Subsystem Diagram [derived] figure in section 5.2.3. The bulleted list below represents the rationale behind the human factors engineer for generating each requirement. While this rationale is not all inclusive, it does provide justification behind the use case statement, the related sequence diagrams, and resulting requirement statements.

- UUV-RTC-T03-027 HFE rationale: The UUV battery charged display will enhance efficiency and environmental capabilities by readily communicating remaining battery percentage to the UUV Operator in a submerged environment.
- UUV-RTC-T03-028 HFE rationale: The UUV startup/shutdown indicator will enhance usability and environmental capabilities by readily communicating a successful UUV startup and shutdown to avoid any accidental interruption of UUV power in a submerged environment.
- UUV-RTC-T03-029 HFE rationale: The UUV manual power shut off switch will enhance efficiency and environmental capabilities by providing a readily accessible shut off switch for ease of troubleshooting or conserving UUV power in a submerged environment.
- UUV-RTC-T03-030 HFE rationale: The UUV wet-mateable recharging plug-in interface will enhance effectiveness and environmental capabilities by providing a means to replenish the UUV using an undersea platform’s power without surfacing.

- UUV-RTC-T03-023 to UUV-RTC-T03-026 HFE rationale: The UUV derived requirements enhance effectiveness by expanding existing battery requirements into a submerged setting with the support of a submersible platform.

As with the previous two sections, the requirements are then traced to the UUV Operator. This allocation relationship was specifically selected based on the dependency relationship. While a weak relationship when compared to other requirement relationships such as refine or satisfy, a trace relationship can highlight downstream impact analysis (22) (1). As mentioned in the previous two sections, if the UUV Operator's responsibility were to adjust in the undersea domain, this may have an impact on the wording, or overall need of the set of battery module subsystem requirements.

5.4 Compiled List of RTC Phase 1 HSI Requirements

With human-in-the-loop requirements developed from behavioral diagrams, the following table provides a complete list from the propulsion, control, and battery module subsystems. Each row calls out the overall count, alphanumeric name, the complete text, the traced to element, and how the requirement is derived. Some specific points to consider when looking at each column are as follows:

- The overall count column includes the parent T03 requirement package and the sub-packages for the propulsion, control, and battery requirements.
- As mentioned in previous sections, the requirement text is formatted to remain consistent with the wording and syntax of the T02 system level requirements.
- The Traced To column represents each requirement specifically traced to, and dependent upon the UUV Operator.
- The derived columns represent where the requirement was Derived From, assuming there is a parent requirement, and where a requirement is Derived To, assuming there is a child requirement. This gives the requirements engineer insight into relationships between specific requirements.

Table 5: Compiled List of T03 Functional Requirements for Evaluation

#	Name	Text	Traced To	Derived To	Derived From
1	T03 Functional Requirements				
2	T03 Propulsion Module Subsystem Requirements				
3	425 UUV-RTC-T03-010	The Propulsion Module Subsystem shroud and propeller components shall require no tooling components to remove in a submerged state.	UUV Operator		
4	424 UUV-RTC-T03-009	The Propulsion Module Subsystem shroud and propeller components shall be removable in a submerged state.	UUV Operator		
5	423 UUV-RTC-T03-008	The Propulsion Module Subsystem shall be visually identifiable within 5 feet in a submerged state.	UUV Operator		
6	422 UUV-RTC-T03-007	The Propulsion Module Subsystem shall include a modular shroud component as a protective barrier for the propeller.	UUV Operator		
7	421 UUV-RTC-T03-006	The Propulsion Module Subsystem shall be capable of receiving propeller rotation halt command within 5 feet in a submerged state.	UUV Operator		
8	420 UUV-RTC-T03-005	The Propulsion Module Subsystem shall enable a Root Sum Square (RSS) of its angle-of-attack and side-slip angles less than or equal to X degrees, at any speed greater than X knots under straight line "flight" conditions.			102 UUV-RTC-046
9	419 UUV-RTC-T03-004	The Propulsion Module Subsystem shall be able to maneuver in reverse thrust.			101 UUV-RTC-045
10	418 UUV-RTC-T03-003	The Propulsion Module Subsystem shall enable a turn radius in both directions of [Threshold] meters or [Objective] meters or less at survey speed.			100 UUV-RTC-044
11	417 UUV-RTC-T03-002	The Propulsion Module Subsystem shall have a through the water sprint speed of at least [Threshold] knots for [Threshold] minutes or at least [Objective] knots for [Objective] hours.			99 UUV-RTC-043

12	416 UUV-RTC-T03-001	The Propulsion Module Subsystem shall operate at submerged through the water at speeds of at least [Threshold] knots, or at least [Objective] knots.			98 UUV-RTC-042
13	T03 Control Module Subsystem Requirements				
14	432 UUV-RTC-T03-017	The Control Module Subsystem shall have acoustic, mesh networking capable of relaying capability that enables the vehicle to report faults, vehicle location, transfer vehicle status and sortie plan information, and receive and execute new or revised sortie plans. within HF acoustic range [Threshold] or LF acoustic range [Objective].	UUV Operator		431 UUV-RTC-T03-016 143 UUV-RTC-104
15	431 UUV-RTC-T03-016	The Control Module Subsystem shall have acoustic, mesh networking capable of relaying commands within HF acoustic range [Threshold] or LF acoustic range [Objective].	UUV Operator	432 UUV-RTC-T03-017	
16	430 UUV-RTC-T03-015	The Control Module Subsystem shall be able to be manually maneuvered while submerged for launch and recovery operations via real-time operator control within HF acoustic range [Threshold] or LF acoustic range [Objective].	UUV Operator		
17	429 UUV-RTC-T03-014	The Control Module Subsystem architecture shall provide for simultaneous operation of a minimum of XX UUVs, within acoustic range, without degrading the capabilities of any of the vehicles.			139 UUV-RTC-100
18	428 UUV-RTC-T03-013	The Control Module Subsystem shall be able to be manually maneuvered while on the surface for launch and recovery operations via real-time operator control.			138 UUV-RTC-099
19	427 UUV-RTC-T03-012	The operational state and setting of the Control Module Subsystem sensors, payloads, and light sources, shall be able to be controlled both pre-sortie and in-situ (when communication link(s) are available).			137 UUV-RTC-098
20	426 UUV-RTC-T03-011	The Control Module Subsystem shall not acoustically transmit communications during submarine rendezvous and prior to recovery, until commanded to by the Host Platform.			136 UUV-RTC-097

21	T03 Battery Module Subsystem Requirements				
22	445 UUV-RTC-T03-030	The Battery Module Subsystem external, wet-mateable recharging plug-in interface shall be readily accessible while the vehicle is submerged, while onboard and while in stow in a submersible.	UUV Operator		
23	444 UUV-RTC-T03-029	The Battery Module Subsystem external manual power shut-off switch shall be directly adjacent to the startup/shutdown confirmation indicator while the vehicle is submerged, while onboard and while in stow in a submersible.	UUV Operator		
24	443 UUV-RTC-T03-028	The Battery Module Subsystem external startup/shutdown confirmation indicator shall be readily accessible to be viewed while the vehicle is submerged, while onboard and while in stow in a submersible.	UUV Operator		
25	442 UUV-RTC-T03-027	The Battery Module Subsystem external percentage charged display shall be readily accessible to be viewed while the vehicle is submerged, while onboard and while in stow in a submersible.	UUV Operator		
26	441 UUV-RTC-T03-026	The Battery Module Subsystem system shall be able to recharge/replenish the vehicle energy onboard a submersible over the temperature range of [See Appendix X] with a relative humidity of [See Appendix X].	UUV Operator		437 UUV-RTC-T03-022
27	440 UUV-RTC-T03-025	The Battery Module Subsystem system shall be able to recharge/replenish the vehicle energy onboard a submersible.	UUV Operator		436 UUV-RTC-T03-021
28	439 UUV-RTC-T03-024	The Battery Module Subsystem shall support a remote vehicle power down/up mode while in a submersible.	UUV Operator		435 UUV-RTC-T03-020
29	438 UUV-RTC-T03-023	The Battery Module Subsystem external manual power shut-off switch shall be readily accessible while the vehicle is submerged, while onboard and while in stow in a submersible.	UUV Operator		434 UUV-RTC-T03-019
30	437 UUV-RTC-T03-022	The Battery Module Subsystem system shall be able to recharge/replenish the vehicle energy onboard a Host Platform over the temperature range of [See Appendix X] with a relative humidity of [See Appendix X], while encapsulated.		441 UUV-RTC-T03-026	199 UUV-RTC-059

31	436 UUV-RTC-T03-021	The Battery Module Subsystem system shall be able to recharge/replenish the vehicle energy onboard a surface ship.		440 UUV-RTC-T03-025	195 UUV-RTC-055
32	435 UUV-RTC-T03-020	The Battery Module Subsystem shall support a remote vehicle power down/up mode while torpedo tube loaded, in conjunction with the vehicle encapsulation.		439 UUV-RTC-T03-024	107 UUV-RTC-051
33	434 UUV-RTC-T03-019	The Battery Module Subsystem external manual power shut-off switch shall be readily accessible while the vehicle is on the surface, while onboard small craft and while on a stow in the torpedo room (including while within any encapsulation, during pre-launch and post-recovery).		438 UUV-RTC-T03-023	106 UUV-RTC-050
34	433 UUV-RTC-T03-018	The Battery Module Subsystem shall be able to switch vehicle power bus between internal and external power without interruption or data loss.			105 UUV-RTC-049

5.5 RTC Phase I [RQ1] Conclusion

Chapter 5.0 proceeded through Phase 1 of the RTC beginning with insertion of an actor block into the architectural framework of a UUV used throughout this research. With the human-in-the-loop architecture constructed, the next subsection focused on development of behavioral diagrams and functional flows for three UUV module subsystems. Once the functional flows were developed, each diagram was translated into HSI functional requirements and complied into a list in the last subsection of Chapter 5.0.

In revisiting Research Question 1, the following RQ1 bulleted questions are restated below with validation responses:

- **RQ1.1:** Can an MBSE model, developed from an architectural and behavioral framework that includes an internal actor block at the subsystem level (Tier 3), address human-in-the loop functional requirement shortfalls during requirements generation through a supplemental process for SOCOM?
  - **By satisfying Task 1.1 and Task 1.2, a UUV system with a SOCOM mission set was selected from an applicable DoD program, which only consisted of 6 HSI requirements out of 370 total requirements. By investigating this UUV system, an architectural framework was developed with an internal block actor at the subsystem level. This actor-to-system relationship supported the design of three behavioral diagrams with the RTC human-in-the-loop centered modeling approach that successfully resulted in an expanded list of HSI requirements.**

- **RQ1.2:** Will functional requirements of a human-in-the-loop centered model supplement the needs of modern SOCOM systems?
    - **By satisfying Task 1.2, the development of three behavioral diagrams through a block actor association with three sampled subsystems confirms the addition of UUV HSI requirements with the potential for human-in-the-loop considerations placed across all subsystems for modern SOCOM systems.**

The remaining RQ1 bulleted question is addressed in Chapter 8.0 Research Validation section, specifically in subsection 8.2.

CHAPTER 6.0 RESEARCH QUESTION 2

SOCOM TASK LIST

6.0 SOCOM Task List [RQ2] Introduction

Chapter 6.0 is going to present the development and validation of a partial SOCOM Task List applied to a UUV platform and the SOCOM undersea domain. Summarized from the Research Questions and Tasks in Chapter 3.0, the RQ2 tasks include generating an all-encompassing, tactical task list from the undersea SOCOM domain, developing PSFs using initial estimations for all SOCOM task attributes, and evaluating the SOCOM Task List for collaboration potential and system design consideration based on PSF scoring. Evaluation of RQ2 also takes place in Chapter 8.0, specifically in the SOCOM Task List subsection.

6.1 Review of UNTL for SOCOM-Related Tasks

In order to bridge the progress made through Phase 1 of the RTC (which fully encompassed Research Question 1) with Phase 2 of the RTC, the need to leverage a task list with SOCOM-related tasks is an identified prerequisite. From a human systems integration standpoint, the justification is simple; the human integration with the system is determined by the tasks performed to accomplish a mission or objective. By holding informal discussions with contacts throughout the SOCOM community, including NSW officers and SMEs who work out of various acquisition offices at the SOCOM HQ in Tampa, FL, I was able to verify that a SOCOM Task List comparable to the UNTL does not presently exist.

Typically, a task list such as the UNTL provides a common language for military leaders to hierarchically interpret, communicate, and document war tasks at the strategic-national, strategic-theater, operational, and tactical levels. This common language will be applied to a novel SOCOM tactical list with an additional capability; a common data value that can be compared across tasks throughout the list. For the purposes of this research, these common data values will be leveraged to generate requirements, but in the future, additional quantitative data may also be subjectively rated and sourced by military leaders for decision making purposes.

In looking closer at the UNTL as well as the AFTL, the common columns and data for both lists include:

- Title:
- Task Number:
- Description:
- Measure number
- Unit of Measure
- Description of Measure

The below table gives a look at the UNTL list as it pertains to one of the two tasks applied to special warfare.

Table 6: UNTL Special Warfare Task (29)

NTA 1.5.7 Conduct Naval Special Warfare
To employ Navy forces that are specially trained, equipped, and organized to conduct special operations in maritime, littoral, and riverine environments.

M1	Time	Between enemy attacks on areas controlled by friendly forces.
M2	Number	Of enemy units destroyed.
M3	Percent	Of enemy units not mission capable.

The objectives of a partial SOCOM Task List is twofold; first, a task list can provide a hierarchal structure to tasks that can enable tiered modeling to exist with the operator at the highest tier. This would tie and expand upon the UUV System Architecture with the Block Actor diagram in section 5.1. Second, each task can be subjectively rated by SMEs to provide quantitative values, which may be aggregated through parametric modeling. The advantage of this is to enable side-by-side quantified values as it pertains to tasks within each tier as well as requirements generation to potentially allow for quantitative-to-qualitative human factors improvements across the system of interest.

6.2 Performance Shaping Factors

Performance shaping factors have been referenced in a variety of applications to derive human error rates and risk analysis. Some common examples of PSFs being applied are in nuclear power plant operations and NASA. In both instances, the use of PSFs is to support Human Reliability Analysis (HRA) (48) (49) (40) (33). One major variable across the use of the PSFs is in the number and types of factors used, even within the same industry. The US Nuclear Regulatory Commission adopts 15 PSFs in its HRA Good Practices, while its Standardized Plant Analysis Risk HRA (SPAR-H) method adopts the use of eight PSFs and its A Technique for Human Error Analysis (ATHEANA) method features an open-ended number of PSFs (48) (49) (40) (33).

In translating PSFs, the two key features are the common PSFs used across applications and methods and how the PSFs are computed in an aggregated manner. The Human Reliability with Human Factors textbook lists seven PSFs (40):

1. Quality of methodology
2. Human redundancy
3. Psychological stress level
4. Training quality
5. HFE applied to displays and controls
6. Human actions independence
7. Type of display feedback

Another textbook with a list of PSFs is the Human Reliability and Safety Analysis Data Handbook (49). In chapter one of this textbook, a more comprehensive list is offered with some overlap against the list provided above. The overlap or relationship is portrayed in the table below by listing the PSF number from the Human Reliability with Human Factors list from above.

Table 7: PSF References and their Associations (40) (49)

Human Reliability and Safety Analysis Data Handbook PSFs with specific associations to the Human Reliability with Human Factors textbook using the numbered bulleted list above.	
Crew experience (4)	Procedure understood (1)
Time to perform	Procedure practiced (4)
Time available	Recovery actions (2)
Stress (3)	Tasks dynamic aspects (6)
Quality of plant interface (5)	Task dependency (6)
Type of instrument/control (5)	Tagging
Feedback to operator action (7)	Local versus remote control
Procedure required	Clothing/tools required
Action covered by procedure	Environment
Procedure well written (1)	

The use and terminology of PSFs in nuclear power plant operations and NASA can translate and apply toward performance characteristics embedded within each SOCOM task. While other PSF lists do exist in literature and in practice, the following PSFs comprise of both common factors found in research and SOCOM-applicable factors. These factors are not in a priority order as the goal will be for the operators to apply a numerical rating to determine each factor's impact on the task.

Table 8: RTC Performance Shaping Factors and Rating Descriptions

Performance Shaping Factor	Label	Rating Description
Task Training	PSF01	How much instruction, practice, or mentoring is required IOT perform the task?
Task Experience	PSF02	How much exposure and familiarity are required IOT perform the task?
Mental Acuity to Perform Task	PSF03	What level of response stimulus is required IOT perform the task?
Motor Skills to Perform Task	PSF04	What level of gross and fine motor skills are required IOT perform the task?
Stress of Performing Task	PSF05	How much mental tension, worry, or concern exists when performing the task?
Task Complexity	PSF06	How sophisticated or complicated is the system in relation to performing the task?
Actor Interfaces During Task (including orientation)	PSF07	How unintuitive, impractical, or unusable are the human interactions with the system when performing the task?
Task Safeguards	PSF08	How much risk, exposure, or jeopardy is the system or end-user subject to when performing the task?
Input Control Capability During Task	PSF09	How difficult or inoperable are the dynamic, interactive interfaces (e.g. joystick, throttle, etc.) to manipulate while performing a task?
Task Feedback and Alarms	PSF10	How limited or nonobvious are the system responses, alarms or signals while performing the task?

