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MONTEREY, CALIFORNIA

Proposed Interoperability Readiness Level Assessment for Mission Critical Interfaces During Navy Acquisition

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The current Department of the Navy (DoN) system development and acquisition system has documented instances of programs failing to detect critical interoperability failures prior to operational level testing. The authors investigated methods of improving capturing, monitoring, implementing and testing the requirements critical to ensuring mission success. Improvements to the DoN systems engineering processes were developed to ensure that these requirements are identified and promulgated through key program documents and design reviews. There was a down selection of alternatives that examined several candidate options for solutions. This down selection incorporated an evaluation of cost and benefits for each alternative. This included an assessment of how the requirements and testing of the system would have changed if this modified review process had been performed. The current process is improved upon by introducing I/ORLs. These enhanced processes were simulated on a representative DoN system in a tabletop exercise to provide an example of how this modified process could be performed. The additional information provided to programs in the form of I/ORL requirements and clarifying definitions will help to improve interoperability in system development and reduce Operational Test failures.

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The current Department of the Navy (DoN) system development and acquisition system has documented instances of programs failing to detect critical interoperability failures prior to operational level testing. The authors investigated methods of improving capturing, monitoring, implementing and testing the requirements critical to ensuring mission success. Improvements to the DoN systems engineering processes were developed to ensure that these requirements are identified and promulgated through key program documents and design reviews. There was a down selection of alternatives that examined several candidate options for solutions. This down selection incorporated an evaluation of cost and benefits for each alternative. This included an assessment of how the requirements and testing of the system would have changed if this modified review process had been performed. The current process is improved upon by introducing I/ORLs. These enhanced processes were simulated on a representative DoN system in a tabletop exercise to provide an example of how this modified process could be performed. The additional information provided to programs in the form of I/ORL requirements and clarifying definitions will help to improve interoperability in system development and reduce Operational Test failures.

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LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

Acronym	**Definition**
ACAT	Acquisition Categories
AoA	Analysis of Alternatives
AOTR	Assessment for Operational Test Readiness
ASN (RDA)	Assistant Secretary of the Navy for Research, Development and Acquisition
CBA	Capability Based Assessment
CDD	Capability Development Document
CDR	Critical Design Review
CFFC	Commander, US Fleet Forces Command
CHSENG	Chief Systems Engineer
COMOPTEVFOR	Commander Operational Test and Evaluation Force
CONOPS	Concept of Operations
CNO	Chief of Naval Operations
CoA	Comparison of Alternatives
COI	Critical Operational Issue
CPD	Capability Production Documents
DA	Developing Agency
DoD	Department of Defense
DoDI	Department of Defense Instruction
DoN	Department of the Navy

Acronym	**Definition**
DT	Developmental Test/Testing
DT&E	Developmental Test and Evaluation
FY	Fiscal Year
GAO	Government Accountability Office
HSI	Human Systems Interfaces
ICD	Initial Capabilities Document
INCOSE	International Council on Systems Engineering
I/ORL	Interoperability Readiness Level
IOT&E	Initial Operational Test and Evaluation
IPR	Interim Progress Review
IRL	Integration Readiness Level
JCIDS	Joint Capabilities Integration and Development System
JFCOM	Joint Forces Command
JROC	Joint Requirements Oversight Council
KPP	Key Performance Parameter
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Programs
MDD	Material Development Decision
MRA	Mission Readiness Assessment
M&S	Modeling and Simulation
MSSE	Masters of Science in Systems Engineering

Acronym	**Definition**
OPTEVFOR	Operational Test and Evaluation Force
ORD	Operational Requirements Document
OT	Operational Test/Testing
OTA	Operational Test Agency
OT&E	Operational Test and Evaluation
OTRR	Operational Test Readiness Review
PDR	Preliminary Design Review
PEO	Program Executive Office
PM	Program Manager
PRR	Production Readiness Review
RDT&E	Research, Development, Test and Evaluation
SE	Systems Engineering
SETR	Systems Engineering Technical Review
SME	Subject Matter Expert
SoS	System of Systems
SYSCOM	Systems Command
TEMP	Test and Evaluation Master Plan
TRL	Technology Readiness Levels
TRR	Test Readiness Review
USD (AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics

Acronym	**Definition**
WSARA	Weapon Systems Acquisition Reform Act

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EXECUTIVE SUMMARY

The current Department of the Navy (DoN) Systems Engineering process has documented instances of programs failing to detect critical inter-operational failures prior to Initial Operational Test & Evaluation (IOT&E). "Approximately 50% of programs completing IOT&E since 2000 have been assessed as not operationally effective and/or suitable" [Defense Science Board Task Force, 2008]. Early detection of problems is critical to prevent cost overruns and schedule delays. The cost and time required to correct a problem are directly related to how late in the process the problem is found and these cost and schedule impacts increase rapidly as the system nears deployment. Programs are successfully passing developmental testing; however, these tests do not provide adequate assurances that the system will satisfy user needs or Concept of Operations (CONOPS) based interoperating requirements of the operational community. Furthermore, requirements that are critical to mission success are not being identified in the current SE process, and allocations or dependency on supporting resources (systems, sensors, data, etc.) are not being reflected in the Systems Engineering, contractor development plans, and testing plans.

The goal of this project was to analyze the current Systems Engineering process supporting Department of Navy (DoN) acquisition to increase the percentage of programs that successfully pass Operational Test & Evaluation (OT&E) and therefore decrease the cost and schedule delays associated with programs failing OT&E. To do this, the authors developed an approach to track InterOperability Readiness Levels (I/ORLs). As part of this task, the authors analyzed deficiencies of the current Systems Engineering process supporting Department of Navy (DoN) acquisition in the area of interoperability.

The deliverables of this project are a detailed description of the I/ORL Process, the results of the table top exercise and model validation used to determine the effect these changes will have on the current Systems Engineering process, and an assessment of their impact with regard to performance and cost.

During the process review and problem identification phase the stakeholder needs and requirements were collected and prioritized. The current DoD Systems Engineering process and Operational Testing process were reviewed and evaluated to determine how system level requirements are developed from user needs and subsequently tested. Finally, recently developed systems that had issues arise during OT&E were identified and examined to determine potential sources of failure. The authors concentrated on areas in the processes that may provide insight into why systems were initially passing DT, and then subsequently failing OT&E.

Based on the results of the open literature and program documentation research, several general conclusions could be made regarding the causes of OT&E failures. The bulk of the systems cited in the literature and the specific programs that were reviewed have seen failures in OT&E due to a lack of operational suitability or interoperability. Additionally, the inclusion of OT&E personnel early in the development process is necessary to ensure adequate, realistic testing or simulation is performed prior to OT&E to discover deficiencies. In some cases, deficiencies found during early testing or simulations have not been identified in the Systems Engineering Technical Review (SETR) process. Or if they have, programs somehow are proceeding to OT regardless.

The analysis of alternatives phase consisted of concept development and down select. During this phase it became apparent that the preferred solution of "Develop Interoperability Readiness Levels" implies one activity only, yet, this process involves much more than simply developing I/ORLs. It uses Interoperability Readiness Levels as a mechanism to assess the maturity of the design of a system with regard to how well it interoperates with other systems in support of mission critical threads, and as a means to predict a system's ability to pass operational testing with regard to interoperability.

In the third phase, the detailed design was developed. To assess interoperability readiness levels, it was determined that I/ORLs would need to be evaluated at multiple SETRs. There is a top level process presented in developing I/ORLs that considers how this process will be implemented at specific SETRs. The authors created an I/ORL standard outlining the I/ORL levels, values, and descriptions. I/ORLs are intended to assess the state of a system's interoperability using the Systems Engineering process within the existing DoD framework. The I/ORL scale ranges from 1 to 9. A value of 1 is considered the least mature as it pertains to interoperability, and a value of 9 is the most mature. For each applicable review, an objective I/ORL value and a threshold value was assigned. The objective value is the level that should be met at a particular review. A threshold value is the minimum value that the interface must meet at the review. If this value is not met, the system cannot proceed to the next technical review without further action.