In determining which factors were selected, there were many other factors that were omitted from the final list for a variety of reasons. Many of the reasons were common across a variety of omitted factors. One common reason included factors that were too closely related to other factors, even though an argument could be made they were different. An example of this are the factors practice and experience, where experience would encompass both practice and mission performance time, so experience was selected, and practice was omitted. Another example is when a factor remains consistent across all tasks. As this is an all-things-being-equal measurement of the operator's ability to execute the task, the environment or fatigue of the operator remains consistent across each task in submersible operations and are thus omitted. Given task dependency and relationships with other tasks are covered in the Transition of Task-Based BDDs into Aggregated Performance Metrics (Section 7.2) during Research Question 3, those factors are omitted from this list of task factors. Overall, the selected factors needed to be as close to an all-inclusive list as possible, while not overwhelming the operators with an excessive amount of rating work.

With the tasks identified, the next step is determining how the PSFs are calculated with the overall objective of getting each task down to one value. PSFs have been used for several decades in a variety of applications and there has been some variance in how they are defined from a qualitative and quantitative standpoint. Many references with quantitative PSFs were reviewed including the Technique for Human Error Rate Prediction and the Engineering Data Compendium – Human Perception and Performance, although these were not well interpreted when presented to operators (40) (49) (32). Therefore, further research was performed to find both an efficient and intuitive PSF solution for the tasks listed in the above SOCOM task table. What stood out to operators from a task rating perspective was linked to Operational Availability (Ao).

6.2.1 Operational Availability

There are many aspects of Ao that align with the PSF goals within this SOCOM Task List and the RTC. The most important aspect of these is how Ao is utilized as a measure of effectiveness in the specifications of requirements of military systems (50). Additional features of Ao consistent with the needs of RTC are the following:

- Ao is a ratio between a partial measure and the overall measure. In the case of Ao, the partial measure is system uptime and the overall is total active time (50).
- Ao measures can be subdivided to account for additional time quantities being tracked. For example, Ao total active time can be broken out into Operating Time (OT), Standby Time (ST), Total Corrective Maintenance (TCM), Total Preventative Maintenance (TPM), and Total Administrative and Logistics Delay Time (TALDT) (50).
- Ao results in a single value that enables modeling and aggregation.
- Ao equations can be customized to adapt to the available time quantities and stakeholder needs. The following equation (1) represents Ao in one of its simplest forms (50):

$$Ao = \frac{Uptime}{Uptime + Downtime} \tag{1}$$

Where,

Uptime = Active operable time

Downtime = Active inoperable time

Comparatively and conversely, Ao can be expressed in the following, more complicated equation 2 (50):

$$Ao = 1 - \left(\frac{OT * (MCMT + ALDT)}{TT * MTBF}\right) - \frac{TPM}{TT} \tag{2}$$

Where,

OT = Operating Time

MCMT = Mean Corrective Maintenance Time

ALDT = Administrative and Logistics Delay Time

TT = Total Time

MTBF = Mean Time Between Failures

TPM = Total Preventative Maintenance

Highlighting the previous equation shows just one of many versions of Ao and emphasizes the PSF equations used in this RQ section, while valuable toward the completion of this research, these formula decisions should be consistently reevaluated to satisfy stakeholder and end-user needs. With an understanding of how Ao is used, the connection is determining the how Ao will service the initial SOCOM Task List PSF formula.

6.2.2 SOCOM Task List PSF Formulas

With Ao identified and interpreted, this section will show the translation and similarity toward the PSF equations used to populate the SOCOM Task List. OPM.gov calls out a formula for maximizing performance by defining a set of common terms and showing their relationship (51). In this instance, we arrive at the following equation with the word 'task' in place of 'job' or 'work' when defining the variables. While commitment is translated by the Office of Personnel Management (OPM) as a dedication to the cause, the definition used below reflects the "ability to overcome" definition of commitment (51):

$$Performance = Capacity * Commitment \tag{3}$$

Where,

Performance = The accomplishment of task assignments and responsibilities

Capacity = The available competencies, resources, and opportunity to complete the task

Commitment = The ability to overcome the restrictions on the freedom to perform the task

While the OPM formula itself is not related to this research, the labeled variables within the formula do hold meaning from both a symbolic and well related perspective. In referencing the Performance Shaping Factor and Rating Descriptions table, each PSF will be rated against every task column on a scale from one-to-ten by submersible operators. From a human factors perspective, a one-to-ten rating provides a more detailed value versus a one-to-five, or one-to-three scale, as examples. Once all ten PSFs have been rated, they will be ingested into the following equation:

$$Performance = \frac{Capacity}{Capacity + Commitment} \tag{4}$$

Or in a more RTC-aligned phrasing,

$$P_{RTC} = \frac{C_A}{C_A + C_O} \tag{5}$$

Where,

P_{RTC} = Performance Value / Fully realized task

C_A = Fully unrestricted task value

C_O = Task rated PSFs

While there will always be additional restrictions at play in accomplishing a task, the design of the RTC equation is formulated around the concept that the summation of each PSF makes up the overall performance of the task. Therefore, with a scale of one-to-ten in place, a fully unrestricted task value would equal ten since each task would comprise of one tenth of the overall task performance value. When rating each PSF, a one would equal 0.1, a two would equal 0.2, etc., until all ten PSFs have been rated for the given tasks. Including the ten PSFs into above equation in replacement of C_O, you arrive with the following equation:

$$P_{RTC} = \frac{10}{10 + (\sum_{i=1}^{10} PSF_i)} \tag{6}$$

Or written out in Excel format:

$$P_{RTC} = C_A/(C_A + SUM(PSF_1{:}PSF_{10})) \quad (7)$$

The above P_{RTC} Excel equation (6) is computed in column 12 of the SOCOM Task List located in Appendix C of this paper. For rows marked as N/A, those will serve as aggregated values based on the roll up of the immediate lower-level tasks. For example, Special Operations Task Number (SOTN) 2.1.2.6 is the aggregated value of SOTN 2.1.2.6.1 and SOTN 2.1.2.6.2 of the SOCOM Task List.

6.3 Development of SOCOM Task List

With the P_{RTC} equation established in the previous section, a single value can be created to represent each task within a SOCOM Task List. Based on our use of the block actor, this overall performance measurement can now be applied toward both submersible tasks and the embedded UUV tasks to be executed by the UUV operator. As no SOCOM Task List presently exists per section 6.1., the next step is to identify submersible tasks. In identifying submersible tasks, consideration is given to ensure the inclusion of UUV tasks within the submersible tasks. In referencing the informal discussions from 6.1 with the SOCOM community, submersible tasks can be directly transferred from the existing list of Operating Procedures (OPs) and Emergency Procedures (EPs) (38) (37). OPs and EPs are established, reviewed, and verified by submersible SMEs inside the military and industry. Each OP and EP used in this research can be defined as a tactical level task within the SOCOM Task List, but only represents a portion of an overall completed SOCOM Task List. A complete SOCOM Task List would include input from each SOCOM community across all branches of service (e.g. Army, Air Force, etc.), involve all forms of operations (air operations, dive operations, land operations, etc.), and contain OPs and EPs at the tactical and operational levels from each community to complete the hierarchy throughout the task list. Ideally, a SOCOM Task List would be a living database that is updated regularly with designated SOCOM SME support. Long-term development would be required to properly capture all OPs and EPs for each form of operations from every SOCOM supporting branch of service. Completion and sustainment of a SOCOM Task List can support long-term collaborative initiatives across SOCOM commands such as cross-community acquisition alignment and streamlined SOCOM-wide tactics and operations. Based on the undersea focus placed on the task list for this research, the following flow chart summarizes the basic development of a partial SOCOM Task List.

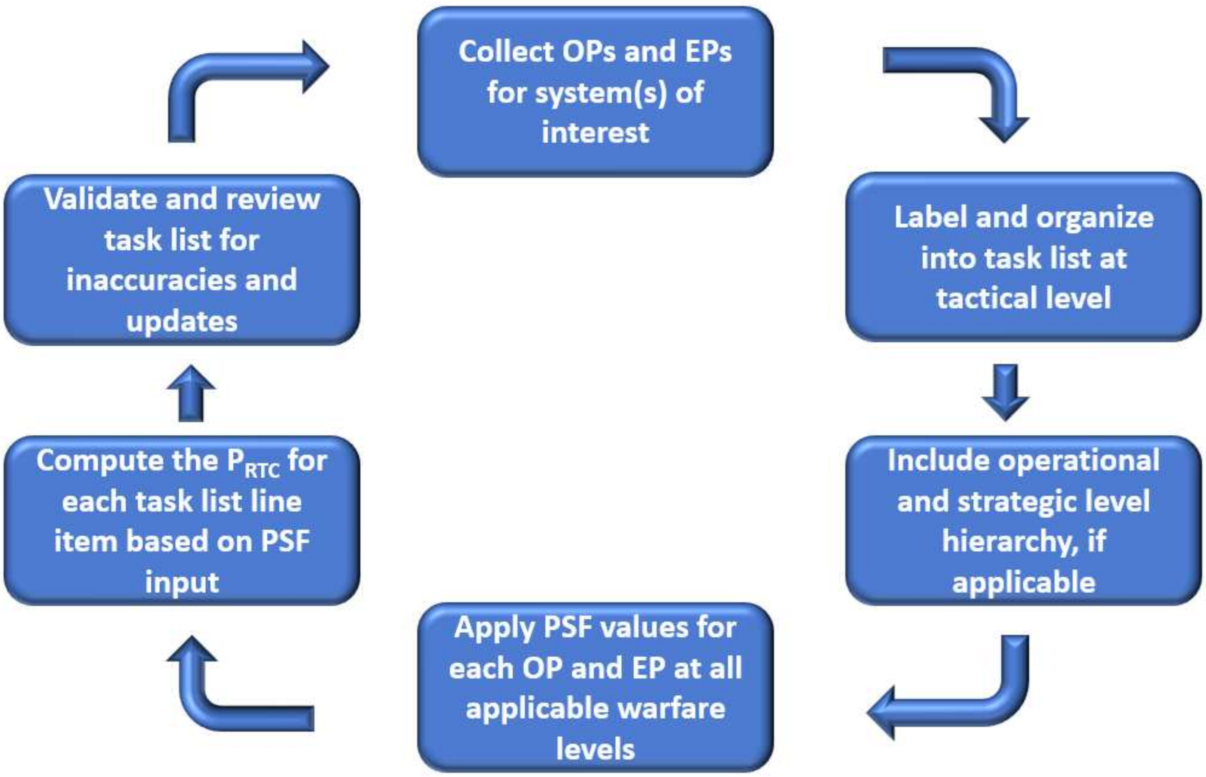

Figure 35: Workflow for SOCOM Task List Development

From this flow chart, the below table places basic sum total values to the key information that is pertinent to OPs and EPs used to develop this partial SOCOM Task List.

Table 9: SOCOM Task List Specification Summary (38) (37)

SOCOM Task List Specification Summary Type	Specification Value
Total Number of Task Rows	61
Total Number of Operating Procedures (OPs)	45
Total Number of General Undersea Tasks	7
Number of Pilot (PLT) OP Tasks	26

Number of Navigator (NAV) OP Tasks	3
Number of Mission Specialist (MS) UUV Tasks	9
Total Number of Emergency Procedures (EPs)	16
Number of Crew (PLT and NAV) EP Tasks	11
Number of MS EP Tasks	5

Once the OPs and EPs are placed into the SOCOM Task List, the next step is to properly organize the OPs and EPs by actor roles and task hierarchy. In the case of submersible roles, the three main jobs required for a non-pressurized manned submersible is a pilot (PLT), navigator (NAV), and one, or more Mission Specialists (MSs) (37). Given the MSs are focused on ancillary, specialized tasks outside of normal submersible operations, the UUV tasks will be structured under the MS role. With regards to hierarchy, tasks are derived from the UNTL, specifically task 2.0 Conduct Naval Special Warfare, to flow down to the submersible OPs and EPs. The SOCOM Task List of OPs and EPs for submersible's and UUVs are summarized within the containment tree in the figure below:

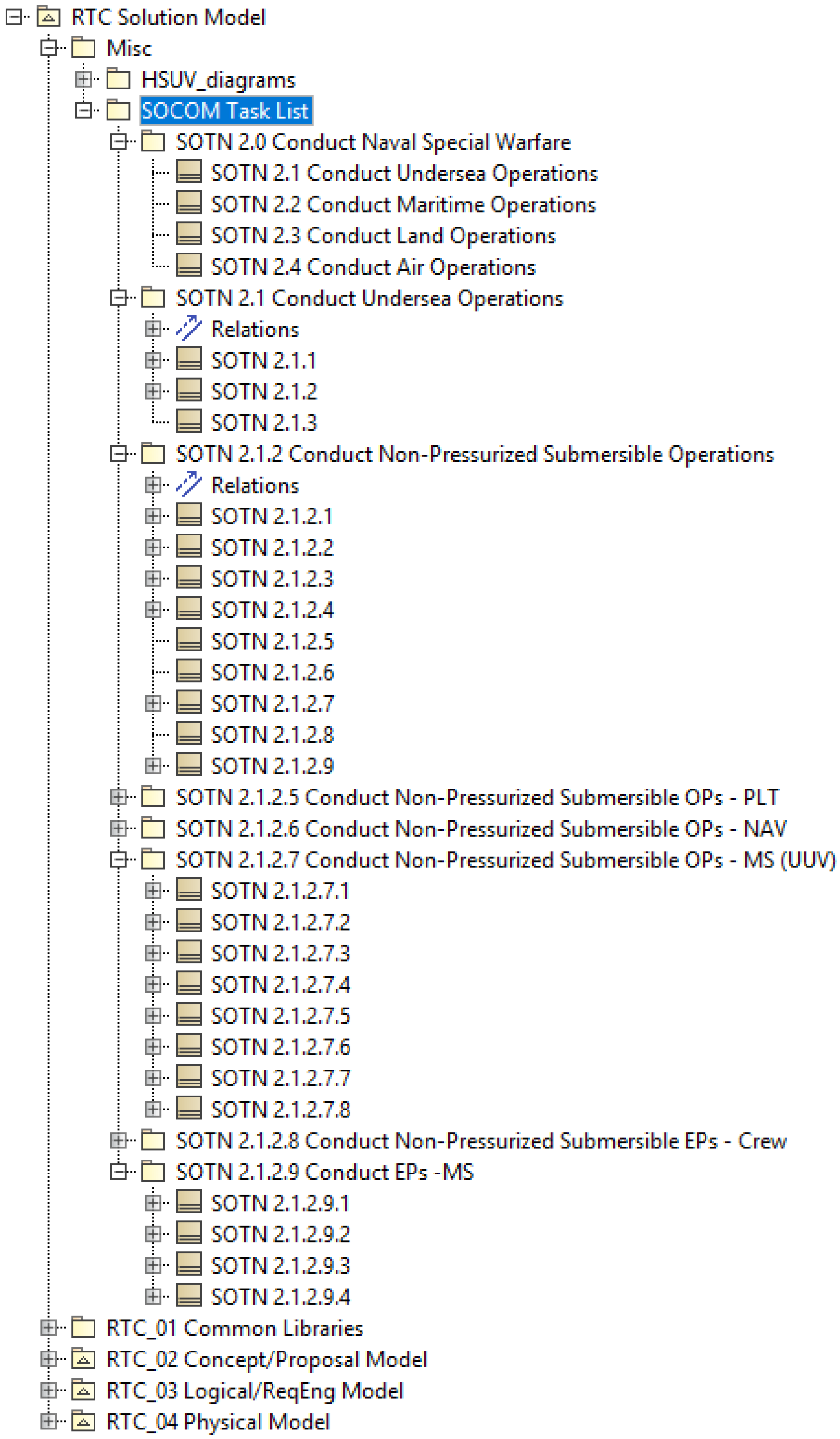

Figure 36: SOCOM Task List Package

Within each task, the PSFs from section 6.2 are filled in notionally based on firsthand experiences as both a submersible pilot, project engineer, and UUV operator. These notional values allow the P_{RTC} equation to be generated for every task, which will be transferred into the model task elements as value properties. The fully reformatted SOCOM Task List for this research is provided in Appendix C of this paper.

6.4 SOCOM Task List [RQ2] Conclusion

Chapter 6.0 proceeded with a review of the UNTL for SOCOM-Related Tasks. Based on the lack of tactical level SOCOM tasks, a series of PSFs were developed based on SOCOM-applicable factors and adoption of the Ao formula. The PSFs and P_{RTC} scoring were then included in the creation of a notional SOCOM Task List based on OPs and EPs within the NSW undersea domain and UUV operations. The complete task list is provided in Appendix C for reference.

In revisiting Research Question 2, the following RQ2 bulleted questions are restated below with validation responses:

- **RQ2.1:** Could the SOCOM community utilize an independent task list, similar to the Air Force Task List (AFTL) or the Universal Naval Task List (UNTL), which encompasses Navy, Marine Corps, and Coast Guard tasks, to catalogue and organize at the tactical level to be translated into an inventory of operator performance attributes to be aligned into quantitative metrics (29) (30)?
    - **By satisfying Task 2.1, a preliminary SOCOM Task List can enable a transition of human-in-the-loop performance metrics into HSI requirements. SOCOM-applicable rows from the UNTL were used as a starting point to generate a tactical task list based on the undersea, manned submersible OPs and EPs.**
- **RQ2.2:** How can SOCOM-related human-in-the-loop performance metrics help to further define the Human System Integration (HSI) requirements for an architectural model?

- **By satisfying Task 2.2, the SOCOM Task List were expanded to include an initial list of performance attributes by deriving PSFs, which were estimated and formulated into a P_{RTC} score for each task.**

The remaining RQ2 bulleted question is addressed in Chapter 8.0 Research Validation section, specifically in subsection 8.3.

CHAPTER 7.0 RESEARCH QUESTION 3

RTC PHASE 2

7.0 RTC Phase 2 [RQ3] Introduction

Chapter 7.0 is going to present the development and validation of RTC Phase 2 applied to a UUV platform. Summarized from the Research Questions and Tasks in Chapter 3.0, the RQ3 tasks include finding a suitable undersea system to be leveraged by SOCOM, constructing new parametric architectures with human-in-the-loop centered task modeling and generate a comprehensive set of human factors performance requirements and the overall quality and effectiveness of the P_{RTC} scoring and resulting performance requirements. Evaluation of RQ3 also takes place in Chapter 8.0, specifically in the RTC Phase 2 subsection.

7.1 Organization of SOCOM Tasks with PSF Assignment by Block Actor

As we begin the RTC Phase 2 process, we begin by selecting each task required by the UUV Operator, which is “dual hatted” as a Mission Specialist. Organizing and associating the tasks into the UUV system architecture with the actor block results in the following diagram with the P_{RTC} values applied as value properties:

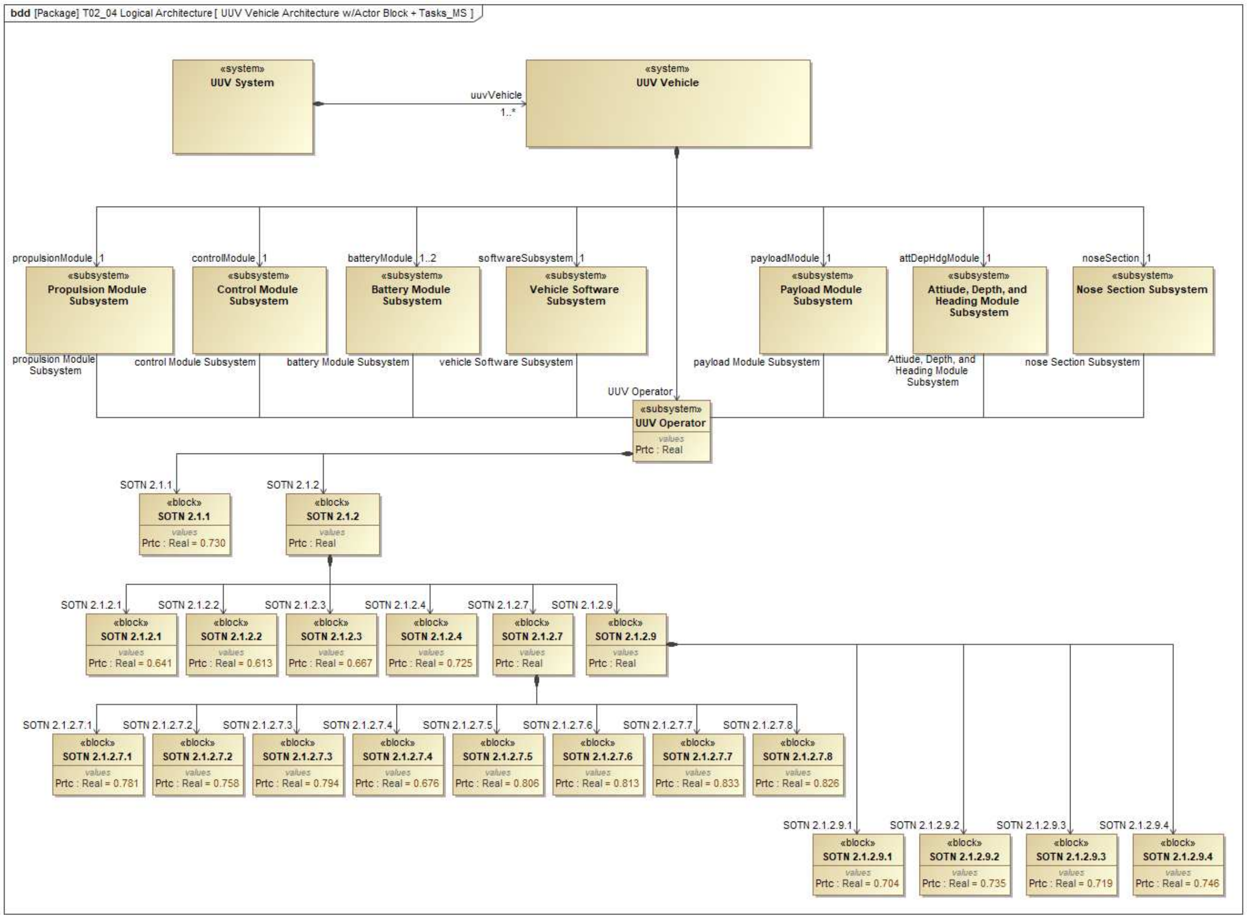

Figure 37: UUV System Architecture with Block Actor and Tasks

As the tasks beneath the UUV operator are labeled by their SOTN numbers, the bulleted list below translates each grouping of tasks categorically.

- SOTN 2.1.2.1 – 2.1.2.4: Mission specialist operating procedures
- SOTN 2.1.2.7.1 – 2.1.2.7.8: Mission specialist UUV operation tasks
- SOTN 2.1.2.9.1 – 2.1.2.9.4: Mission specialist emergency procedures

In submersible operations, the role of the MS is to conduct mission specific operations from the passenger compartment while the pilot and navigator focus on submersible operations in the crew compartment. With that, the MS would be designated as the UUV Operator with support from an additional MS since each diver requires a dive buddy for safety (37). Therefore, from this point forward, the terms UUV Operator and Mission Specialist are synonymous with each other.

With P_{RTC} values applied to each of the specific tasks that comprise of a UUV Operator working from a submersible, the next step is applying an aggregated equation to the blocks at the composite end of each association. Based on the above diagram, the four blocks include the UUV Operator, SOTN 2.1.2, SOTN 2.1.2.7, and SOTN 2.1.2.9. The next section will determine the aggregated P_{RTC} formula to insert as constraint values.

7.2 Transition of Task-Based BDDs into Aggregated Performance Metrics

In order to generate aggregated performance metrics, the architecture requires parametric diagrams to compute and aggregate each P_{RTC} value using an equation that accurately relates each task as well as the overall hierarchy structure. In understanding the task list developed for the UUV operator (as well as for all future operational roles to be added to the task list across all special operations), some characteristics desired for the equation to work effectively include the following:

- The more tasks applied at the same tier level is viewed as added complexity for the operator to understand and accomplish. Therefore, the equation must account for a progressively lower score as more tasks are assigned at the same tier level.
- As a grouping of tasks at the same tier level are aggregated to the next tier higher, a dedicated constraint block is utilized to calculate and aggregate the task group to the next tier level.

In researching a host of candidate equations, several provided a level of acceptability in its original form, or with slight edit. These equations include, but are not limited to the arithmetic mean, parallel resistance, exponential decay sum, and the reciprocal of the geometric mean (52) (53) (54). While in some instances, the equations listed in the previous sentence may support an aggregated effort, the formula that provided the foundation for building out the P_{RTC} aggregated values is the weighted harmonic average as listed below (52). This equation has shown to be useful when working with rates or ratios sensitive to outliers with smaller weights.

$$WHM = \frac{n}{\sum_{i=1}^{n} \frac{1}{x_i}} \tag{8}$$

Where,

WHM = Weighted Harmonic Mean

n = Number of Tasks

x_i = P_{RTC} Values

However, the only shortfall to the equation is it does not account for the first bullet mentioned above where the more tasks applied at the same tier level is viewed as added complexity for the operator to understand and accomplish. To remedy this, a +1 is added to the numerator, which lowers the score based on a greater number of parallel tasks required of the operator. This provides the following P_{RTC} Aggregated formula.

$$P_{RTC}\ Aggregated = \frac{n+1}{\sum_{i=1}^{n}\frac{1}{x_i}} \tag{9}$$

Where,

P_{RTC} Aggregated = Aggregated Performance Values / Fully realized tasks

Based on the extreme circumstances of the P_{RTC} Aggregated formula, the maximum lower limit would be greater than 0.00 and the maximum upper limit would be 2.00 or less. While continued application is recommended to prove out acceptable limits, an initial, preferential result would be a P_{RTC} aggregated value of 1.00 or higher, with an initial, acceptable range of 0.80 to 1.00.

With the P_{RTC} Aggregated formula developed, incorporating it into the model is then done using the Python programming language as provided by Cameo Systems Modeler. The advantage of using Python is its emphasis on readability and ease of use across many applications. The figure below shows the P_{RTC} Aggregated formula translated into Python to be used to compute SOTN 2.1.2.9 from SOTN 2.1.2.9.1, 2.1.2.9.2, 2.1.2.9.3, and 2.1.2.9.4. This is provided in the blue, constraint block in the middle of the figure.

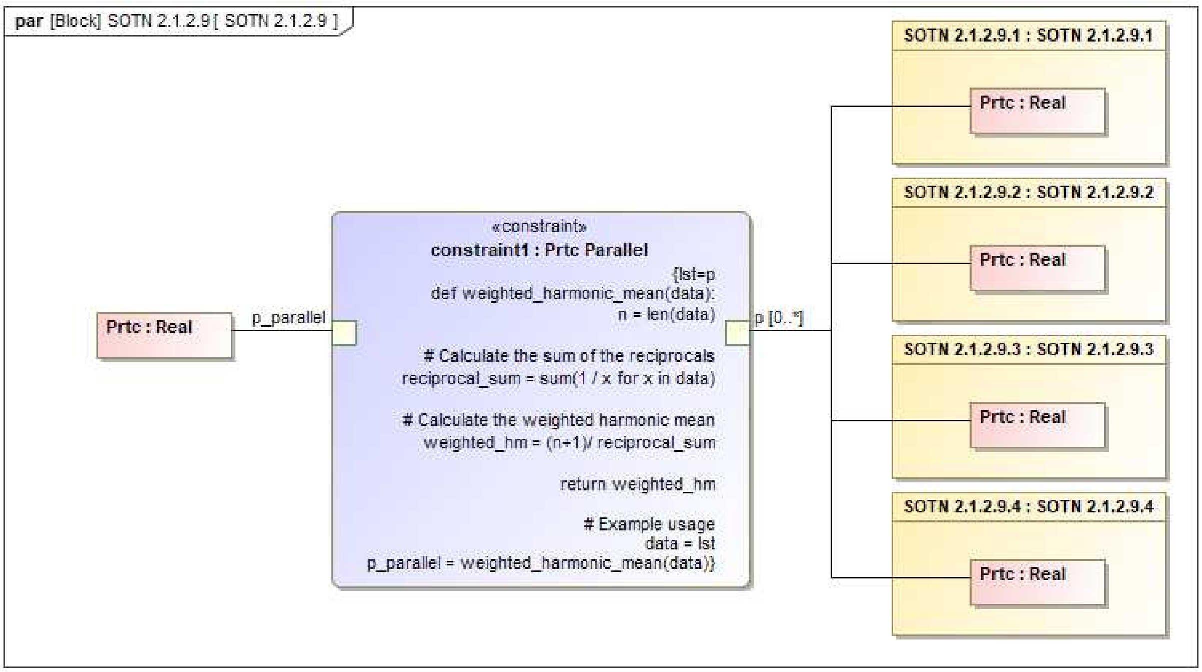

Figure 38: P_{RTC} Aggregated Formula in Python for SOTN 2.1.2.9

Taking this one step further, the next diagram shows the P_{RTC} Aggregated formula solved for SOTN 2.1.2.9 aggregated EP task along with each P_{RTC} value solved from the 10 PSFs for the four EPs taken from the SOCOM Task List.

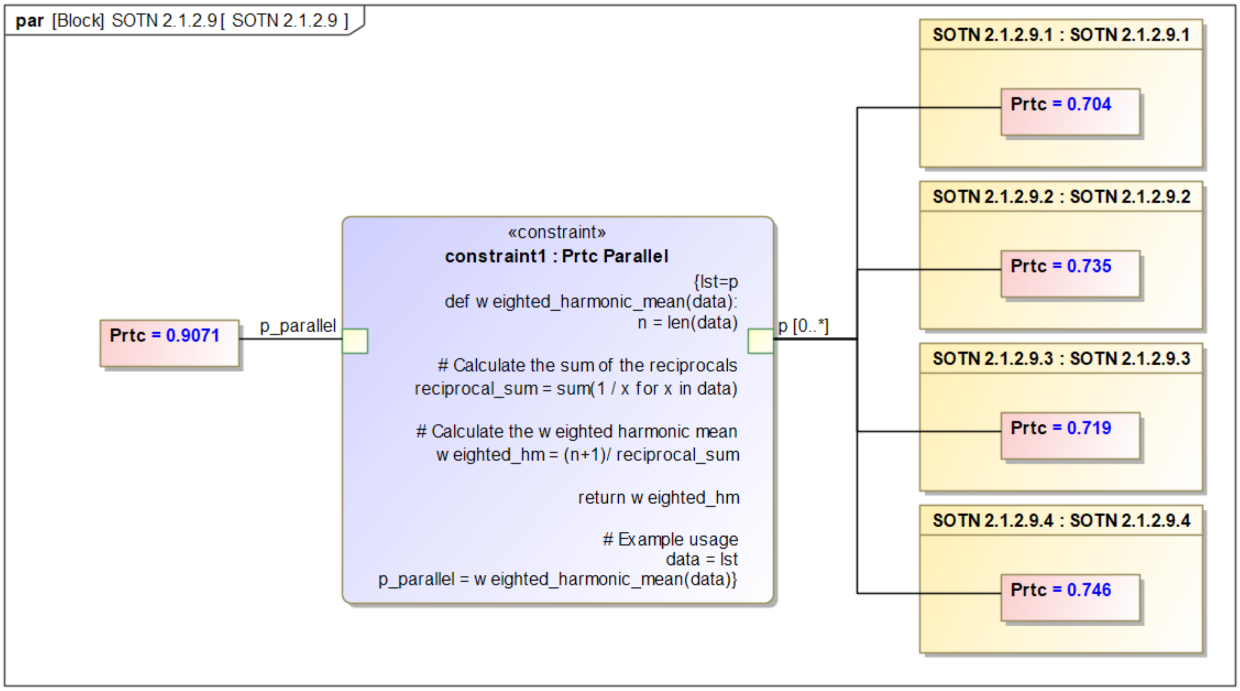

Figure 39: P_{RTC} Aggregated Formula in Python for SOTN 2.1.2.9 [Computed with Simulation Toolkit]

The SOTN 2.1.2.9 value of 0.9071 will then be verified where every P_{RTC} value and P_{RTC} aggregated value are solved for the UUV Operator. The UUV architecture with the block actor and tasks is revisited to show the addition of the constraint block used to solve for each P_{RTC} aggregated value and the application of the constraint block to the UUV Operator, SOTN 2.1.2, SOTN 2.1.2.7, and SOTN 2.1.2.9.

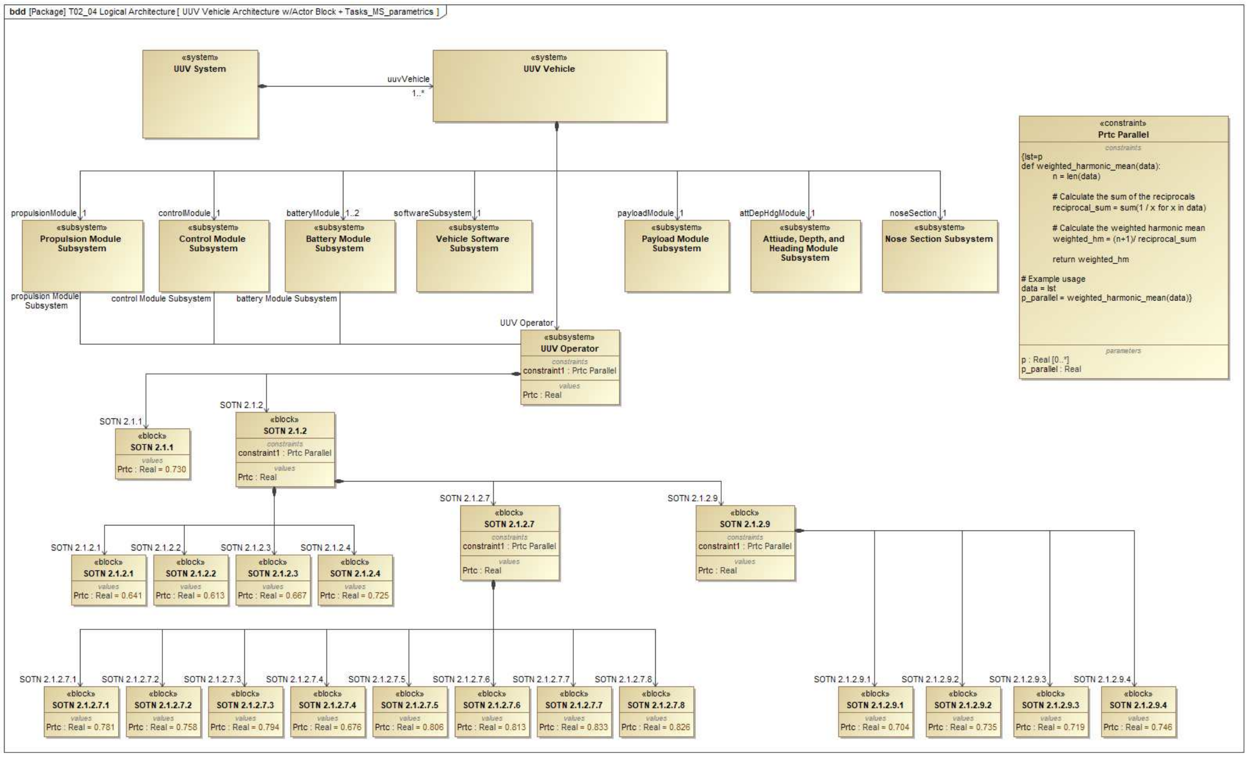

Figure 40: UUV System Architecture with Block Actor and Task Hierarchy with P_{RTC} Parallel Constraint Block Applied

Looking at it from the parametric perspective, the internal blocks, values, and connections that result in a P_{RTC} aggregated value for the UUV Operator are provided in the figure below.