In the event that the I/ORL review yields results below the objective value, the program manager will need to demonstrate a risk mitigation plan to correct the issues prior to moving to the next phase of the system development. The purpose of this is to address potential trouble areas in more detail before they delay the system. This approach highlights potential system interoperability issues allowing them to be resolved earlier in the system development. While this process adds an administrative burden, the benefits of tracking I/ORLs and developing mitigation strategies outweighs the cost of this burden.

The process validation phase utilized two methodologies. A tabletop exercise (TTX) was used to demonstrate the functional details of the I/ORL Process as it tracks the interoperability of a fictitious system. Secondly, a computer-based model was developed to track the effectiveness of the I/ORL Process if applied across the Navy/DoD.

During the tabletop exercise, the authors noted shortcomings in the I/ORL Process, generated solutions, and applied improvements to the I/ORL Process. The fictitious Advanced Combat Integrated Helmet (ACIH) was selected as a sample system for the TTX because it has many internal and external interfaces used for communication. The audio and visual communication between headquarters and ground troops was selected to focus the TTX on the ACIH communications mission thread.

The second part of the validation was a computer-based model designed to simulate the I/ORL system. It simulates the interoperability requirements progress throughout the System Engineering process, assigns I/ORL values, and compares the assigned value to the required values at each review. If the system does not meet the prescribed I/ORL threshold for the review, the system is reworked to meet the threshold at an additional cost that is assessed according to the development phase.

Based on the modeling and the table top exercise, the authors believe that the current Systems Engineering process could benefit from the implementation of I/ORLs. The modeling estimates a savings of approximately 14.2% or a reduction of 6.29% in rework costs over the current DoD System Engineering process. Additionally, the model shows an OT&E pass rate of

93.73% with the implementation of the I/ORL evaluations. This is a significant increase in the pass rate of systems from DT to OT&E.

I. INTRODUCTION

A. BACKGROUND

Department of the Navy (DoN) Systems Engineering (SE) processes and practices have evolved over time. Systems Engineering methods and process guidelines have been in development since the early 1960's. The Department of Defense pioneered these processes and practices and developed MIL-STD-499 which was the original specification for Systems Engineering. These Systems Engineering methods have continued to evolve both within the federal government and in private industry, particularly since the role of military specifications has diminished due to acquisition reform. Current Systems Engineering methods are documented in numerous publications such as the International Council on Systems Engineering (INCOSE) *Systems Engineering Handbook,* and ISO/IEC 15288 *Systems and Software Engineering – System Life Cycle Process.* The Federal Government, and in particular the Department of the Navy, also specifies how these Systems Engineering methods will be implemented within the context of naval systems acquisition and these guidelines are specified in documents such as the NAVSEAINST 5000.9 *Naval SYSCOM Systems Engineering Policy, Naval SYSCOM Engineering Technical Review Handbook*. Although the DoN has put in place numerous system design review checks, these enforcement measures on Systems Engineering development practices are not preventing systems from failing operational criteria associated with Operational Test (OT) at the end of their system development cycles.

Independent Operational Testing organizations can trace their origins to the 1970 Blue Ribbon Defense Panel Report. The report concluded that "There has been, and is currently no effective means for conducting productive joint operations test and evaluations. The fact that some such efforts heretofore have encountered difficulties and achieved few useful results does obviate the requirements for much needed joint operational test and evaluation (OT&E)" [JT&E Handbook, 1996]. The current role of the operational test organizations is to make an independent determination of the operational effectiveness and suitability of programs of record prior to full rate production and deployment. Prior to the establishment of the independent OT&E organizations, individual commands were responsible for all testing prior to delivery of systems to the field; which led to many problems after delivery. Individual commands, specifically the program offices, retain cognizance over Developmental Test and Evaluation (DT&E).

B. PROBLEM STATEMENT

The current Department of the Navy (DoN) Systems Engineering process has documented instances of programs failing to detect critical inter-operational failures prior to Initial Operational Test & Evaluation (IOT&E). "Approximately 50% of programs completing IOT&E since 2000 have been assessed as not operationally effective and/or suitable" [Defense Science Board Task Force, 2008]. Early detection of problems is critical to prevent cost overruns and schedule delays. The cost and time required to correct a problem are directly related to how late in the process the problem is found and these cost and schedule impacts increase rapidly as the system nears deployment. Programs are successfully passing developmental testing; however, these tests do not provide adequate assurances that the system will satisfy user needs or Concept of Operations (CONOPS) based interoperating requirements of the operational community. Furthermore, requirements that are critical to mission success are not being identified in the current SE process, and allocations or dependency on supporting resources (systems, sensors, data, etc.) are not being reflected in the Systems Engineering, contractor development plans, and testing plans.

Department of Defense Instruction (DoDI) 5000.02 and related documents describe the Defense Acquisition System used for development of Department of the Navy programs. Despite extensive guidance and multiple decision gates, programs are still failing to ensure that all requirements critical to meeting the user need are identified and properly tested prior to the start of the OT&E process. Improvements must also be made to the Systems Engineering requirements process to ensure that these critical requirements are made visible at key technical reviews(s) such as Preliminary Design Review (PDR), Critical Design Review (CDR), Test Readiness Review (TRR), and Production Readiness Review (PRR).

C. RESEARCH QUESTIONS

The following research questions guided the direction of this project's research and analysis and were answered as the work progressed:

- How are mission critical elements identified and managed using the existing acquisition and SE processes?

- What are the common failures in the engineering process that result in missing mission critical elements? Where do these failures occur?
- How prevalent are mission critical failures of programs discovered during OT&E?
- What kinds of Modeling and Simulation (M&S) can be leveraged to analyze DoN Systems Engineering processes?
- Can process improvements be used to supplement the DoN Systems Engineering processes to improve handling of mission critical interoperability elements of programs?
- What are the cost ramifications and possible benefits of implementing these enhanced processes?

D. INITIAL ASSUMPTIONS

It is understood that Systems Engineering involves balancing the often conflicting requirements of development costs, development schedules and system performance. However, this a significant oversimplification of the situation due to the interrelations between cost and schedule that exist in the budgetary process. While on the surface, making small investments in time and money early in the process in order to save much larger amounts of money in the later lifecycles would seem like an obvious choice; this is actually quite difficult due to how funding is allocated into the different "colors" of money and how this funding is time phased through the program. The authors do not address these issues in this paper. The discussions in this paper regarding how money should be allocated to various types of testing and when this testing should occur do not take into account the reprogramming of funding that must occur to facilitate these changes or the levels of approval that these changes would require.

E. PROJECT GOALS AND DELIVERABLES

The goal of the project is to analyze the deficiencies of the current Systems Engineering process supporting Department of Navy (DoN) Acquisition in the area of requirements critical to ensuring mission success. This includes detailing recommended changes to the Systems Engineering (SE) processes in the Defense Acquisition System in order to increase the percentage of programs that successfully pass Operational Test & Evaluation (OT&E) and therefore decrease the cost and schedule delays associated with programs failing OT&E. The deliverables of this project are a detailed description of the recommended process changes, the results of the validation methods used to determine the effect these changes will have on the current SE process, and an assessment of their impact with regard to performance and cost. It should be noted that during the initial research phase of this project the scope was reduced to only address deficiencies related to interoperability, and the deliverables listed above reflect the narrowed solution space.

F. TAILORED SYSTEMS ENGINEERING PROCESS

The authors implemented a tailored Systems Engineering approach that started with the identification of the customers' needs and proceeded through the phases illustrated in Figure 1 until a recommended solution was generated. This approach was based on the waterfall model introduced by Royce [Blanchard, 2006] and has been tailored to contain elements from Buede [Buede, 2009] and lifecycle design to specifically address the goals of the project. This customized process focuses on the development of the system and less on its support, given its ideological nature.

The project consisted of five phases: Process Review and Problem Identification, Analysis of Alternatives, Detailed Process Design, Process Validation, and Present Recommendations as shown in Figure 1. Each phase was executed by taking the inputs and feedback from later phases. Once the given outputs were of suitable quality, then each phase was considered complete. A detailed description of each phase is found in the subsequent sections.

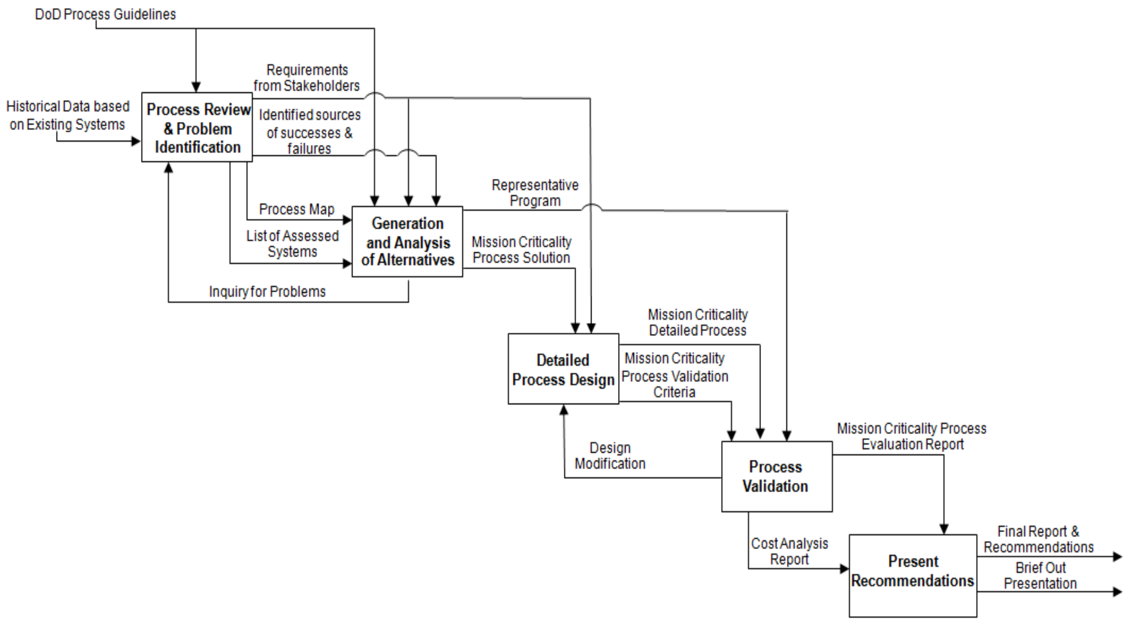

Figure 1. Tailored SE Process

This Systems Engineering process was developed for studying this problem and development of the solution.

1. Process Review and Problem Identification

All stakeholder needs and requirements were collected and prioritized based on pertinence to the project objectives and stakeholder importance. Conflicting needs and requirements were discussed with the required stakeholders to reach an agreement before the authors baselined the requirements.

The team reviewed the current guidance and instructions on applying Systems Engineering in Department of Defense (DoD) acquisitions. The goal was to examine the process's overall effectiveness at identifying the mission critical requirements and evaluating these requirements during developmental testing. The process was evaluated to determine how system level requirements are developed from user needs. Further investigation was conducted to examine how operational tests are developed based upon the system requirements and the underlying user needs.

Research was done to identify recently developed systems that passed and failed operational testing. Each system was examined to determine sources of success and causes of failure. This was accomplished by addressing questions such as:

- How are system requirements captured in a Capability Development Document (CDD) supported by (or connected to) doctrinally-defined missions?
- Are appropriate user-centric, solution-neutral metrics identified?
- Are a system's external interfaces identified?
- Are realistic Concepts of Operation (CONOPS) used?
- Were testers and end users formally involved in the Systems Engineering Technical Review (SETR)?

The system's ability to meet their requirements and objectives that satisfy the stakeholders' needs were analyzed to determine the mission critical beneficial concepts and shortfalls for a system's engineering process.

2. Generation and Analysis of Alternatives

The analysis of alternatives or down-select was accomplished following the identification of the source of failures pertaining to requirements critical to mission success within the Systems Engineering process. Key decisive criteria were established at this phase to determine feasible alternatives. The application of decisive criteria was employed to exclude undesirable solutions and highlight acceptable alternatives. Multiple process concepts were developed based upon these decisive criteria. Each concept was evaluated for the relative cost of implementation and the cost of execution. These concepts were also rated based on the quality of process improvement, looking at factors concerning thoroughness, traceability, and simplicity. The resulting concepts were evaluated and chosen to develop the best mission criticality process based on cost-effectiveness and process improvement in order to prevent the shortfalls identified in the previous phase.

The programs identified in the previous phase were evaluated to determine what program was going to be used as the representative example. This evaluation was done based on availability of critical information, team knowledge of the programs, and the representative nature of each program. The representative nature was defined as being of sufficient complexity to adequately demonstrate the process and also the likelihood of the problems encountered on that program.

3. Detailed Process Design

The selected process concept was used to develop a mission criticality process that can be integrated into the DoD Systems Engineering process. The new process included new deliverables such as: new exit/entrance criteria, modified documents, new/modified instructions, and organizational charts that describe roles and responsibility. Mission Criticality Process Alternatives were used as reference material when encountering detail design issues. Concepts for improvement were taken from the alternatives developed during the AoA phase during the detailed design. While designing the new process, the mission criticality validation criteria were developed. In the next phase, this process was simulated via a model on the representative program selected in this phase.

4. Process Validation

The new mission criticality process was evaluated on the representative system by performing table-top exercises. The exercises used the validation criteria developed during the detailed process design phase to evaluate the process. Cost data concerning the execution of the process was collected while the process/model was validated. The results from the evaluation were analyzed and reported.

5. Present Recommendations

Once the process was simulated and analyzed, the findings and recommendations were presented to the stakeholders and are reported in this document. This report includes how successful the new process was at addressing the problems encountered on the representative system and how other systems examined could have benefited from this new process. This report includes a cost analysis for implementation of this process for future systems.

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II. PROCESS REVIEW AND PROBLEM REFINEMENT

The authors accomplished several tasks concurrently during this initial phase of the project. First, stakeholder needs and requirements were collected and prioritized. Second, the current DoD Systems Engineering process and Operational Testing process were reviewed and evaluated to determine how system level requirements are developed from user needs and tested. Finally, recently developed systems that had issues arise during OT were identified and examined to determine potential sources of failure. The results of these tasks are discussed in more detail in the paragraphs below.

A. STAKEHOLDER NEEDS ANALYSIS

The stakeholders' needs for this project are based on the results of literature research, communication with the stakeholders, and team experience. The stakeholder needs translate into derived requirements that capture the system's capabilities and constraints for performance design parameters. It was important to the team to understand the stakeholders' needs, as well as the mission requirements, to transform them into defined requirements for the Systems Engineering detailed design phase of the project [Buede, 2009].

1. Stakeholder Identification

The authors produced a list of potential stakeholders for the project. This list was further synthesized to identify additional candidates to ensure that each had an interest in the results of a design solution. Also important to this identification process, was the distinction of which stakeholders may be impacted as a result of the project findings and recommendations. As a result of this process, the following stakeholders were identified:

- <u>ASN (RDA) CHSENG</u>

The Assistant Secretary of the Navy for Research, Development and Acquisition Chief Systems Engineer's Office is responsible for Systems Engineering Technical Reviews (SETR) for all ACAT programs, regardless of the ACAT designation [ASN(RDA), 2008]. CHSENG staffers are interested in the utilization of the possible process changes for incorporation into the SETR [SETR, 2009] process. ASN (RDA) CHSENG also served as the sponsor for this project, the authors were engaged with his representative on a continuous basis to understand and receive guidance on the direction of the project.

- Program Office/Program Managers

The Program Offices and Program Managers for specific development systems may be impacted by this project. The programs may be able to utilize the output of this project to re-define their Systems Engineering process, requirements definition, test planning and conduct.