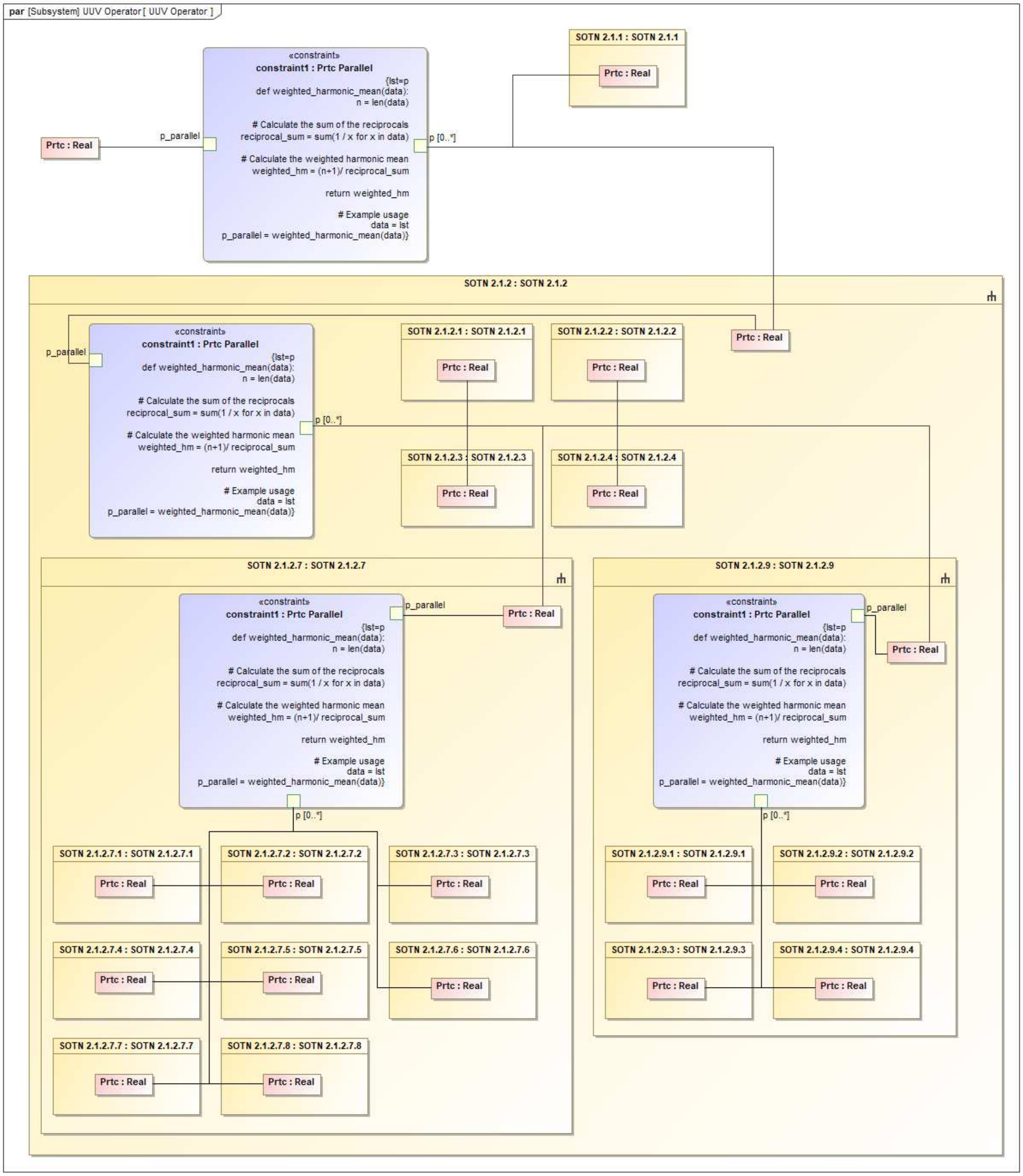

Figure 41: P_{RTC} Aggregated Diagram for the UUV Operator

In using the Cameo Systems Modeler Simulation Toolkit plugin, the above diagram can be computed for each P_{RTC}: Real value as demonstrated in the equivalent figure below.

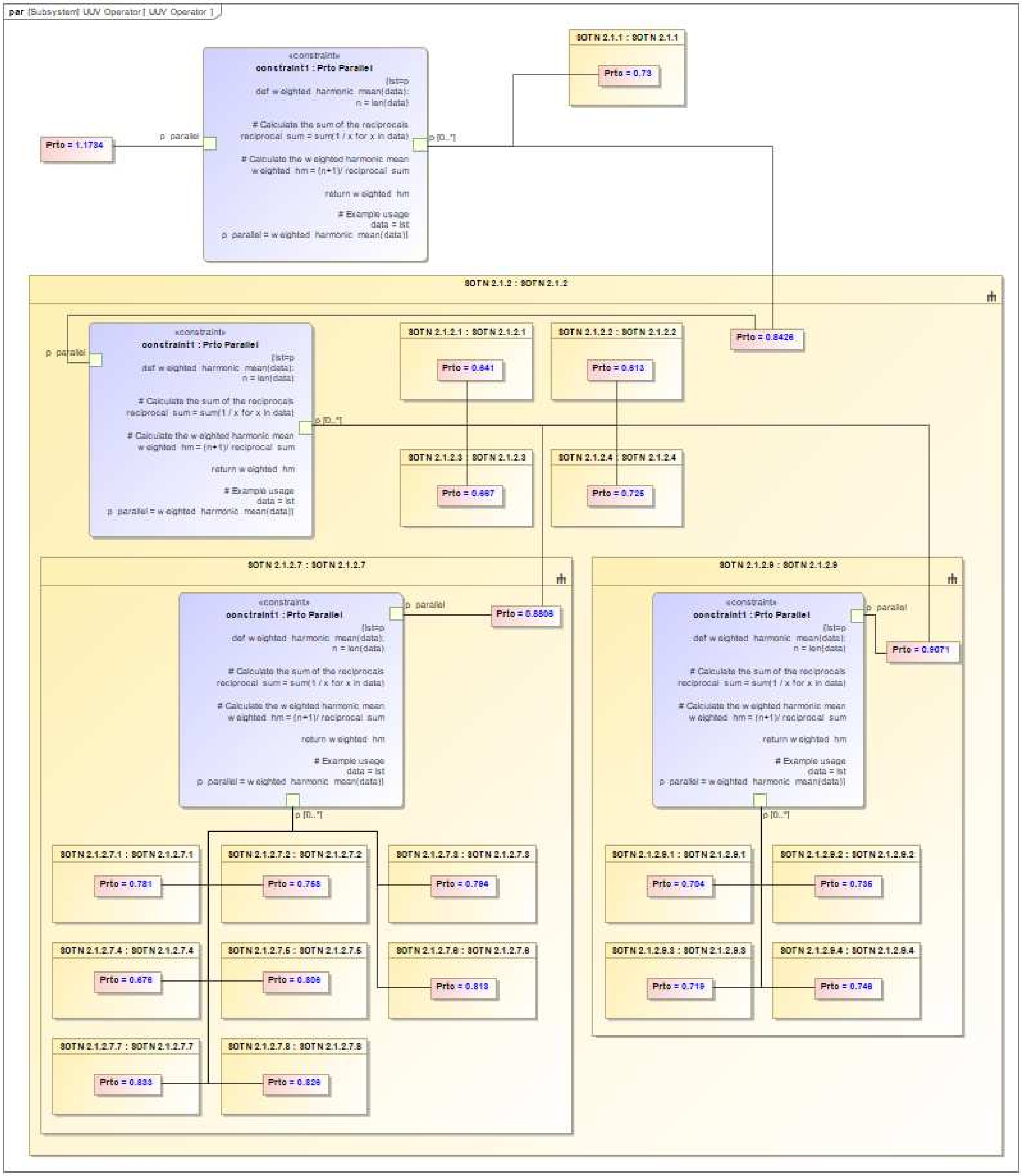

Figure 42: PRTC Aggregated Diagram for the UUV Operator [Computed with Simulation Toolkit]

From strictly a Simulation Toolkit output perspective, the figure below provides the same general information, but has the SOTN 2.1.2.9 expanded to verify the 0.9071 P_{RTC}: Real value captured in the P_{RTC} Aggregated Formula in Python for SOTN 2.1.2.9 figure, which is emphasized in the red box.

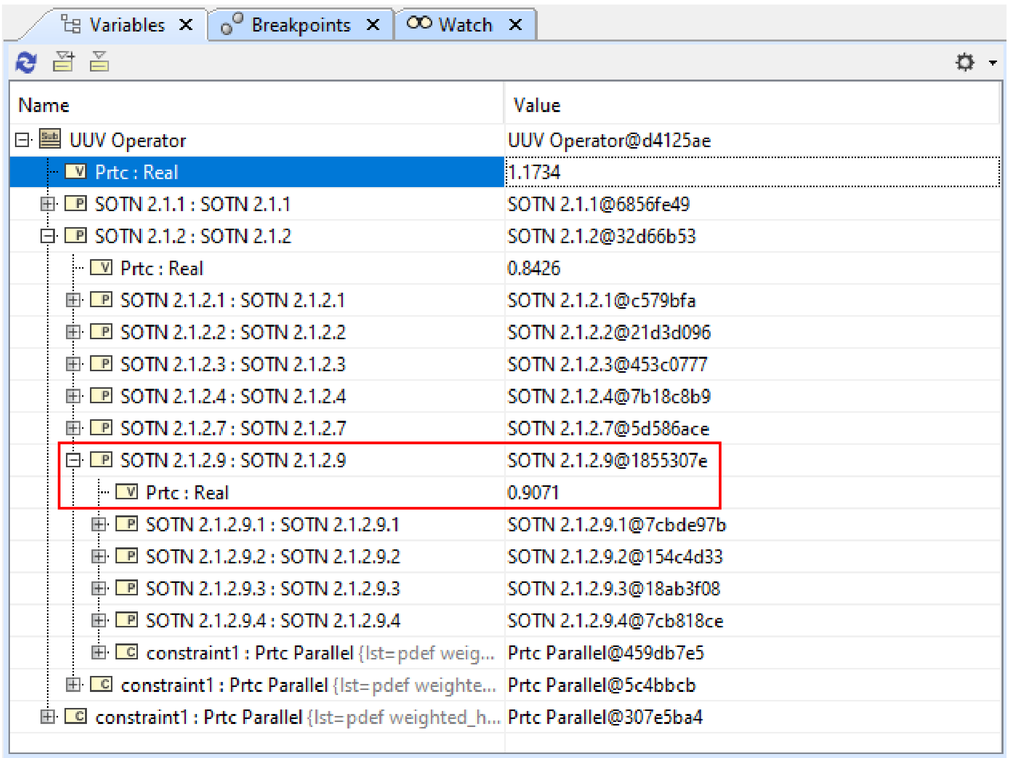

Figure 43: P_{RTC} Aggregated Output Computed with Simulation Toolkit

As mentioned above, the UUV Operator P_{RTC} Aggregated value of 1.1734 is a preferential result. The EPs required by the UUV Operator, and the OPs required by the UUV are 0.9071 and 0.8808, respectively, which represents acceptable results. From a system design standpoint, this may limit the engineering considerations as all three values are viewed as satisfactory.

With the UUV Operator P_{RTC} performance values revealed in both the parametric diagram and the simulation toolkit results above, and by referencing existing UUV system requirements for pertinent and consistent wording formats per the characteristics of sets of requirements as outlined and described in the INCOSE Guide to Writing Requirements and the Needs and Requirements Manual, the following new set of performance requirements can be generated into the model (45) (46) (47). These requirements are provided in section 7.3 and are to be added into the SRS in the appropriate section.

7.3 Translation of Task-Based BDDs into HSI Requirements

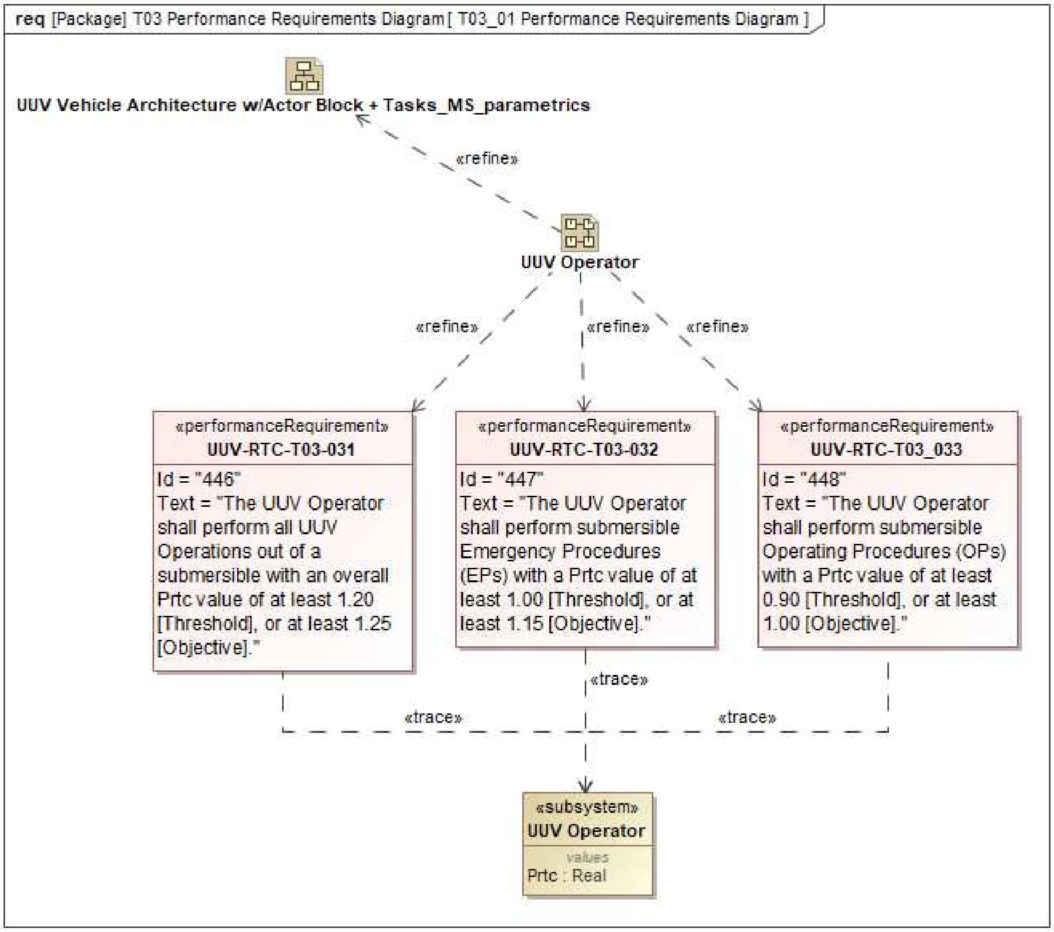

Figure 44: Trace Relationship between UUV Operator and New P_{RTC} Performance Requirements

Based on the process from section 7.1 and 7.2, the above requirements diagram is generated in support of the P_{RTC} aggregated performance values. The UUV Operator parametric diagram developed by the human factors engineer create a refine relationship to both the BDD and the three requirements in the middle of the diagram. The bulleted list below represents the rationale behind the human factors engineer for generating each performance requirement. While this rationale is not all inclusive, it does provide justification behind the use of parametrics, the PSFs within the SO task list, and resulting requirement statements.

- UUV-RTC-T03-031 HFE rationale: With an initial P_{RTC} aggregated performance value of 1.1734, the UUV Operator threshold represents an achievable and flexible consideration or set of considerations in system design in order to improve to a 1.20 P_{RTC} value. The minimum objective of 1.25 provides a less achievable option for system design.
- UUV-RTC-T03-032 HFE rationale: With an initial P_{RTC} aggregated performance value of 0.9071 for emergency procedures, the UUV Operator threshold represents an achievable and flexible consideration or set of considerations in system safety design in order to improve to a 1.00 P_{RTC} value. The minimum objective of 1.15 provides a less achievable option for system safety design.
- UUV-RTC-T03-033 HFE rationale: With an initial P_{RTC} aggregated performance value of 0.8808 for UUV operating procedures, the UUV Operator threshold represents an achievable and flexible consideration or set of considerations in system design in order to improve to a 0.90 P_{RTC} value. The minimum objective of 1.00 provides a less achievable option for system design.

As seen in Chapter 5.0, the requirements are then traced to the UUV Operator. This allocation relationship was specifically selected based on the dependency relationship. While a weak relationship when compared to other requirement relationships such as refine or satisfy, a trace relationship can highlight downstream impact analysis (22) (1). As mentioned in Chapter 5.0, if the UUV Operator's responsibility were to adjust in the undersea domain, this may have an impact on the wording, or overall need of the set of performance requirements.

7.4 RTC Phase 2 [RQ3] Conclusion

In utilizing the human-in-the-loop architecture from Chapter 5.0, Chapter 7.0 proceeded through Phase 2 of the RTC beginning with the organization of SOCOM tasks with PSF constraint assignment by block actor into the model based on the UUV used throughout this research. The next subsection focused on transition of task-based BDDs into aggregated performance parametrics. Once the P_{RTC} values were aggregated up to the block actor, each aggregated P_{RTC} score from the task-based BDDs was translated into HSI performance requirements in the last subsection of Chapter 7.0.