- Naval War Fighter

The key stakeholder for this project is the naval war fighter or “user” of the system. Although the war fighter does not encounter the identified problem until a system becomes operational, the war fighter is left to deal with consequences of an ineffective system that is delivered with deficiencies. The Joint Capabilities Integration and Development System (JCIDS) [CJCSI 3170.01G, 2009] process describes the Joint Forces Command (JFCOM) as the war fighter representative into the acquisition infrastructure. This representation is flowed down from the Joint Requirements Oversight Council (JROC) to the user. The war fighter or “user” is defined as: “An operational command or agency that receives or will receive benefit from the acquired system” [CJCSI 3170.01G, 2009].

- System Design, Development and Validation Teams

The design engineering teams may be affected by the outcome of this project. This could be the prime contractors, working with the Program Office and also the System Commands (SYSCOM) field activities charged with the system development efforts. The criteria identified for “mission criticality” may have impacts on the design and development of a system, along with the testing requirements identified.

- U.S. Navy Operational Test and Evaluation Force (OPTEVFOR)

OPTEVFOR is the independent operational test agent responsible for assessing the operational effectiveness and suitability of new and improved war fighting systems and capabilities for the military services. The U.S. Navy has its own specific evaluators when reviewing a Navy only system that has no joint services capabilities. The outcome of this project may provide additional information in order to evaluate systems under test.

2. Stakeholder Initial Requirements

As a result of the stakeholder identification process, perceived needs were documented from the definition of the initial problem statement. These perceived needs were further analyzed to ascertain which ones would have an effect, if any, on which stakeholders. This analysis resulted in the identification of requirements that would be of interest to multiple stakeholders. The stakeholder requirements analysis provided the following:

A. Develop a Method to Track Mission Critical Requirements

The first requirement, a method to track mission critical requirements was derived from the ASN (RDA) Chief Systems Engineer Staffer project proposal discussion [McKinlay, 2010]. This requirement would also be shared by the program offices and system design, development and validation teams. The outcome for this requirement is to capture and track critical needs related to a specific mission or missions.

B. Explore a Mission Thread with Respect to Mission Critical Requirements

As a continuation of this need, the ASN (RDA) Chief Systems Engineer specifically requested the exploration of mission threads with respect to mission critical requirements in order to assess the impact to successful completion of OT. The objective of this is to demonstrate how mission critical requirements can be derived from mission threads.

C. Develop a Conceptual Approach to Improve OT Results

The intent of developing a conceptual approach to improve OT results is to allow the authors to present findings in a methodology that could be implemented in a system to identify and track mission critical requirements.

D. Improve OT Success Rate

An inherent need from stakeholders is that the proposed solution offers an improved OT success rate when compared to the current process.

E. Reduce Rework Costs

Finally, the program offices and system design, development, and validation teams communicated that they would desire a net reduced development cost as a result of the implementation of the final recommendation. This net reduced cost will be realized by the reduction in rework from systems passing the first phase of verification testing known as Developmental Testing (DT), but failing to pass the final validation phase of testing, known as Operational Testing (OT).

The combined results of the stakeholder requirements analysis are provided in Table 1.

Table 1. Stakeholders Requirements Results

This table shows the relationship between key stakeholders and high level requirements of this process.

Stakeholders / Requirement	ASN(RDA) CHSENG	Program Office/ Manager	Naval War Fighter	Design & Development Team	OPTEVFOR
A. Develop Method to Track Mission Critical Requirements	●	●		●	
B. Explore a Mission Thread with Respect to Mission Critical Requirements	●				
C. Develop Conceptual Approach to Improve OT Results	●	●			●
D. Improve OT Success Rate	●	●	●	●	●
E. Reduce Rework Costs		●		●	

B. PROCESS RESEARCH

The research process for the Process Review and Problem Identification Phase of the project comprised the following research segments: Requirements Process, Operational Test Process and Failed Systems research. Each segment required investigating and documenting possible root causes for operational test failures. The authors concentrated on areas in the processes that may provide insight into why system were initially passing DT, and then subsequently failing OT. Figure 2 provides an illustration of the segments to the process research phase for the project.

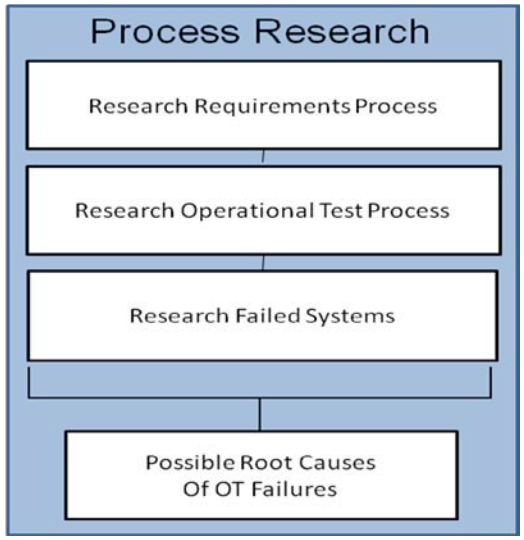

Figure 2. Process Research

The Process Research Phase of this project was comprised of research into three areas and was directed towards determining the root causes of operational test failures.

1. Requirements Process

a. Research Methodology and Objectives

A principal goal of the first stage of the project was to conduct research on the overall Operation of the Defense Acquisition System [DoDI 5000.02, Enclosure 12, 2008] with respect to how requirements are managed throughout the process. This is much more than merely the initial determination of requirements but also includes requirements documentation, validation, decomposition, and testing, etc. This research includes much of the Systems Engineering process that is embedded into the Defense Acquisition System process. The authors focused their research efforts on the regulatory guidance to determine how the process is "supposed" to work. It is important to note here that the program office development organizations are responsible for the generation of the artifacts produced as a result of the acquisition design and development process. These documents are required for incremental delivery to the evaluation authorities in concert with the Systems Engineering Technical Review Process [SETR, 2009]. The quality, clarity and completeness of this documentation are important in the evaluation of systems as it progress through the acquisition process.

The scope of the process that the authors studied for Process Review and Requirements

Identification Phase of this project is shown in Figure 3. This process starts with the determination of system requirements based upon the needs identified by the Capability Based Assessment (CBA) process that occurs as part of Joint Capability and Integration Development System (JCIDS) [CJCSI 3170.01G, 2009] and includes the overall process of determining how well the system meets those requirements over the course of the system development process. Additionally, this process includes how these requirements are communicated from the user community to the development community and how these requirements are documented.

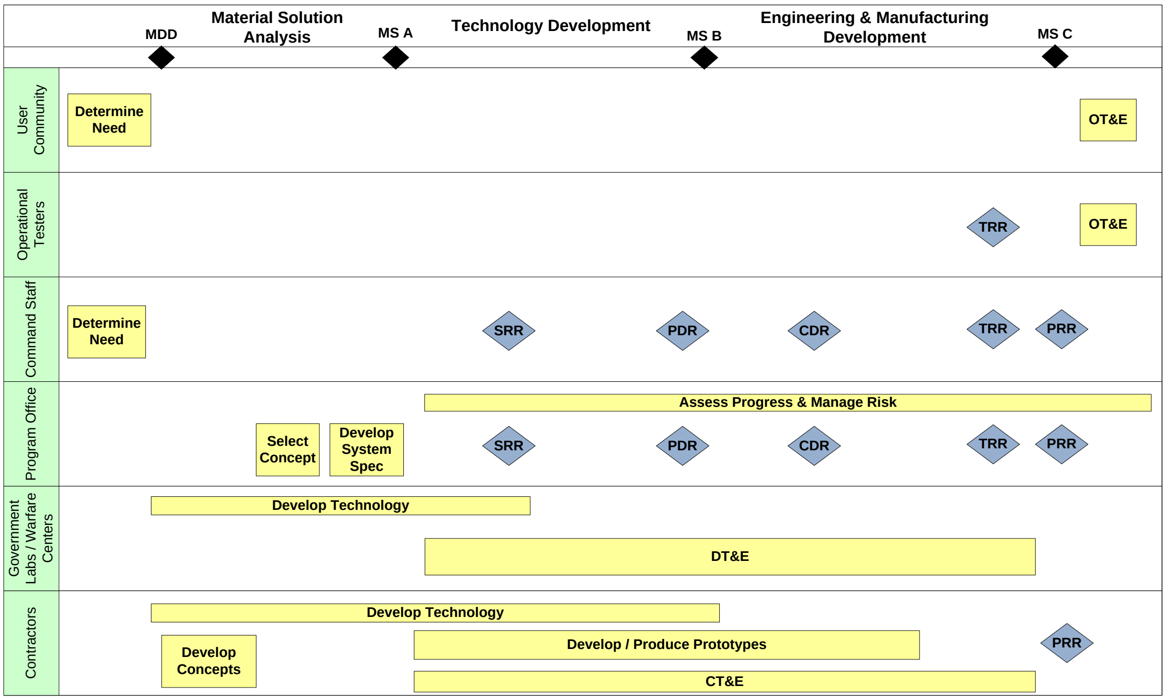

Figure 3. Overview of the Systems Development Process

This high level overview of the systems development process was adapted from CJCSI 3170.01G.