In revisiting Research Question 3, the following RQ3 bulleted question is restated below with a validation response:

- **RQ3.1:** Utilizing a human-in-the-loop centered modeling architecture from RQ1 and the task list performance metrics from RQ2, does combining these into a parametric architecture to address human-in-the-loop performance requirements improve how SOCOM executes on acquisition programs?
    - **By initiating Task 3.1, an MBSE architecture has been constructed that includes the structure from RQ1 combined with the UUV Operator tasks from RQ2. Based on the formation of the tasks and the UUV Operator within the architecture, a constraint equation is utilized to properly convey the overall block actor PSF value to be traced to HSI performance requirements.**

The remaining RQ3 bulleted question is addressed in Chapter 8.0 Research Validation section, specifically in subsection 8.4.

CHAPTER 8.0 RESEARCH VALIDATION

With each research question chapter completed, this section will support the validation of the applied and clinical research steps. This will consist of both quantitative and qualitative findings broken up within an evaluation survey along with informal input taken during survey presentations.

8.1 Research Survey

The primary validation of each research question comes from a survey conducted on seven subject matter experts. As approved by the CSU Institutional Review Board (IRB), this survey with USSOCOM experts inquires to understand how well a human-centered approach using MBSE can create HSI requirements for USSOCOM system development. The survey is divided into survey question sections from the three research questions from this dissertation. The format of the survey was to present each research subject with four or five survey questions for each research question with three general survey questions for the overall dissertation for 5 to 10 research subjects. The specific breakout of the survey questions is listed in the following bullets:

- 17 research questions total (55) (56) (57)
    - 5 Likert scale survey questions for RQ1 (1-9 scale)
    - 4 Likert scale survey questions for RQ2 (1-9 scale)
    - 4 Likert scale survey questions for RQ3 (1-9 scale)
    - 3 fillable survey questions for the overall research

Each of the 13 survey questions include a Likert scale ranging from one to nine, with one labeled as "Strongly Disagree" and nine labeled as "Strongly Agree." Along with five being labeled as "Neutral," the Likert scale is provided in a slider visualization format where the research subject can click and drag on the slider tab to the appropriate whole number. The Likert scale and slider does not allow for fractional numbers such as 4.5 or 7.75.

Based on the SOCOM target community and the topic areas, the qualifications of the research subjects were an engineering professional or an operational SME in SOCOM acquisition industry. To qualify the research subjects, the following SOCOM acquisition roles or job titles were captured for each research subject based on the question listed at the top row of the table below:

Table 10: Job Titles for SOCOM Research Subjects

Job Title - Please list your title as it applies to your profession or expertise within the USSOCOM acquisition industry.
Submersible Test Pilot and SOCOM SME
Executive Director
Industry Representative. Capability Development and Delivery, Maritime and Defense Systems
Director of Business Development for Special Operations
Capability Development and Delivery, Maritime Systems
SOCOM SME and Test Engineer
Technical Director, PMS340 (Naval Special Warfare)

Each job title provided a clear indication as to the professional relevance of each research subject with some indicators toward SOCOM involvement. To further qualify each research subject as a qualified SOCOM professional, a second multiple selection question was included to check among four key areas of additional experience beyond a job title:

Table 11: Additional Experience for SOCOM Research Subjects

Additional Exp. - Please select any additional experience as it applies to USSOCOM or USSOCOM acquisition industry.	Number of responses
Current or Former USSOCOM Operator	**7**
Current or Former Engineer	**2**
Current or Former USSOCOM Subject Matter Expert (Air Operations, **Submersible**s, etc.)	**7**
Current or Former USSOCOM Executive (Military, Government, Industry, etc.)	**2**

Based on the count of each selectable option, each of the seven research subjects served as a current or former SOCOM operator and was a SME. While less common, two subjects also performed as an engineer and two subjects considered themselves to be a SOCOM executive at some point in their career. Given the low number of research subjects sampled and the lack of distinct survey groups, the statistical method and data analysis used for all research questions consisted of mean and standard deviation values (58) (59). With the survey purpose, format, and subject selection described, the first research question involves the creation of a human-system model to derive a set of HSI requirement statements to support system development through functional relationships.

8.2 Research Question 1 Validation [RTC Phase 1]

Based on the scores of each research subject on the first five survey questions, the following figure provides the mean and standard deviation results from the survey questions for research question 1. The table containing the raw data for each of the survey questions can be found in Appendix A.

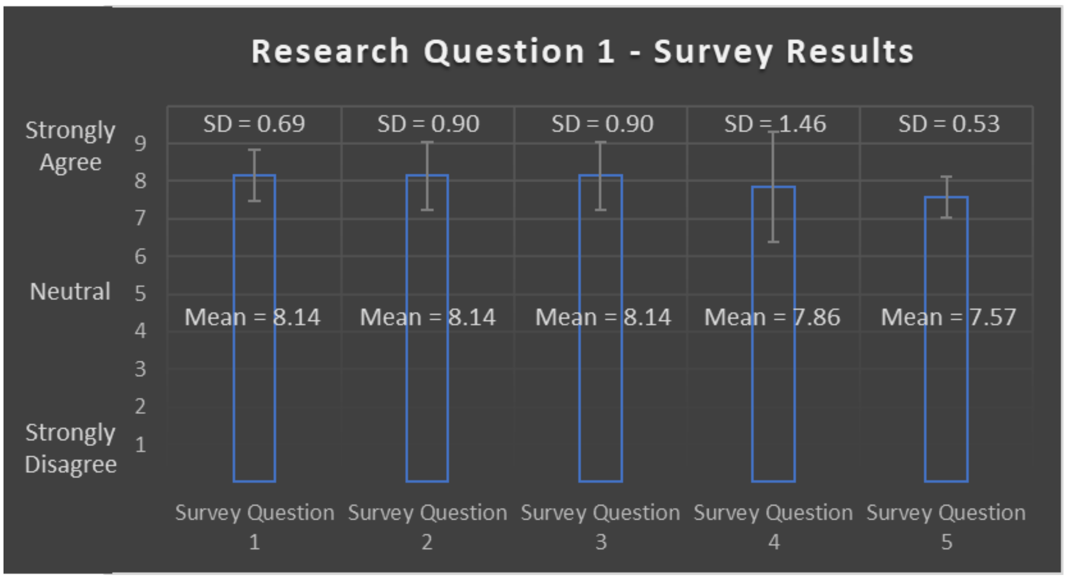

Figure 45: Survey Mean and Standard Deviation for Research Question 1

Based on this graph, the following paragraphs provide a summary analysis based on each survey question.

Survey Question 1: Can modeling behavioral diagrams, showing the operators functioning with a subsystem, provide an improved understanding of operator needs with system interfaces?

The survey results indicate a highly positive consensus regarding the efficacy of using behavioral diagrams to enhance the understanding of operator needs with system interfaces. With a mean score of 8.14 out of 9 and a low standard deviation of 0.69, the responses from the seven survey subjects suggest a strong agreement and consistency in their perceptions. This high mean score implies that respondents generally believe that modeling behavioral diagrams is significantly beneficial for comprehending operator interactions with subsystems, reflecting an endorsement of this approach.

Survey Question 2: Can new functional requirements, based on behavioral diagrams demonstrating operators functioning with a subsystem, provide improved operator interfaces for existing and future systems (beyond commonly used HSI requirements)?

The survey results for the second question reveal a similarly positive outlook on the value of new functional requirements derived from behavioral diagrams, with a mean score of 8.14 out of 9 and a standard deviation of 0.90 based on responses from seven subjects. This mean score indicates that respondents strongly believe in the potential of these new requirements to enhance operator interfaces for both current and future systems beyond common HSI requirements. Compared to the previous survey results, the mean value remains unchanged at 8.14, demonstrating consistent approval of the approach. However, the slightly higher standard deviation of 0.90 suggests a marginally greater variability in opinions on this particular aspect.

Survey Question 3: Does modeling the operators, as an operator subsystem, support a better USSOCOM representation of human systems integration (versus modeling the system with the operator removed)?

The survey results for the question about modeling operators as an operator subsystem to support a better USSOCOM representation of HSI are highly positive, with a mean value of 8.14 out of 9 and a standard deviation of 0.90, based on seven respondents. This suggests a strong belief among the participants that including operators as part of the subsystem significantly enhances the representation of HSI compared to models that exclude the operator. Compared to the previous survey results, the mean value remains consistently high at 8.14, indicating ongoing strong approval of Research Question 1. The standard deviation of 0.90, which is the same as in the previous survey, indicates a similar level of variability in responses, reflecting a shared yet slightly varied perspective.

Survey Question 4: Does the RTC Phase 1 methodology encourage the use of Model Based Systems Engineering (MBSE) for existing and future USSOCOM programs of record (over Document Based Systems Engineering (DBSE))?

The survey results for the question on whether the RTC Phase 1 methodology encourages the use of MBSE over DBSE show a positive, yet slightly less enthusiastic, response as the previous questions. With a mean value of 7.86 out of 9 and a higher standard deviation of 1.46 based on the seven responses, the data indicate a general agreement that RTC Phase 1 promotes MBSE, though there is more variability in opinions compared to previous questions. When compared to the prior survey results with mean values consistently at 8.14 and lower standard deviations, this question shows a slightly lower average approval and greater divergence in views. One consideration is the limited number of current or former engineers based on the additional experience question.

Survey Question 5: Does the RTC Phase 1 methodology encourage an improved process for human factors engineers for existing and future USSOCOM programs of record (over the current use of human factors engineers on programs)?

The survey results regarding the RTC Phase 1 methodology's impact on improving the process for human factors engineers in existing and future USSOCOM programs of record are notably positive, with a mean score of 7.57 out of 9 and a standard deviation of 0.53, based on the seven respondents. As with the previous MBSE question, this suggests the research subjects generally agree that RTC Phase 1 offers an improved process. The low standard deviation indicates a high level of consensus among research subjects. Compared to the prior results, where mean scores were 8.14 with higher variability in some cases, this question reflects a moderately positive yet slightly less enthusiastic response, but with more uniformity.

With all of the research subjects holding backgrounds as both SOCOM servicemembers and SOCOM SMEs, the results of the survey questions for RQ1 may present alignment with each subject's professional background. As RQ1 is centered on RTC Phase 1, the fundamental understanding of inserting the end user as part of the system architecture was viewed as one of the strongest positives for this research by all subjects. As only two of the seven research subjects had a background in engineering, the process of converting the architecture into various behavioral diagrams came across as difficult to understand by most subjects and perceived less enthusiastically. One way to simplify this for SOCOM representatives is to stick with a single behavioral diagram to build out all functional flows into HSI requirements.

In revisiting Research Question 1, the following RQ1 bulleted question is restated below with a validation response:

- **RQ1.3:** How can the characteristics of a human-in-the-loop centered model and resulting functional requirements be validated for SOCOM acquisition?

By initiating Task 1.3 and conducting an IRB survey, RQ1 (RTC Phase 1) stands out with the highest mean value of 7.97 out of 9, when compared to RQ2 and RQ3, as well as a standard deviation of 0.92, indicating the strongest agreement and moderate variability. In surveying SOCOM engineering or SME professionals, evaluation of the quality and effectiveness of the human-in-the-loop model and resulting functional requirements was accomplished per Task 1.3.

8.3 Research Question 2 Validation [SOCOM Task List]

The primary validation of research question 2 comes from an IRB-approved survey conducted on seven research subjects, which is introduced and described in detail in section 8.1. Stated directly from the IRB summary, the second research question explores the formation of a USSOCOM Task List similar to those used by the Air Force and Navy to organize and catalog human tasks. Based on the scores of each research subject on the next four survey questions, the following figure provides the mean and standard deviation results from the survey questions for research question 2. The table containing the raw data for each of the survey questions can be found in Appendix A.

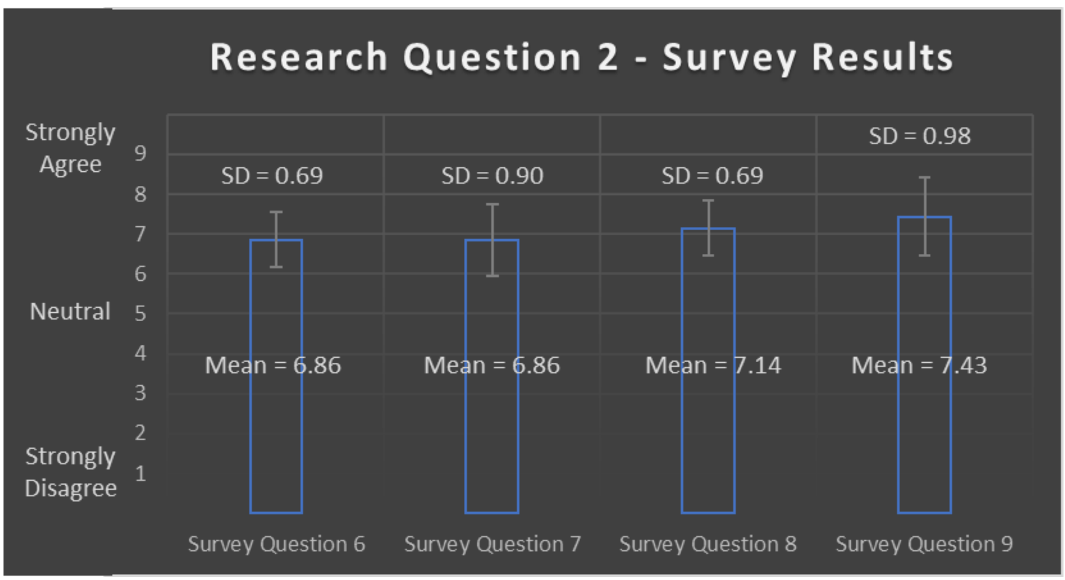

Figure 46: Survey Mean and Standard Deviation for Research Question 2

Based on this graph, the following paragraphs provide a summary analysis based on each survey question.

Survey Question 6: Does a consolidated task list database of Operating Procedures (OPs) and Emergency Procedures (EPs) for all communities within USSOCOM assist with tactical collaboration across operational commands with similar task and procedural capabilities?

The survey results for the OPs and EPs collaboration question reveal a moderately positive outlook. The mean score is 6.86 out of 9, indicating a general agreement that such a database would be beneficial, although not overwhelmingly so. The standard deviation of 0.69 suggests a relatively consistent view among research subjects, with only moderate variability in their opinions. Compared to higher mean values (7.57 to 8.14) from research question 1, this lower mean score indicates a less enthusiastic response, though favorable towards the idea of a consolidated task list database within USSOCOM.

Survey Question 7: Does a consolidated task list database of OPs and EPs for all communities within USSOCOM assist with collaboration across USSOCOM acquisition programs?

The survey results for the OPs and EPs acquisition program question show a moderately positive response, with a mean value of 6.86 out of 9 and a standard deviation of 0.90 based on seven research subjects. While not as strong as research question 1 averages, this mean score indicates a general agreement that such a database would aid in collaboration. The standard deviation of 0.90 reveals a slightly higher variability in opinions compared to the previous survey question's standard deviation of 0.69, suggesting a more diverse set of views on this question. While the mean value remains the same at 6.86 in both a tactical collaboration and acquisition programs context, the greater standard deviation in this instance may points to less familiarity with the defense acquisition domain as compared to the operational command domain with respect to the research subjects.

Survey Question 8: Can a P_{RTC} value, based on Performance Shaping Factors (PSF), align with mission-related tasks to quantify and measure future system design considerations and improvements?

The survey results for the P_{RTC} value and PSF task question are an improvement within research question 2. With a mean value of 7.14 out of 9 and a standard deviation of 0.69 based on the seven research subjects, the results indicate a strong agreement that the use of P_{RTC} values is beneficial for system design considerations. The mean score is slightly higher than the previous two questions about the OPs and EPs, which both had a mean of 6.86. The consistent standard deviation of 0.69 suggests a uniformity in responses, indicating a favorable view toward using P_{RTC} values for aligning with mission-related tasks to enhance system design and improvements.

Survey Question 9: Can a P_{RTC} value, based on Performance Shaping Factors (PSF), provide valuable insight into individual PSF questions and resulting scores for future system design considerations and improvements?

The survey results for the individual PSF questions and resulting scores question are highly favorable. With a mean score of 7.42 out of 9 and a standard deviation of 0.98 based on the seven research subjects, the results indicate a strong agreement on the value of P_{RTC} for this purpose, but with slightly more variability in opinions. This mean score is higher than the previous three survey questions, suggesting greater confidence in the utility of each PSF within an OP or EP. The higher standard deviation of 0.98 implies a broader range of views among respondents, indicating some differences in the perceived effectiveness of leveraging each PSF for design considerations and improvements.

Along with the quantitative results above, there are a few qualitative results focused directly on research question 2 with the raw feedback from the last three survey questions provided in Appendix B. From a positive perspective, one research subject mentions the task management enhancements and the ability to estimate future manpower and skill requirements as well as the limits of human performance & task saturation. These statements all stem from the PSFs and follow on P_{RTC} values. From a negative perspective, one research subject had concerns of push back from different branches/units on consolidating OPs and EPs as commanders and military leaders may not want to lose control of risk mitigation and acceptance by grouping with other branches/units. Another research subject had doubts on the potential for extreme scope and costs required to generate PSF scoring across all OPs and EPs, which can still result in subjectiveness in P_{RTC} values. As all of the research subjects are familiar with the larger SOCOM infrastructure, the ability to collaborate across SOCOM branches of service and programs is considered difficult by most subjects due to the existing division with each branch. This is seen as a negative and would require a further scope as a dedicated RTC representative or office is likely needed to both generate stronger branch-to-branch relationships while further developing the SOCOM Task List.

In revisiting Research Question 2, the following RQ2 bulleted question is restated below with a validation response:

- **RQ2.3:** How can the characteristics of a SOCOM Task List be validated for SOCOM acquisition?