The end goal of this process is to have confidence that when systems reach Milestone C, they will be able to provide the required operational capability in the intended environment. Since problems are being encountered during operational test, one can assume that there is a flaw in the process or that it is not being followed correctly. The overall time of interest is from the CBA process that is performed prior to the Material Development Decision (MDD), through Milestone C, which is essentially the final gate prior to proceeding to Operational Test & Evaluation (OT&E). That being said, official program initiation does not begin until Milestone B and the work performed in the early phases is to lay the foundation for the formal Defense

Acquisition Program that begins at that point. The entire acquisition process varies depending on the nature of the program. For example, a newly designed weapons combat system could take over 5 years to complete its acquisition cycle, while a system or component already in the fleet could take as little as 6 months to integrate since it is already developed. This acquisition timeline varies according to the complexity, technology and funding provided to programs.

Figure 3 is at too high of a level for any amount of meaningful assessment, so the authors developed process maps that were at a lower level so specific steps in the process could be identified for potential improvements. These improvements were viewed from the perspective of possible changes that could be made early in the acquisition cycle that would improve the OT pass criteria. The depiction of the processes in a graphical representation provides the visual insight to understand any inter-dependencies in the processes and associations that may otherwise not be apparent. The authors reviewed Department of Defense, as well as Department of the Navy regulations and guides [CJCSI 3170.01G; DoDI 5000.02, 2008; SECNAV 5000.2D, 2008] to identify the key steps that must occur in order to translate the capability needs into system requirements and then ensure that the system is going to meet those requirements. Inputs for these steps were identified including the Initial Capabilities Document (ICD), Capability Development Document (CDD), system specification, and other requirements documents in addition to additional sources of information that are available [DAU Guidebook, 2010; JCIDS Manual, 2009]. Outputs were also identified and consist primarily of the work products that are generated, including specifications, architectures, etc. The authors also determined the key individuals that are involved in the SE process. These included high-level personnel that are responsible for signing documents and authorizing actions, along with support staff that perform formal or informal assessments which are used as the basis for those high-level decisions [DoDD 5000.01, 2007; DoDI 5000.02, 2008]. Finally, the authors conducted an initial assessment of the regulations to locate potential weaknesses based on sound Systems Engineering principles and to isolate what steps in the process had the highest potential for improvement.

b. Capability Based Assessment Phase

The Capability Based Assessment (CBA) is the first phase of the process and is conducted prior to the decision to pursue a materiel solution. The key activities and work products of this process are shown in Figure 4. Figures 4 through 7 that follow were adapted from the Life Cycle chart produced by the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System, DAU Press, Version 5.3.4 of 15 June 2009 [DAU, 2009]. The ICD captures the results of the Capabilities Based Assessment if a materiel solution is recommended. Alternatively, a DOTMLPF Change Request (DCR) describes a non-materiel solution if one is determined to be feasible. For Navy systems, Chief of Naval Operations (CNO) Code N8 is responsible for acting as the user representative and oversees the CBA assessment once the Joint CONOPS has been developed by the Joint Staff. At this point in the process when a materiel solution is required by an approved ICD, the Milestone Decision Authority (MDA) determines the scope of the subsequent follow on analysis such as the Analysis of Alternatives (AoA) [CJCSI 3170.01G, 2009].

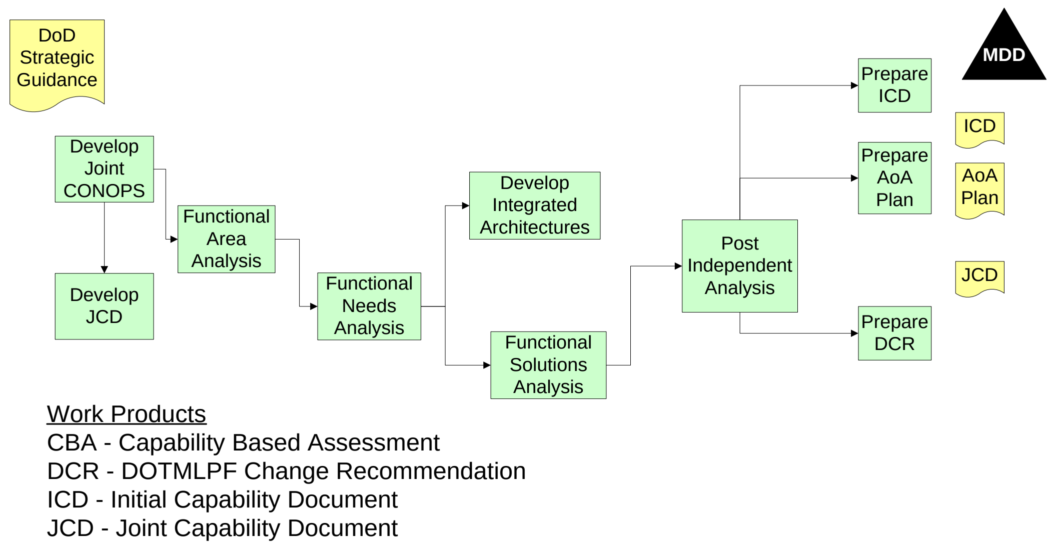

Figure 4. Capability Based Assessment Process

The capability based assessment is the initial JCIDS process for determining if a materiel or non-materiel solution is required to address a user need.

Based on the documents reviewed, there is a heavy emphasis placed upon the performance aspects of meeting the capability needs. Identifications of constraints was discussed in the DAU Guidebook [DAU, 2010]; however, it is unclear how thorough this constraint identification process is and the degree to which the constraints are incorporated into the AoA plan. These constraints would include the operational environment, the support infrastructure that is expected to be available, and what interfaces would be required to external systems.

c. Material Solution Analysis Phase

The Material Solution Analysis phase is built around a traditional V-based SE process, starting with an analysis of the system needs. The major difference in this phase compared with the traditional system development V-based SE process is that no real product is produced. The design ideas and concepts are "paper-based" and are produced as desk-top analyses at this point. This would also include any modeling and simulation that may be required. The process continues with development of multiple concepts down to a level sufficient for a thorough comparison of those concepts, and then testing of those concepts for their relative ability to meet the user needs within the constraints. The key activities and work products of this process are shown in Figure 5.

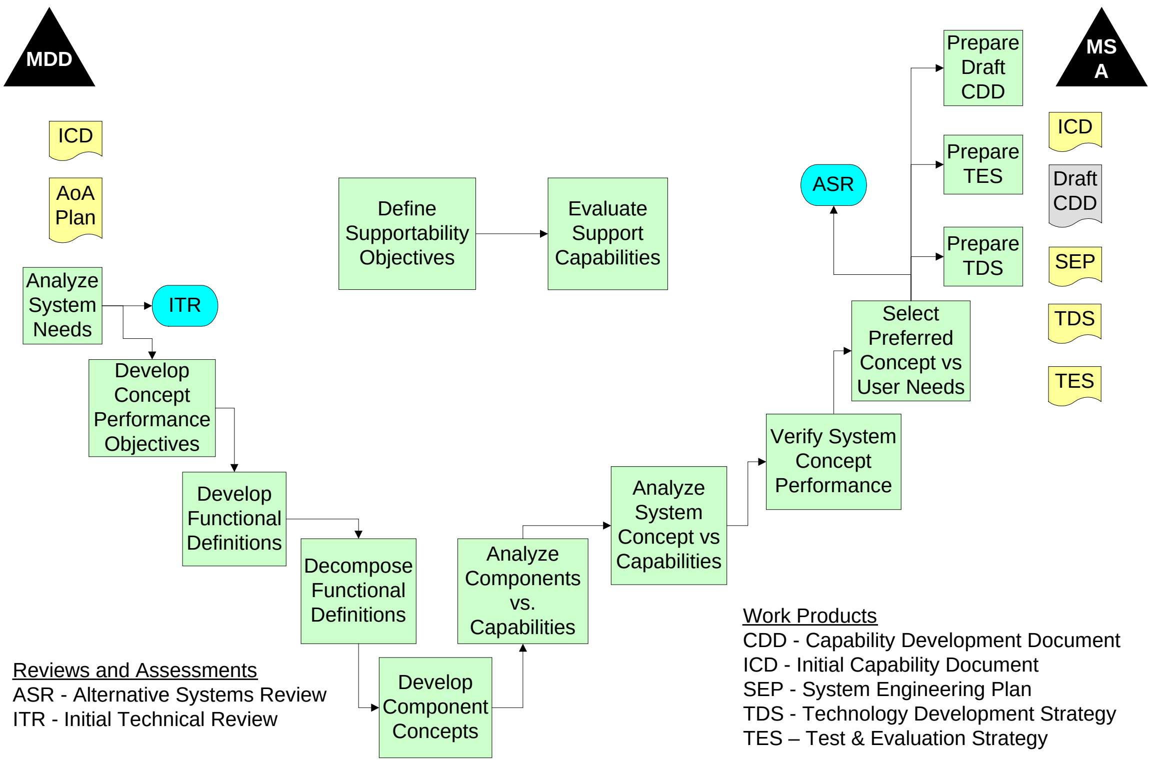

Figure 5. Material Solution Analysis Phase

The Material Solution Analysis Phase selects a preferred concept for meeting the identified user need.

The Analysis of Alternatives (AoA) is the major activity in this phase and is an analytical comparison based on operational effectiveness, suitability, and life-cycle cost. However, the authors' review of the Defense Acquisition Guidebook [DAU, 2010] showed a clear bias towards analysis of effectiveness and life-cycle cost but no mention of how to incorporate operational suitability into this analysis. A system that is not reliable or cannot be maintained will not be of use to the war-fighter, even if the theoretical operational effectiveness of the system is very high. Logistics, packaging, handling, and other factors were included in the Alternative Systems Review checklist but no clear guidance on how much weight suitability factors should carry in the selection of the preferred concept.

In addition, technical risk is not mentioned within the context of the AoA. The concern here is that a concept will be selected that has very promising performance; however, the estimated performance is based upon technology that is not yet mature. If the substitution of these technologies becomes necessary due to lack of Technology Readiness Levels (TRL) growth, there is a significant risk that the actual delivered performance of a system will be quite low even though the program initially offered very good performance.

Another area of concern is the lack of continued development of the concept for how the system will be used. In the CBA process prior to MDD, mission threads are developed that describe how the overall mission will be accomplished and how this system fits into that mission thread. However, at that point in the process, the specifics of the system have not yet been defined. At the end of the Material Solution Analysis phase, a preferred concept for a system has been developed. It would now be possible to specify additional details as to how the system will operate within the context of the mission threads that were previously identified. The authors found no indication that a detailed concept of operational use was required as a deliverable for Milestone A. It was also noted that although specific documents are required for transition out of the Material Solution Phase [DAU, 2010], it was unclear on how these translate into requirements and if these requirements would have a level of traceability back to the original inputs drivers.

d. Technology Development Phase

The primary focuses of the Technology Development phase are to prepare the system and its underlying technology ready for formal program initiation at Milestone B. The key activities and work products of this process are shown in Figure 6. This phase also follows the V process, starting with an assessment of the user needs and culminates with demonstrating or modeling the system to verify compliance with the specification and finally, demonstrating the system concept against the user needs. On the surface, this sounds appropriate; however, two major issues arise.

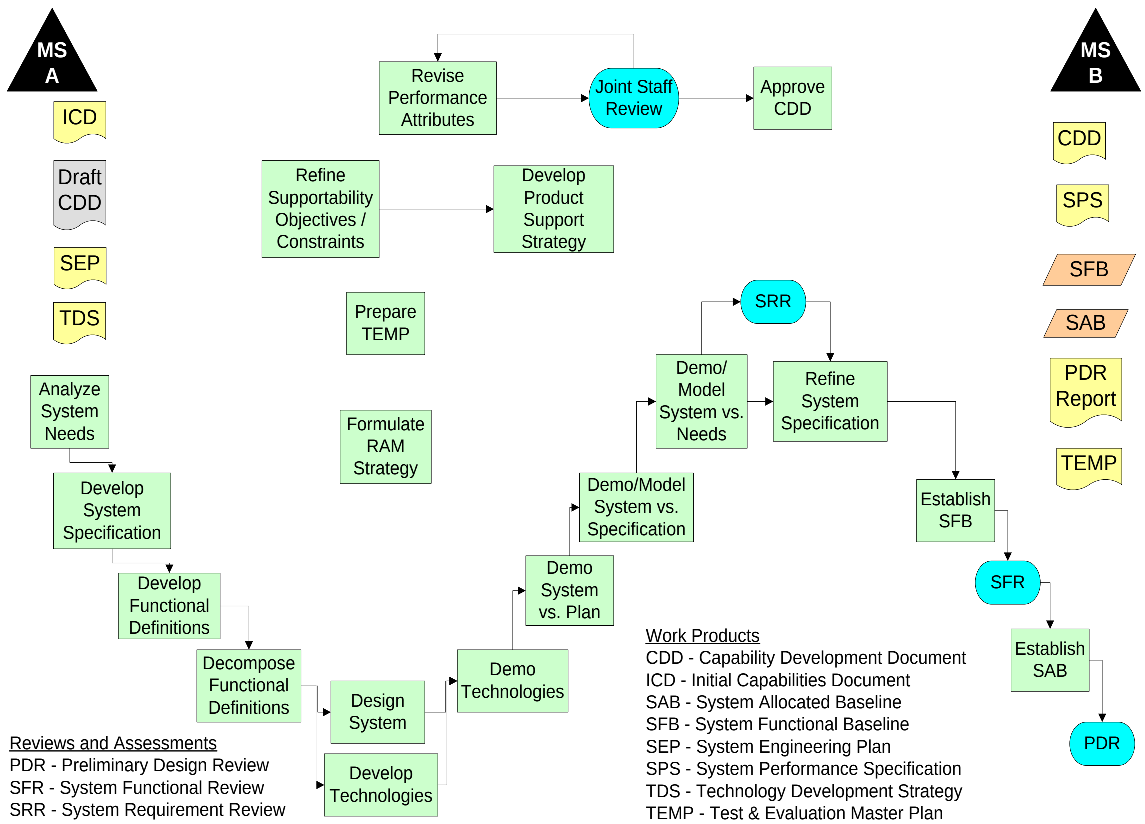

Figure 6. Technology Development Phase

This Technology Development Phase further develops the system design and required technologies.

The first concern is that modeling is considered as a valid alternative to prototyping with no caveats as to when it is or is not appropriate to use models as a substitute for prototypes. The use of modeling has been pushed over the years as a way of reducing testing costs and has come a long way in terms of being able to provide useful information. Development and Contractor Testing results are used in combination with system models to predict performance of the overall system without requiring system level testing. While this approach has proven to be effective for predicting operational effectiveness in many systems, accurate models for operational suitability have proven elusive.