By conducting an IRB survey of SOCOM engineering or SME professionals, evaluation of the SOCOM Task List for collaboration potential and system design considerations was accomplished per Task 2.3. While an accomplishment, RQ2 (SOCOM

Task List) has the lowest mean value of 7.07 out of 9, when compared to RQ1 and RQ3, with a standard deviation of 0.81, reflecting a positive but less enthusiastic response and slightly less variability, indicating a more uniform level of lesser agreement.

8.4 Research Question 3 Validation [RTC Phase 2]

The primary validation of research question 3comes from an IRB-approved survey conducted on seven research subjects, which is introduced and described in detail in section 8.1. Stated directly from the IRB summary, the third research question derives a set of HSI requirement statements for modern USSOCOM systems through performance calculations and validates them against existing HSI requirements. Based on the scores of each research subject on the next four survey questions, the following figure provides the mean and standard deviation results from the survey questions for research question 3. The table containing the raw data for each of the survey questions can be found in Appendix A.

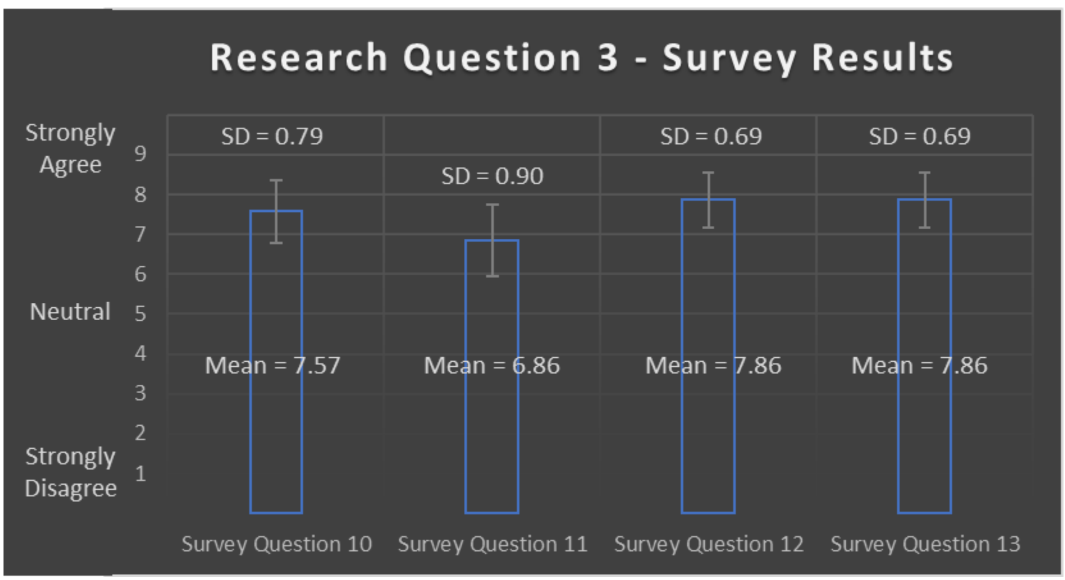

Figure 47: Survey Mean and Standard Deviation for Research Question 3

Based on this graph, the following paragraphs provide a summary analysis based on each survey question.

Survey Question 10: Can modeling parametric diagrams, showing the operators represented as OPs and EPs, provide an improved understanding of operator workload with system interfaces?

The survey results for the improved understanding using OPs and EPs question indicate a positive response. The mean score is 7.57 out of 9, based on the seven subjects, suggesting that participants generally agree that this approach is beneficial for operator representation. The standard deviation of 0.79 implies a relatively consistent viewpoint among the respondents, with moderate variability. Overall, the results suggest that respondents see value in using parametric diagrams to enhance the understanding of operator workload in relation to system interfaces.

Survey Question 11: Can new performance requirements, based on parametric diagrams demonstrating operators represented as OPs and EPs, provide improved operator interfaces for existing and future systems (beyond commonly used HSI requirements)?

The survey results for the new performance requirements question are moderately positive. The mean value is 6.86 out of 9, with a standard deviation of 0.90, indicates general agreement but with some variability in opinions. Compared to the previous question, which had a mean of 7.57 and a standard deviation of 0.79, these results suggest a slightly lower and more varied level of enthusiasm for the potential of improved operator interfaces. This indicates that while the research subjects see value in the approach, they are less convinced of its impact compared to understanding operator workload with system interfaces by modeling with parametric diagrams.

Survey Question 12: Does the RTC Phase 2 methodology encourage the use of Model Based Systems Engineering (MBSE) for existing and future USSOCOM programs of record (over Document Based Systems Engineering (DBSE))?

Similar to the question in research question 1, the survey results on whether the RTC Phase 2 methodology encourages the use of MBSE over DBSE show an equivalent response. The mean value of 7.86 out of 9, with a standard deviation of 0.69 based on the seven responses, indicating a high level of agreement with minimal variability. Compared to question 4 from research question 1, this lower standard deviation may suggest the use of an advanced parametric diagram versus a more foundational block definition diagram could provide added effectiveness in promoting MBSE. The lower standard deviation further reflects a consistent viewpoint among the research subjects, highlighting a solid consensus on the value of MBSE for USSOCOM programs facilitated by the RTC Phase 2 methodology.

Survey Question 13: Does the RTC Phase 2 methodology encourage an improved process for human factors engineers for existing and future USSOCOM programs of record (over the current use of human factors engineers on programs)?

Also similar to research question 1, the survey results on whether the RTC Phase 2 methodology encourages an improved process for human factors engineers show a similar positive response, with a mean value of 7.86 out of 9 and a standard deviation of 0.69. This indicates a high level of agreement that the RTC Phase 2 methodology enhances the process for human factors engineers, with minimal variability in opinions. Compared to question 5 of research question 1, this mean score is slightly higher than the score of 7.57 from research question 1, which had a mean of 7.86, reflecting consistent support for the RTC Phase 2 methodology toward human factors. Conversely, the standard deviation shows slightly more variability than question 5 of research question 1, which had an SD of 0.53, demonstrating a strong overall consensus for both RTC Phase 1 and RTC Phase 2. Overall, the research subjects perceive the phases to be particularly beneficial toward human factors engineers.

Along with the quantitative results above, there are a few qualitative results focused directly on research question 3 with the raw feedback from the last three survey questions provided in Appendix B. From a positive perspective, one research subject mentions an additional use case where P_{RTC} scores could support SOCOM manpower decisions at a macro level (e.g. force-wide cut by 10%) by realizing which systems require more operators or incur a low P_{RTC} to perform tasks simply by reviewing the SOCOM Task List or parametric output. A second research subject highlights the complementary potential with other SOCOM support applications. Specifically, the subject calls out a Joint Medical Planning Toolkit, which could provide additional PSF data toward the OP portion of the task list and the overall P_{RTC} valuation. From a negative perspective, one research subject sees limited value in retroactive performance analysis on existing systems, unless it is strictly for the purpose of identifying candidate systems for replacement. The subject further explains how a retroactive system analysis would likely be an out-of-scope effort from a contractual standpoint, and any alterations would rarely be cost effective. Through continued informal discussion with SMEs, an unknown to be considered for RQ3 is the validation of the P_{RTC} formula. While the architecture of the SOCOM Task List into the model was regarded with positive feedback, ensuring the aggregated P_{RTC} values are "providing the right numbers" for use toward a system of interest is of importance. This would require an evaluation from a mathematics expert for both P_{RTC} validation as well as any recommendations for improvement.

In revisiting Research Question 3, the following RQ3 bulleted question is restated below with a validation response:

- **RQ3.2:** How can the characteristics of a parametric architecture and resulting performance requirements be validated for SOCOM acquisition?

By initiating Task 3.2 and conducting an IRB survey, RQ3 (RTC Phase 2) falls between the other two questions with a mean value of 7.53 out of 9, when compared to RQ1 and RQ2, and a standard deviation of 0.84, showing a generally favorable view with moderate consistency among respondents. Evaluation of the quality and effectiveness of the P_{RTC} scoring and resulting performance requirements was accomplished per Task 3.2.

8.5 RTC Summary

With each phase of the RTC demonstrated and assessed, an overall assessment based on the quantitative comparison of research question survey results as well as qualitative feedback is delivered in this section. Beginning with the survey results, the following figure provides the mean and standard deviation results from all survey questions for research questions 1, 2, and 3. The table containing the raw data for each of the survey questions can be found in Appendix A.

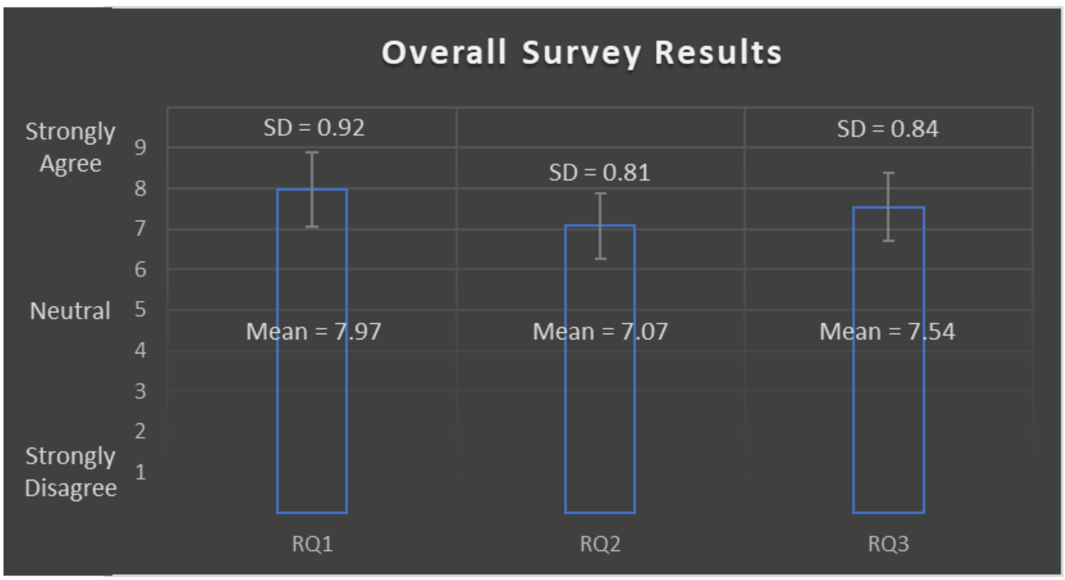

Figure 48: Survey Mean and Standard Deviation for All Research Questions

The comparative analysis of the survey results for the three research questions reveals differences in the levels of agreement and variability among the seven research subjects. Research Question 1 stands out with the highest mean value of 7.97 out of 9 and a standard deviation of 0.92, indicating the strongest agreement and moderate variability. This suggests that subjects are most confident and comfortable about the aspects covered in Research Question 1. In contrast, Research Question 2 has the lowest mean value of 7.07 out of 9 with a standard deviation of 0.81, reflecting a positive but less enthusiastic response and slightly less variability, indicating a more uniform level of lesser agreement. As covered in the comparative evaluation section in Chapter 6.0, the comments on consolidation of OPs and EPs along with the high scope and cost potential for SOCOM-wide implementation provide direct justification for the lower mean score. Research Question 3, with a mean value of 7.53 out of 9 and a standard deviation of 0.84, falls between the other two questions, showing a generally favorable view with moderate consistency among respondents. While the RTC Phase 2 process and performance requirements output from research question 3 is more straight forward than the SOCOM Task List process and output from research question 2, it likely is not as foundationally understood as the RTC Phase 1 process and functional requirements output from research question 1. Overall, while all questions received positive responses, the strength of agreement and the consistency of opinions are highest for Research Question 1 and lowest for Research Question 2, with Research Question 3 showing intermediate levels.

The overall qualitative survey results were based on research subject comments that had an all-encompassing, generic context that did not specifically point to any one of the research questions. These were captured in both the survey itself on questions 15, 16, and 17 with the raw feedback from these questions provided in Appendix B, as well as informal notes taken during each of the survey sessions. Only minor edits were made to each research subjects' qualitative feedback to assist with clarity.

Survey Question 15: Do you foresee any critical flaws or setbacks with implementing the RTC on programs throughout USSOCOM (examples: added cost, added scope, resource constraints, etc.)?

Research Subject 1 states establishing a baseline understanding of the RTC with the workforce will be challenging. Although the research project drives towards a more objective construct, there are some concerns with addressing the "subjective." While unethical, I wonder if a PM might "game" the system within the fairly subjective nature of HSI." I do believe this could add cost to programs initially, but once integrated as a plug-in feature to the MBSE construct, the RTC could be a useful tool to derive more meaningful requirements. Research subject 2 and 5 simply state that added scope will be a setback. Finally, research subject three states that communicating the RTC to "softer" (more flexible) programs will be challenging.

Survey Question 16: What do you foresee as the biggest advantages and overall benefits with implementing the RTC on programs throughout USSOCOM?

Research subject one states expending additional energy will allow the engineer to really think how a human will actually interoperate with the system being developed to serve USSOCOM. This extra time and effort go beyond the simple HSI "look-up" process from a MIL-STD and brings reality into the design, development, testing, manufacturing, fielding and sustainment. Research subject two states how the RTC will result in thorough and detailed HSI requirements. Research subject five states the overall growth potential for human performance by utilizing the RTC. Research subject six states how the RTC should be used at the program management level in order to help them guide their acquisition decisions. Finally, research subject seven states how the RTC will result in a better, more customized experience for the operators as well as a clearer definition of requirements for the engineers.

Survey Question 17: Any additional comments?

Research subject one states how improving HSI requirements is a tough problem to solve. Writing solid, useful requirements is an art and the RTC model may provide a construct for SOCOM and other DoD/Commercial entities to consider when the human is the center of the system being developed. Based on the UUV system used in this paper, research subject two states how he would like to see a more SOCOM-centric system example in the future. Finally, research subject four feels that multiple PEOs including PEO Maritime and PEO Soldier Systems would benefit greatly from using the RTC. The first additional note captured by a research subject during the survey presentation is whether the RTC can help build an experienced operator in 5 years, instead of 10 to 15 years as is the case currently. A second note captured suggested the RTC be used by both the government (customer) and industry.

In revisiting Research Question 3, the following RQ3 bulleted question is restated below with a validation response:

- **RQ3.3:** Overall, does this new methodology strengthen or weaken existing human factors requirements commonly applied to programs?

By initiating Task 3.3 and conducting a comparative analysis on the results of each research question, the RTC methodology shows a supplemental improvement (a strengthening) to existing human factors requirements per Task 3.3.

CHAPTER 9.0 RESEARCH CONTRIBUTIONS

By addressing each task and resolving these research questions, we are confident the SOCOM community will see value in this novel human-in-the-loop centered, SOCOM-friendly MBSE methodology. Not only does the RTC provide an integrated representation of the warfighter(s) within a SOCOM acquisition system, but also value towards existing human factors, or HSI requirements commonly used in acquisition programs through the use of MBSE and the SysML. We anticipate the proposed human-in-the-loop centered, SOCOM-friendly MBSE methodology delivers the following upgrades and improvements over existing MBSE methodologies for SOCOM:

- This novel, RTC methodology is consistent and generalized for diverse applications across SOCOM acquisition programs and projects.
- As opposed to the majority of system models within defense acquisition, the RTC creates an architecture that immerses SOCOM operators into the system of interest to better capture the characteristics and attributes of the operator(s) (stakeholder(s)) who serve in an end user role. This is not being done in SOCOM or larger defense acquisition.
- This novel SOCOM Task List will be developed and directly correlated to PSFs to align mission-related tasks with individual characteristics to be augmented throughout the SOCOM community.
- This tailored, PSF data is adapted to SOCOM operator attributes to quantify and measure the impact an operator introduces into a system to better shape the respective system architecture.

- The RTC employs the PSF data into an architecture to directly link the SOCOM Task List into the system via the PSF values, which shows the significance of the system against the mission-related tasks and allows for a process-developed set of HSI requirements from the structural, behavioral, social, and cultural aspects of the model (60).
- The mission engineering domain can now be adopted into the early stages of system development through a targeted approach at informing acquisition requirements in a pre-build versus post-build condition, resulting in significant cost savings potential during the operational period of a system lifecycle.
- The RTC results in added value in the use of human factors and digital engineering, with MBSE and SysML for SOCOM.

9.1 Dissemination of Research Findings

The research presented in this dissertation has resulted in several peer-reviewed products. The products, and corresponding dissertation research questions, are as follows:

- Corl, K., & Gallegos, E. (under review). A USSOCOM Methodology for Generating Human Systems Integration Requirements within Model Based Systems Engineering: The Relational and Technological Capstone (RTC) Phase 1 Solution.
    - This journal manuscript focuses on RQ1. Based on the 2024 research topics for special operations, this paper seeks to help address the Human/Technology Interface topic within the larger "People" research category. While the submission remains in review, the HSI content from research question 1 fosters intuitiveness and adaptability toward procurement systems as well as brings to light the importance of personnel in mission success (61) (62).
- Corl, K., & Gallegos, E. (2024). A Method to Customize Human Systems Integration Requirements for Advancement of Existing and Future Mission Platforms. *To be Presented at the 27th Annual Systems & Mission Engineering Conference.* Norfolk, VA: Oct 2024.
    - This conference presentation focuses on RQ2. Based on a mission engineering variant of this research, this presentation aligns with the conference theme spotlights "Digital Transformation across the lifecycle for Mission Success." This presentation seeks to address the System of Systems, MBSE, and Human Factors Engineering conference topics.
- Corl, K., & Gallegos, E. (2024). A Method for Human Systems Integration Requirements within Model Based Systems Engineering. *Proceedings of the 34th Annual International*

Council on Systems Engineering International Symposium (INCOSE IS), 34(1), 1787-1806. Dublin, Ireland: July 2024. https://doi.org/10.1002/iis2.13237

- This conference presentation and proceedings focused on RQ3. The INCOSE committee accepted the paper for publication in the symposium proceedings and was selected for oral presentation at The Convention Center Dublin. Once accepted, a complementary brief based on the content of the white paper was developed and presented to both colleagues at CSU and fellow systems engineering professionals as part of the HSI Track (63) (64).