One thing to note here is the Weapon Systems Acquisition Reform Act of 2009 – (WSARA) which requires competitive prototyping prior to Milestone B. On the surface, this looks to be moving in the right direction. Unfortunately, if the prototypes are only compared on the basis of the KPPs and these KPPs do not encompass the full range of requirements including suitability and interoperability, then the full potential is wasted. No guidance could be found that specified the full range of testing that should be done on prototypes prior to Milestone B and how this data should be used in a down-select decision. In addition, this requirement only applies to Major Defense Acquisition Programs (MDAPs). MDAPs are defined as ACAT I programs which is based on guideline dollar values provided by the USD (AT&L) and decided upon by the program office. Dollar value distinctions for ACAT I programs are total expenditure for research, development, test and evaluation (RDT&E) of more than $365 million in fiscal (FY) 2000 constant dollars or, for procurement of more than $2.190 billion in FY 2000 constant dollars [DoDI 5000.02, 2008]. For programs with a smaller expected expenditure, the Acquisition Categories (ACAT) level is lower. Lower ACAT levels result in lower Decision Authority levels required for acquisition decision-making.

e. Engineering and Manufacturing Development Phase

The Engineering and Manufacturing Development phase is focused on implementation of the design and developing sufficient test data upon which to ensure that the system is ready to proceed to operational test. The key activities and work products of this process are shown in Figure 7. At this point, the majority of the system level data should be based upon prototype testing rather than modeling.

A key issue in this phase is the level of user involvement. The authors had some concerns as to the ability of CNO (N8) to act as a user representative with respect to issues that are close to the actual operational environment. In the CBA and MSA phases, having CNO (N8) act as the user representative was appropriate since the focus was on system level interactions. In this phase, user input is needed to resolve operational usage, training, and human interface issues. CNO (N1) has been designated as the lead for Human Systems Interfaces (HSI) although their focus is on manpower requirements, rather than human-machine interactions. The only way to do a proper assessment of these issues is to have prototypes of the system or key components tested by actual users. The only formal mechanism for this in the current process is the Operational Assessments performed by OPTEVFOR but no across-the-board requirement could be found for this

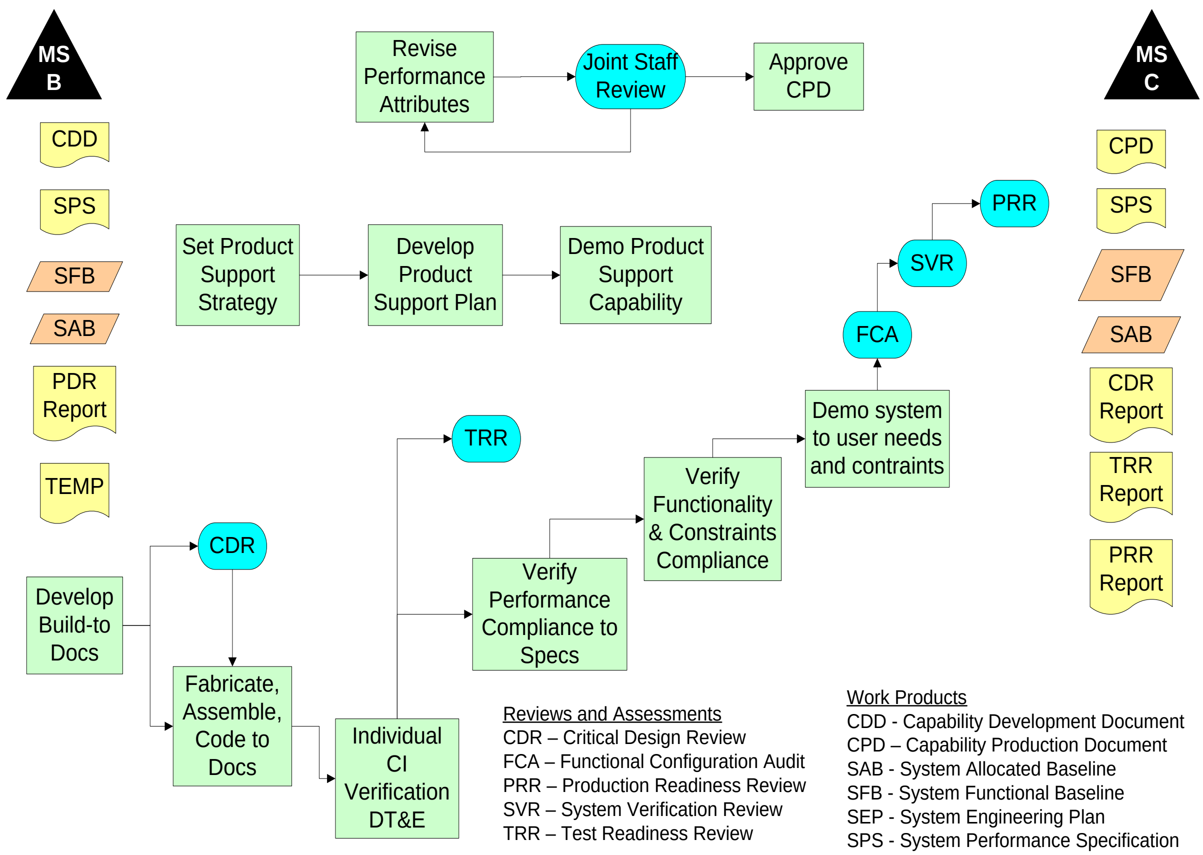

Figure 7. Engineering and Manufacturing Development Phase

This Engineering and Manufacturing Development phase is focused on implementation of the design and developing sufficient test data upon which to ensure that the system is ready to proceed to operational test.

This also raises the issue of a lack of an independent assessment of the readiness for operational test early in this phase. An Operational Test Readiness Review (OTRR) is held immediately prior to Milestone C and the Assessment for Operational Test Readiness (AOTR) is held for some programs after Milestone C and these reviews are focused on assessing if the system is likely to achieve the operational suitability and effectiveness goals in OT. Having a preliminary independent AOTR performed early in the Engineering & Manufacturing Development phase has the potential to identify problems in the design early enough to make changes, or identify if DT&E data is insufficient early enough to plan additional testing.

f. Assessment for Change Potential and Ease of Change

In preparation for the next phase, the authors conducted an assessment of each step that was identified for each of these phases for the relative potential for improvement and leverage for each step. The results of this assessment are shown in Figure 8 The color scheme of the graph is intended to communicate that steps that are in the upper-right-hand corner are the best candidates for change and the lower-left-hand corner indicates poor candidates for change. This initial evaluation was based on the authors' understanding of the SE process and investigation of the researched materials.