CHAPTER 10.0 CONCLUSION

With the acceptance of two submitted papers to the INCOSE International Symposium and the Systems and Mission Engineering Conference in the first half of 2024, future work will continue for the remainder of 2024 and 2025. Given the above submissions focused on RQ2 and RQ3, the acceptance of a monograph with focus on RQ1 is still underway. While this paper was targeted for JSOU, future guidance and direction will expand RQ1 submission potential to other professional organizations such as IEEE. Additionally, an abstract is currently in development for submission to a SOFWERX Tech Event in the spring of 2025. SOFWERX is a 501(c)(3) nonprofit and serves as the innovation hub for SOCOM where government, industry, academia, and national labs bring technical solutions together to solve challenging problems for special operations (65).

As with all engineering disciplines, Human-Centered Systems Engineering is a growing field and has an expanding presence in the medical domain as well as a few universities across the country (66). The RTC seeks to both advance this discipline and help an elite military community where its servicemembers are their most exploited asset. Through expert evaluations, the RTC model has comparatively improved structural and behavioral qualities over existing system models. Moreover, a task list was initiated for SOCOM, providing them with maritime tasks in the tactical setting, then appointing measured values to be incorporated. Finally, the task list values are integrated into the existing model to establish aggregated parametrics and deliver human-centered criteria and requirements for SOCOM to use as consideration when designing a complex system.

There are many definitions of HFE across professional societies, scientific literature, government agencies, industry, and various open sources. One applicable definition to this dissertation is by Alphonse Chapanis, who is regarded as one of the fathers and pioneers of HFE and Ergonomics (67). His definition was, “Human Factors is a body of knowledge about human abilities, human limitations, and other human characteristics that are relevant to design.” (68). Similarly, the regarded father of modern systems engineering, Simon Ramo, defines systems engineering as, “a branch of engineering which concentrates on the design and application of the whole as distinct from the parts, looking at a problem in its entirety, taking account of all the facets and all the variables and linking the social to the technological” (69).

In linking the two definitions above from these engineering visionaries, one could define Human-Centered Systems Engineering as, “a new branch of engineering which combines the design and the human into a whole by looking at the problem in its entirety, taking account of all the facets and all the variables, while linking human abilities, human limitations, and other human characteristics to the technological.” The use of the RTC serves as a leap toward this definition and Human-Centered Systems Engineering.

As covered early in the paper, Mission Engineering, and the larger Mission Integration Management (MIM) activity, can ultimately expand beyond the utilization and support stages defined by INCOSE and into the concept stage where capability gaps can be identified early and with far less cost implications and mission complexities as expressed through exorbitant multi-system scenarios and intricate vignettes (1) (13).

REFERENCES

1. International Council on Systems Engineering (INCOSE). Systems Engineering Handbook. 4th [ed.] David D Walden, et al. s.l., NY : John Wiley & Sons, Inc., 2015. INCOSE-TP-2003-002-04.

2. Gräbler, I., Roesmann, D. and Wiechel, D. Integrating Human Factors in the Model-Based Development of Cyber-Physical Production Systems. s.l. : ScienceDirect, 2021. Vol. 31st CIRP Design Conference.

3. Temin, T. Model-Based Systems Engineering Leads to Better Systems, Faster. s.l. : Federal News Network, 2022.

4. Chief Information Officer. DoDAF Architecture Framework Version 2.02. s.l. : U.S. Department of Defense, 2010.

5. Bligärd, L-O and Nilsson, R. Connecting Systems Engineering and Human Factors through MBSE. s.l. : 26th Annual INCOSE International Symposium, 2016.

6. Purdy, J.A. and Schwartz, M. United States Special Operations Command Acquisition Authorities. s.l. : Congressional Research Service, 2018.

7. Magnuson, S. Power Remains Key Challenge for Building SOCOM's Iron Man Suit. s.l. : National Defense, 2015. Vol. 99, 738.

8. Department of Defense. Human Engineering, MIL-STD 1472F. *Design Criteria Standard.* 1999.

9. —. Handbook for Human Engineering Design Guidelines, MIL-HDBK-759C. 1995.

10. American Society for Testing and Materials. Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities, ASTM-F1166. 2021.

11. O'Connell, M. TALOS Exoskeleton Presents Technological, Acquisition Hurdles for SOCOM. s.l. : Federal News Network, 2018.

12. Defense Acquisition University. ENG101 Fundamentals of Systems Engineering, Lesson 2.1 - Introduction to Technical Processes. 2014.

13. Office of the Deputy Director for Engineering, Office of the Under Secretary of Defense for Research and Engineering. Mission Engineering Guide. 2020.

14. Lehto, M. and Landry, S.J. Introduction to Human Factors and Ergonomics for Engineers, 2nd Edition. s.l. : CRC Press, 2013.

15. The Human Factors and Ergonomics Society. HFES History, About HFES. 2023.

16. Defense Acquisition University. CLE062 Human Systems Integration Awareness, Lesson 1 - The Domains of HSI. 2014.

17. Strain, J.D. and Preece, D.A. Project Management and the Integration of Human Factors in Military System Procurement. s.l. : International Journal of Project Management, 1999. Vol. 17.

18. Human Factors Engineering Technical Advisory Group. Index of Government Standards on Human Engineering Design Criteria, Processes, and Procedures. s.l. : Department of Defense, 2004.

19. Object Management Group. SysML Model User Exam Overview. 2023.

20. —. SysML Model Builder Fundamental Exam Overview. 2023.

21. —. SysML Model Builder Intermediate Exam Overview. 2023.

22. Delligatti, L. SysML Distilled: A Brief Guide to the Systems Modeling Language. s.l. : Addison-Wesley, 2014.

23. Friedenthal, S., Moore, A. and Steiner, R. A Practical Guide to SysML The Systems Modeling Language 3rd Edition. s.l. : Morgan Kaufmann, 2015.

24. Object Management Group. OMG Systems Modeling Language (OMG SysML™) Hybrid SUV Non-Normative Example. 2010.

25. Chami, M. and Bruel, J-M. A Survey on MBSE Adoption Challenges. s.l. : INCOSE EMEA Sector Systems Engineering Conference, 2018.

26. Morris, B.A., et al. Issues in Conceptual Design and MBSE Successes: Insights from the Model-Based Conceptual Design Surveys. s.l. : 26th Annual INCOSE International Symposium, 2016.

27. Akundi, A., Luna, S. and Mondragon, O.A. Perceptions and the Extent of Model-Based Systems Engineering (MBSE) Use - An Industry Survey. s.l. : ResearchGate Conference, 2022.

28. Rozanski, N. and Woods, E. Software Systems Architecture: Working with Stakeholders Using Viewpoints and Perspectives, 2nd Edition. s.l. : Person Education Inc., 2012.

29. Chief of Naval Operations. Universal Naval Task List, OPNAVINST 3500.38B. 2007.

30. Department of the Air Force. Air Force Task List (AFTL) Air Force Doctrine Document 1-1. 1998.

31. Swain, A.D. and Guttmann, H.E. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications, NUREG/CR-1278, SAND80-0200. 1983.

32. Boff, K.R. and Lincoln, J.E. Engineering Data Compendium: Human Perception and Performance. s.l. : Harry G. Armstrong Aerospace Medical Research Laboratory: Wright-Patterson Air Force Base, 1988.

33. Birch, D.S. Development of a Human Factors Hazard Model for use in System Safety Analysis. s.l. : Colorado State University, 2021.

34. Teledyne Brown Engineering, Inc. DRAFT System/Subsystem Specification (SSS). Huntsville : s.n., 2020. Vol. Appendix I.

35. —. Unmanned Undersea Vehicle System Technical Volume. Huntsville : s.n., 2020. Vol. 1.

36. United States Navy. U.S. Navy Dive Manual Revision 7 SS521-AG-PRO-010. s.l. : Naval Sea Systems Command, 2018.

37. Non-Pressurized Submersible Vehicle Team One. SubVT-1 Standard Operating Procedures (SOP) for Diving 3120.4G.

38. Teledyne Brown Engineering, Inc. Operator's Guide Manual for EX-11 Non-Pressurized Submersible Vehicle. Huntsville : s.n., 2017.

39. Pew, Richard. Some New Perspectives for Introducing Human-Systems Integration into the System Development Process. *Journal of Cognitive Engineering and Decision Making.* Cambridge : s.n., 2008. Vol. 2, 3.

40. Dhillon, Balbir. Human Reliability with Human Factors. s.l. : Pergamon Press, 1986.

41. Dolan, Nancy and McGovern Narkevicius, Jennifer. Systems Engineering, Acquisition and Personnel Integration (SEAPRINT): Achieving the Promise of Human Systems Integration. *In Strategies to Maintain Combat Readiness during Extended Deployments – A Human Systems Approach.* 2005.

42. Benson, Craig, Ryan, Michael and Frater, Michael. High-Frequency Underwater Acoustic Communication Development System. *IEEE Xplore.* New South Wales : s.n.

43. Kida, Yukihiro, Deguchi, Mitsuyasu and Shimura, Takuya. Experimental demonstration on long-range time-reversal multiple-input/multiple-output underwater acoustic communication over tens of kbps in 12.5 km range. *Japanese Journal of Applied Physics.* Yokosuka : s.n., 2022.

44. Eslami, Mohammad, Karimi, Omidreza and Khodadadi, Touraj. A Survey on Wireless Mesh Networks: Architecture, Specifications and Challenges. *IEEE 5th Control and System Graduate Research Colloquium.* s.l. : IEEE, 2014.

45. International Council on Systems Engineering (INCOSE). Needs and Requirements Manual: Needs, Requirements, Verification, Validation Across the Lifecycle. 2022. INCOSE-TP-2021-002-01.

46. —. Guide to Needs and Requirements. 2022. INCOSE-TP-2021-003-01.

47. —. Guide to Writing Requirements. 2022. INCOSE-TP-2010-006-03.1.

48. Gertman, D., et al. The SPAR-H Human Reliability Analysis Method. Idaho Falls : Idaho National Laboratory, 2005. NUREG/CR-6883 INL/EXT-05-00509.

49. Gertman, D.I. and Blackman, H.S. Human Reliability and Safety Analysis Data Handbook, 3rd Edition. s.l. : Wiley-Interscience, 1993.

50. Pryor, Gary. Methodology for Estimation of Operational Availability as Applied to Military Systems. *ITEA Journal.* s.l. : International Test and Evaluation Association, 2008.

51. U.S. Office of Personnel Management (OPM). Formula for Maximizing Performance. https://www.opm.gov/policy-data-oversight/performance-management/performance-management-cycle/developing/formula-for-maximizing-performance/#:~:text=Performance%20%3D%20Capacity%20x%20Commitment,either%20factor%20will%20affect%20performance.

52. Bromberg, Michael. Harmonic Mean Definition, Formula, and Examples. s.l. : Investopedia, 2023.

53. Coleman, Ben. Fitting Exponential Decay Sums with Positive Coefficients. s.l. : Randorithms, 2020.

54. Pachaiyappan, Divyakumari, et al. Relation between electrical resistance and conductance using multifarious functional equations and applications to parallel circuit. *Journal of Inequalities and Applications.* 2022.

55. Trochim, W. and Donnelly, J. Research Methods Knowledge Base 3rd Edition. s.l. : Atomic Dog, 2006.

56. Conjointly. Likert Scaling. https://conjointly.com/kb/likert-scaling/#rating-the-items.

57. QuestionPro. Guttman Scale: Definition, Characteristics and Examples. https://www.questionpro.com/blog/guttman-scale/.

58. Ott, L. and Longnecker, M. An Introduction to Statistical Methods & Data Analysis 7th Edition. s.l. : Cengage Learning, 2016.

59. Kutner, M., et al. Applied Linear Statistical Models 5th Edition. s.l. : McGraw-Hill Irwin, 2005.

60. Samaras, E.A. and Samaras, G.M. Using Human-Centered Systems Engineering to Reduce Nurse Stakeholder Dissonance. s.l. : Biomedical Instrumentation & Technology, 2010.

61. Joint Special Operations University (JSOU). 2024 Special Operations Research Topics. s.l. : JSOU Press, 2024. JSOU Report 24-1.

62. —. Special Operations Research Topics 2023. s.l. : JSOU Press, 2022.

63. International Council on Systems Engineering (INCOSE). 34th Annual INCOSE International Symposium Call for Submissions. www.incose.org/symp2024.

64. —. 34th Annual INCOSE International Symposium Book of Abstracts. 2024. https://www.incose.org/symp2024/downloads.

65. SOFWERX. About. https://sofwerx.org/about.

66. Human Centered Medical Systems Engineering, Bachelors Degree. s.l. : University of Trento, 2021.

67. Pew, R.W. Alphonse Chapanis: Pioneer in the Application of Psychology to Engineering Design. s.l. : Association for Psychological Science, 2010.

68. Chapanis, A. To Communicate the Human Factors Message, You Have to Know What the Message Is and How to Communicate It. s.l. : Human Factors Society Bulletin, 1991. Vol. 34.

69. Hambleton, K., et al. Conquering Complexity: Lessons in Defence Systems Acquisition. s.l. : The Defence Engineering Group, University College London, 2005.

70. Kossiakoff, A., et al. Systems Engineering Principles and Practice. 3rd s.l., NJ, USA : John Wiley & Sons, Inc., 2020.

71. Albers, A. and Lohmeyer, Q. Advanced Systems Engineering - Toward a Model-Based and Human-Centered Methodology. s.l. : Academia, 2012.

72. Kim, S.Y., Wagner, D. and Jimenez, A. Challenges in Applying Model-Based Systems Engineering: Human-Centered Design Perspective. s.l. : California Institute of Technology, 2019.

73. Handley, H. Human Systems Engineering @ODU. s.l. : Old Dominion University, 2022.

74. No Magic, Inc., a Dassault Systems Company. Cameo Systems Modeler 2021x LTR User Manual. 2020.

75. Birch, D. Development of a Human Factors Hazard Model for use in System Safety Analysis. Ft. Collins : Colorado State University, 2021.

76. Undersea Technology Innovation Consortium (UTIC). Scholarship Opportunities. https://www.underseatech.org/undersea-technology/scholarship-opportunities/.

APPENDIX A: Quantitative Survey Data

Appendix A provides the tabular, quantitative details of the IRB survey for Research Question 1, 2, and 3 to include:

- Responses from each of the seven research subjects
- Research Question 1 survey questions (Q1_1 – Q5_1)
- Research Question 2 survey questions (Q6_1 – Q9_1)
- Research Question 3 survey questions (Q10_1 – Q13_1)

		Research Subject 1	Research Subject 2	Research Subject 3	Research Subject 4	Research Subject 5	Research Subject 6	Research Subject 7
Q1_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	7	8	9	9	8	8	8
Q2_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	7	9	7	9	8	8	9
Q3_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	8	7	9	9	8	7	9
Q4_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	8	9	5	9	8	7	9
Q5_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	8	8	7	7	8	7	8
Q6_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	6	6	8	7	7	7	7
Q7_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	6	8	6	8	7	7	6
Q8_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	7	7	8	8	7	6	7
Q9_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	8	7	8	9	7	6	7

Q10_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	7	8	8	9	7	7	7
Q11_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	6	6	8	8	7	6	7
Q12_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	7	9	7	8	8	8	8
Q13_1	1 = Strongly Disagree 5 = Neutral 9 = Strongly Agree	7	7	8	8	8	8	9

APPENDIX B: Qualitative Survey Data

Appendix B provides the tabular, qualitative details of the IRB survey for the overall research:

- Responses from each of the seven research subjects
- Overall research survey questions (Q14_1 – Q16_1)

	Q14 Do you foresee any critical flaws or setbacks with implementing the RTC on programs throughout USSOCOM (examples: added cost, added scope, resource constraints, etc.)?	Q15 What do you foresee as the biggest advantages and overall benefits with implementing the RTC on programs throughout USSOCOM?	Q16 Any additional comments?
Research Subject 1	Establishing a baseline understanding with the workforce will be challenging. Although unethical, I wonder if a PM might "game" the system within the fairly subjective nature of HSI? Although the project drives towards a more objective construct, there are some concerns with addressing the "subjective". I do believe this could add cost to programs initially, but once integrated as a "plug-in" model to the MBSE construct could be a useful tool in expending more energy by the acquisition community to derive more meaningful requirements. If programs spent more time on requirements derivation with the operator in mind, I would argue the system would have a higher likelihood of success.	Expending additional energy really thinking about how a human will actually interoperate with the system being developed to serve them. This extra time and effort goes beyond the simple HSI "look-up" from a MIL-STD and brings reality into the design, development, testing, manufacturing, fielding and sustainment.	This is a tough problem to solve. Writing solid, useful requirements is an art. The RTC model may provide a construct for SOCOM and other DoD/Commercial entities to consider when the human is the center of the system being developed.

Research Subject 2	Added scope.	Thorough and detailed HSI requirements	Would like to see a more SOCOM-centric system example.
Research Subject 3	Communicating to "softer" programs will be challenging, Validated assumptions will be critical.	Manpower and skill / task management enhancements. Estimating future manpower and skill requirements / limits of human performance & task saturation	
Research Subject 4	I think that retroactive analysis will be of limited value- outside of identifying candidate systems for replacement. Otherwise I think it might be leveraged to spend money out of budget and alterations to platforms are rarely cost effective.	Executing this analysis with a tool such as TBEs JMPTK (Joint Medical Planning Tool Kit) might make these analysis more dynamic.	In addition to PEO-Maritime, I think PEO Soldier Systems absolutely needs to see this.
Research Subject 5	Scope: Unsure if we can build the experienced operator in 5 years, instead of 10 or 15 years.	Growth potential for human performance.	
Research Subject 6	since we are a T&E facility, we only test to our customer requirements.	should be used at the Program Management level in order to help them guide their acquisition decisions.	
Research Subject 7	Might get push back from different branches/units on limping OP's and EP's together. Commanders may not want to lose control of risk mitigation/acceptance by grouping with other branches/units.	Better experience, more customized experience for the operators. Clearer definition of requirement for the engineers.	

APPENDIX C: SOCOM Task List

Appendix C provides the tabular, quantitative details within the SOCOM Task List and the associated PSFs.

Performance Shaping Factors (PSFs)

Task	Task Training	Task Experience	Mental Acuity to Perform Task	Motor Skills to Perform Task	Stress of Performing Task	Task Complexity	Actor Interfaces During Task	Task Safeguards	Input Control Capability During Task	Task Feedback and Alarms	P_{RTC}	C_A
SOTN 1.0 Conduct Unconventional Warfare	How much instruction, practice, or mentoring is required up IOT perform the task?	How much exposure and familiarity are required IOT perform the task?	What level of response stimulus or concentration is required IOT perform the task?	What level of gross and fine motor skills are required IOT perform the task?	How much mental tension, worry, or concern exists when performing the task?	How sophisticated or complicated is the system in relation to performing the task?	How unintuitive, impractical, or unusable are the human interfaces with the system when performing the task?	How much risk, exposure, or jeopardy is the system or end-user subject to when performing the task?	How difficult or inoperable are the dynamic, interactive interfaces (e.g. joystick, throttle, etc.) to manipulate while performing a task?	How limited or nonobvious are the system responses, alarms or signals while performing the task?	**Fully realized task**	**Fully unrestricted task value**
												10
SOTN 2.1 Conduct Undersea Operations	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	User Rating Input
												P_{RTC} Adjustment
SOTN 2.1.1 Conduct Swimmer Operations	3	3	3	6	4	4	3	4	2	5	N/A	User Rating Input
	0.3	0.3	0.3	0.6	0.4	0.4	0.3	0.4	0.2	0.5	**0.730**	**P_{RTC} Adjustment**
SOTN 2.1.2 Conduct Submersible Operations	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	User Rating Input
												P_{RTC} Adjustment
SOTN 2.1.2.1 Conduct Gas 01 Submersible Operations	7	5	6	1	6	7	6	6	5	7	N/A	User Rating Input
	0.7	0.5	0.6	0.1	0.6	0.7	0.6	0.6	0.5	0.7	**0.641**	**P_{RTC} Adjustment**
SOTN 2.1.2.2 Conduct Gas 02 Submersible Operations	8	6	7	1	7	8	7	7	5	7	N/A	User Rating Input
	0.8	0.6	0.7	0.1	0.7	0.8	0.7	0.7	0.5	0.7	**0.613**	**P_{RTC} Adjustment**
	6	4	6	1	6	6	5	5	5	6	N/A	User Rating Input

SOTN 2.1.2.3 Conduct Gas 03 Submersible Operations	0.6	0.4	0.6	0.1	0.6	0.6	0.5	0.5	0.5	0.6	**0.667**	**P_{RTC} Adjustment**
SOTN 2.1.2.4 Conduct Gas 04 Submersible Operations	5	3	5	1	5	4	3	4	4	4	**N/A**	User Rating Input
	0.5	0.3	0.5	0.1	0.5	0.4	0.3	0.4	0.4	0.4	**0.725**	**P_{RTC} Adjustment**
SOTN 2.1.2.5 Conduct Submersible Operating Procedures (OPs) - PLT	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	User Rating Input
												P_{RTC} Adjustment
SOTN 2.1.2.5.1 Conduct Submersible PLT OP 01	2	1	2	1	1	3	3	1	1	1	**N/A**	User Rating Input
	0.2	0.1	0.2	0.1	0.1	0.3	0.3	0.1	0.1	0.1	**0.862**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.2 Conduct Submersible PLT OP 02	2	1	2	1	1	2	3	2	1	1	**N/A**	User Rating Input
	0.2	0.1	0.2	0.1	0.1	0.2	0.3	0.2	0.1	0.1	**0.862**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.3 Conduct Submersible PLT OP 03	3	1	1	3	1	2	2	2	2	1	**N/A**	User Rating Input
	0.3	0.1	0.1	0.3	0.1	0.2	0.2	0.2	0.2	0.1	**0.847**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.4 Conduct Submersible PLT OP 04	3	1	1	3	1	2	2	2	2	1	**N/A**	User Rating Input
	0.3	0.1	0.1	0.3	0.1	0.2	0.2	0.2	0.2	0.1	**0.847**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.5 Conduct Submersible PLT OP 05	4	2	2	3	2	3	3	3	3	1	**N/A**	User Rating Input
	0.4	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.1	**0.794**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.6 Conduct Submersible PLT OP 06	4	2	2	3	2	3	3	4	3	1	**N/A**	User Rating Input
	0.4	0.2	0.2	0.3	0.2	0.3	0.3	0.4	0.3	0.1	**0.787**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.7 Conduct Submersible PLT OP 07	7	4	3	3	6	6	3	4	3	1	**N/A**	User Rating Input
	0.7	0.4	0.3	0.3	0.6	0.6	0.3	0.4	0.3	0.1	**0.714**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.8 Conduct Submersible PLT OP 08	7	4	3	3	6	6	3	4	3	1	**N/A**	User Rating Input
	0.7	0.4	0.3	0.3	0.6	0.6	0.3	0.4	0.3	0.1	**0.714**	**P_{RTC} Adjustment**

SOTN 2.1.2.5.9 Conduct Submersible PLT OP 09	3	2	1	2	2	4	3	3	2	4	**N/A**	User Rating Input
	0.3	0.2	0.1	0.2	0.2	0.4	0.3	0.3	0.2	0.4	**0.794**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.10 Conduct Submersible PLT OP 10	5	4	3	3	4	4	4	2	3	3	**N/A**	User Rating Input
	0.5	0.4	0.3	0.3	0.4	0.4	0.4	0.2	0.3	0.3	**0.741**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.11 Conduct Submersible PLT OP 11	5	5	3	7	4	4	4	4	7	6	**N/A**	User Rating Input
	0.5	0.5	0.3	0.7	0.4	0.4	0.4	0.4	0.7	0.6	**0.671**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.12 Conduct Submersible PLT OP 12	3	3	6	1	2	4	4	1	1	1	**N/A**	User Rating Input
	0.3	0.3	0.6	0.1	0.2	0.4	0.4	0.1	0.1	0.1	**0.794**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.13 Conduct Submersible PLT OP 13	3	1	2	3	2	3	3	2	2	4	**N/A**	User Rating Input
	0.3	0.1	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.4	**0.800**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.14 Conduct Submersible PLT OP 14	6	4	2	5	5	4	4	5	4	6	**N/A**	User Rating Input
	0.6	0.4	0.2	0.5	0.5	0.4	0.4	0.5	0.4	0.6	**0.690**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.15 Conduct Submersible PLT OP 15	6	4	2	5	5	4	4	3	4	6	**N/A**	User Rating Input
	0.6	0.4	0.2	0.5	0.5	0.4	0.4	0.3	0.4	0.6	**0.699**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.16 Conduct Submersible PLT OP 16	8	5	3	7	7	4	4	6	4	7	**N/A**	User Rating Input
	0.8	0.5	0.3	0.7	0.7	0.4	0.4	0.6	0.4	0.7	**0.645**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.17 Conduct Submersible PLT OP 17	8	5	3	7	7	4	4	5	4	7	**N/A**	User Rating Input
	0.8	0.5	0.3	0.7	0.7	0.4	0.4	0.5	0.4	0.7	**0.649**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.18 Conduct Submersible PLT OP 18	7	4	2	6	6	4	4	5	4	6	**N/A**	User Rating Input
	0.7	0.4	0.2	0.6	0.6	0.4	0.4	0.5	0.4	0.6	**0.676**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.19 Conduct Submersible PLT OP 19	7	4	2	6	6	4	4	4	4	6	**N/A**	User Rating Input
	0.7	0.4	0.2	0.6	0.6	0.4	0.4	0.4	0.4	0.6	**0.680**	**P_{RTC} Adjustment**

SOTN 2.1.2.5.20 Conduct Submersible PLT OP 20	3	1	1	2	2	3	3	3	2	3	**N/A**	User Rating Input
	0.3	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.2	0.3	**0.813**	**P_{RTC} Adjustment**
SOTN 2.1.2.5.21 Conduct Submersible PLT OP 21	3	2	1	3	2	3	3	2	5	6	**N/A**	User Rating Input
	0.3	0.2	0.1	0.3	0.2	0.3	0.3	0.2	0.5	0.6	**0.769**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.22 Conduct Submersible PLT OP 22	3	2	2	2	3	4	4	3	4	1	**N/A**	User Rating Input
	0.3	0.2	0.2	0.2	0.3	0.4	0.4	0.3	0.4	0.1	**0.781**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.23 Conduct Submersible PLT OP 23	3	2	2	2	3	4	4	3	4	3	**N/A**	User Rating Input
	0.3	0.2	0.2	0.2	0.3	0.4	0.4	0.3	0.4	0.3	**0.769**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.24 Conduct Submersible PLT OP 24	2	1	1	2	2	3	3	2	2	1	**N/A**	User Rating Input
	0.2	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.2	0.1	**0.840**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.25 Conduct Submersible PLT OP 25	6	3	2	4	5	4	4	4	3	4	**N/A**	User Rating Input
	0.6	0.3	0.2	0.4	0.5	0.4	0.4	0.4	0.3	0.4	**0.719**	**P_{RTC} Adjustment**
SOTN 2.1.2.6 Conduct Submersible Operating Procedures (OPs) - NAV	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	User Rating Input
												P_{RTC} Adjustment
SOTN 2.1.2.6.1 Conduct Submersible NAV OP 01	3	2	7	1	4	7	5	1	1	1	**N/A**	User Rating Input
	0.3	0.2	0.7	0.1	0.4	0.7	0.5	0.1	0.1	0.1	**0.758**	**P_{RTC} Adjustment**
SOTN 2.1.2.6.2 Conduct Submersible NAV OP 02	3	2	4	1	3	6	5	1	1	3	**N/A**	User Rating Input
	0.3	0.2	0.4	0.1	0.3	0.6	0.5	0.1	0.1	0.3	**0.775**	**P_{RTC} Adjustment**
SOTN 2.1.2.7 Conduct Submersible Operating Procedures (OPs) - MS	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	User Rating Input
												P_{RTC} Adjustment
SOTN 2.1.2.7.1 Conduct Submersible Mission Specialist (MS) UUV Launch	3	3	1	4	3	3	3	2	3	3	**N/A**	User Rating Input
	0.3	0.3	0.1	0.4	0.3	0.3	0.3	0.2	0.3	0.3	**0.781**	**P_{RTC} Adjustment**

SOTN 2.1.2.7.2 Conduct Submersible Mission Specialist (MS) UUV Recovery	5	5	1	4	4	3	3	2	3	2	**N/A**	User Rating Input
	0.5	0.5	0.1	0.4	0.4	0.3	0.3	0.2	0.3	0.2	**0.758**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.3 Conduct Submersible Mission Specialist (MS) UUV Mission Tasking	3	2	3	1	2	5	4	1	1	4	**N/A**	User Rating Input
	0.3	0.2	0.3	0.1	0.2	0.5	0.4	0.1	0.1	0.4	**0.794**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.4 Conduct Submersible Mission Specialist (MS) UUV Maneuvers	6	6	3	5	5	5	5	3	4	6	**N/A**	User Rating Input
	0.6	0.6	0.3	0.5	0.5	0.5	0.5	0.3	0.4	0.6	**0.676**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.5 Conduct Submersible Mission Specialist (MS) UUV Download	3	2	2	1	2	5	4	1	1	3	**N/A**	User Rating Input
	0.3	0.2	0.2	0.1	0.2	0.5	0.4	0.1	0.1	0.3	**0.806**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.6 Conduct Submersible Mission Specialist (MS) UUV Scuttle	3	1	2	1	3	4	3	2	2	2	**N/A**	User Rating Input
	0.3	0.1	0.2	0.1	0.3	0.4	0.3	0.2	0.2	0.2	**0.813**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.7 Conduct Submersible Mission Specialist (MS) UUV Startup	3	2	2	1	1	3	3	1	1	3	**N/A**	User Rating Input
	0.3	0.2	0.2	0.1	0.1	0.3	0.3	0.1	0.1	0.3	**0.833**	**P_{RTC} Adjustment**
SOTN 2.1.2.7.8 Conduct Submersible Mission Specialist (MS) UUV Shutdown	3	2	2	1	1	3	3	2	1	3	**N/A**	User Rating Input
	0.3	0.2	0.2	0.1	0.1	0.3	0.3	0.2	0.1	0.3	**0.826**	**P_{RTC} Adjustment**
SOTN 2.1.2.8 Conduct Submersible Emergency Procedures (EPs) - Crew	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	User Rating Input
												P_{RTC} Adjustment
SOTN 2.1.2.8.1 Submersible Crew EP 01	5	2	3	5	9	5	4	3	3	4	**N/A**	User Rating Input
	0.5	0.2	0.3	0.5	0.9	0.5	0.4	0.3	0.3	0.4	**0.699**	**P_{RTC} Adjustment**
SOTN 2.1.2.8.2 Submersible Crew EP 02	3	1	2	3	6	4	2	2	2	4	**N/A**	User Rating Input
	0.3	0.1	0.2	0.3	0.6	0.4	0.2	0.2	0.2	0.4	**0.775**	**P_{RTC} Adjustment**

SOTN 2.1.2.8.3 Submersible Crew EP 03	3	1	2	3	9	4	2	2	2	4	N/A	User Rating Input
	0.3	0.1	0.2	0.3	0.9	0.4	0.2	0.2	0.2	0.4	**0.758**	**P_{RTC} Adjustment**
SOTN 2.1.2.8.4 Submersible Crew EP 04	5	1	3	5	10	5	4	3	3	3	N/A	User Rating Input
	0.5	0.1	0.3	0.5	1	0.5	0.4	0.3	0.3	0.3	**0.704**	**P_{RTC} Adjustment**
SOTN 2.1.2.8.5 Submersible Crew EP 05	4	2	2	3	6	4	2	2	2	4	N/A	User Rating Input
	0.4	0.2	0.2	0.3	0.6	0.4	0.2	0.2	0.2	0.4	**0.763**	**P_{RTC} Adjustment**
SOTN 2.1.2.8.6 Submersible Crew EP 06	4	2	2	1	4	5	4	1	2	4	N/A	User Rating Input
	0.4	0.2	0.2	0.1	0.4	0.5	0.4	0.1	0.2	0.4	**0.775**	**P_{RTC} Adjustment**
SOTN 2.1.2.8.7 Submersible Crew EP 07	3	2	2	2	5	3	2	2	2	4	N/A	User Rating Input
	0.3	0.2	0.2	0.2	0.5	0.3	0.2	0.2	0.2	0.4	**0.787**	**P_{RTC} Adjustment**
SOTN 2.1.2.8.8 Submersible Crew EP 08	5	1	2	4	8	4	3	2	4	3	N/A	User Rating Input
	0.5	0.1	0.2	0.4	0.8	0.4	0.3	0.2	0.4	0.3	**0.735**	**P_{RTC} Adjustment**
SOTN 2.1.2.8.9 Submersible Crew EP 09	5	1	2	5	9	4	3	3	4	3	N/A	User Rating Input
	0.5	0.1	0.2	0.5	0.9	0.4	0.3	0.3	0.4	0.3	**0.719**	**P_{RTC} Adjustment**
SOTN 2.1.2.8.10 Submersible Crew EP 10	4	2	2	2	8	4	3	2	3	4	N/A	User Rating Input
	0.4	0.2	0.2	0.2	0.8	0.4	0.3	0.2	0.3	0.4	**0.746**	**P_{RTC} Adjustment**
SOTN 2.1.2.9 Conduct Submersible Emergency Procedures (EPs) - MS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	User Rating Input
												P_{RTC} Adjustment
SOTN 2.1.2.9.1 Submersible MS EP 01	4	2	3	5	9	5	4	3	3	4	N/A	User Rating Input
	0.4	0.2	0.3	0.5	0.9	0.5	0.4	0.3	0.3	0.4	**0.704**	**P_{RTC} Adjustment**
SOTN 2.1.2.9.2 Submersible MS EP 02	5	1	2	4	8	4	3	2	4	3	N/A	User Rating Input
	0.5	0.1	0.2	0.4	0.8	0.4	0.3	0.2	0.4	0.3	**0.735**	**P_{RTC} Adjustment**

SOTN 2.1.2.9.3 Submersible MS EP 03	5	1	2	5	9	4	3	3	4	3	**N/A**	User Rating Input
	0.5	0.1	0.2	0.5	0.9	0.4	0.3	0.3	0.4	0.3	**0.719**	**P_{RTC} Adjustment**
SOTN 2.1.2.9.4 Submersible MS EP 04	4	2	2	2	8	4	3	2	3	4	**N/A**	User Rating Input
	0.4	0.2	0.2	0.2	0.8	0.4	0.3	0.2	0.3	0.4	**0.746**	**P_{RTC} Adjustment**