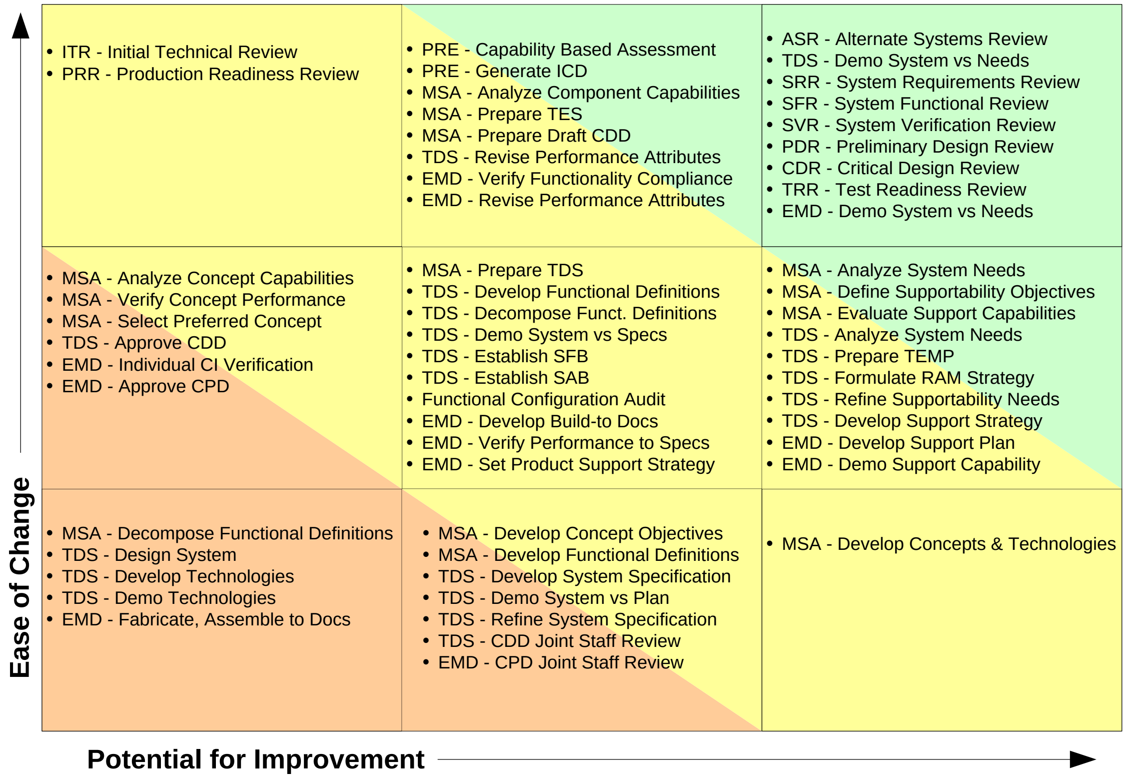

Figure 8. Assessment of Potential and Ease of Change

Each of the steps identified on the previous figures were assessed for their potential for improvement and ease of change. The lower left corner corresponds to steps in which changes are likely to be difficult to implement due to high cost or higher levels of approval in addition to having a low potential for improvement. These steps are labeled in red as being poor candidates for change. The upper right corner is comprised of steps that would require relatively lower levels of approval and funding to change and have a high likelihood of making a significant improvement to the overall process. These steps are labeled in green as being excellent candidates for change. The areas in the middle, shown in yellow, are steps that fall in between these two extremes.

Potential for Improvement is defined as the importance of the step to the requirements process in terms of its ability to predict or prevent problems. The left-hand column of the chart shows steps that do not appear to have many shortcomings from a Systems Engineering standpoint. Also, improvements that are made to these steps will not have a substantial improvement upon the overall results of the process, which is defined as ensuring that systems pass operational test. By contrast, the right-hand column shows steps that appear to not be working as intended such as the design reviews that are supposed to be ensuring that programs do not move to the next stage in the process if they are not ready. This right-hand column also indicates that making improvements to those steps should have a direct improvement on the overall process, more specifically, a higher likelihood of passing OT&E.

Ease of Change is defined as our ability to effect significant change to the step and degree to which that change will be consistent for a wide variety of programs. Steps that have more latitude and are tailored to the program are going to be more difficult to improve because changes to those steps will affect different programs in different ways. Changes to a step may improve the results of some systems but may actually hurt other systems. In addition, steps that are performed by contractors or other organizations are going to be more difficult to change because we have less control over how those steps are performed. Additionally, changes that require additional funding are more difficult. Therefore, the bottom row is those steps that are going to be the most difficult or expensive to change. The top row is those steps that should be easier to change.

g. Summary of Systems Engineering and Acquisition Process Guidance Research

One finding concluded from the research was that there is a significant amount of latitude built into the Defense Acquisition System. This latitude or flexibility was intentional in the design of the process based on the understanding that the process needed to be tailored to the type of system, level of technology development that was necessary and other factors. That being said, there is a limit on the amount of tailoring that is allowed. One example of this limitation is in the checklists that are used for the design and technical reviews. In the past these checklist were modifiable and are now provided as intentionally locked. This was done to prevent the program from changing a wording of a question in order to allow a satisfactory response to a question in order to eliminate oversight. Questions that do not apply to a program can still be marked as being Not Applicable and will not negatively affect the "score" for that category; however, marking a question as Not Applicable still allows an oversight body to question whether a question is truly outside the system scope. This does raise the question of how are programs using this latitude, and whether programs are using the latitude or flexibility allowed by the process or are merely tailoring the process to make it easier for those programs to pass through the gates?

Another finding showed a lot of emphasis was placed on the Defense Acquisition System measurable performance parameters. KPPs are just an example of a high level of these parameters that are used for measuring performance of a system; there are many other requirements that are derived from those KPPs. This is done to facilitate testing that can be performed at a lower level in order to predict higher-level system performance. However, some requirements are very difficult to quantify and if system engineers only look at the measurable requirements and do not take into account the context of those requirements; these developers may believe that they are meeting the system requirements, when in fact they are not. This raises the question of whether the intent of the requirement is getting lost as system developers move down through the decomposition process.

Another issue is the lack of communication between the development community, user community and operational test communities. There was little mention of direct operational test community involvement prior to the Test Readiness Review even though the planning for the Operational Testing starts earlier in the process. The research indicated that the development community and the operational test community essentially work in parallel. The process by which the operational testers develop the testing criteria based upon the user needs is very similar to how the system developers derive the system requirements and earlier communication between these teams should improve the accuracy of both those processes.

2. Operational Test Process Research

a. Research Methodology and Objectives

As this project is in support of naval acquisition, the research methodology was to review the existing Defense Acquisition University (DAU) T&E Management Guide and the existing OT&E process of COMOPTEVFOR, the Navy's OTA. The objective was to identify the existing process steps including inputs and outputs, and to identify participants. Further, the goal was to critically review the regulations for weaknesses and identify potential areas for improvement.

In order to review the existing OT&E process, the following documents currently providing guidance to naval testers were reviewed:

- Defense Acquisition University (DAU) T&E Management Guide
- COMOPTEVFOR Instruction 3980.1 Operational Test Director's Manual
- COMPOPTEVFOR Policy and Information Notice 05-1A, Mission-Based Test Design, The Operational Test and Evaluation Framework, and Integrated Test
- COMOPTEVFOR Policy and Information Notice 05-2, Critical Operational Issue Risk Assessment Reporting Methodology
- COMOPTEVFOR Policy and Information Notice 10-01, Operational Reporting Guidance and Procedure.

The documents provide information on the role of COMOPTEVFOR, apparent overlap of Developmental Test and Evaluation (DT&E) with OT&E, OT&E foundation documents, the Test and Evaluation Master Plan (TEMP), and the test planning process. The overall OT&E planning process is documented in Appendix B.

b. Types of Operational Test and Evaluation

Operational Test and Evaluation (OT&E) can be divided into two phases: OT&E before Full Rate Production (FRP) and OT&E after FRP. OT&E before FRP consists of Early Operational Assessments (EOA), Operational Assessments (OA), and Initial Operational Test and Evaluation (IOT&E). IOT&E is conducted late during low rate production when actual test assets are available in support of a full rate decision review. After FRP, all OT&E is referred to as Follow-on Operational Test and Evaluation (FOT&E). It is conducted using fielded production systems with modifications, upgrades or increments fixing issues that were found during IOT&E.

c. Operational Test and Evaluation Planning

OTAs usually become involved during a system's life cycle during the program's evaluation concepts. It is during this time that OTAs begin to develop strategies for conducting operational tests. The system Program Manager (PM) working with the T&E Working-level Integrated Product Team (T&E WIPT) providing support, is responsible for producing the Test and Evaluation Master Plan (TEMP). All T&E stakeholders participate early in the T&E strategy development and make timely updates. Stakeholders include representatives from Under Secretary of Defense for Acquisition, Technology and Logistics and Director, Operational Test and Evaluation (DOT&E). For programs on the Office of the Secretary of Defense (OSD) T&E oversight list, DOT&E and the Director Developmental Test and Evaluation (DDT&E) approve the TEMP [Defense Acquisition Guide, Chapter 9]. For all other programs, the Component Acquisition Executive (CAE) or designated representative approves the TEMP [Defense Acquisition Guide, Chapter 9]. OTAs are members of the T&E WIPT, working together they are responsible for developing Part III (Test and Evaluation Strategy) and Part IV (Resource Summary) of the TEMP. Part III identifies Critical Operational Issues, future OT&E limitations, and any Live Fire Test and Evaluation (LFT&E). COIs define operational effectiveness and operational suitability for a given program. Prior to IOT&E, COIs are assessed by evaluating risks associated with each COI. During IOT&E, all COI capabilities and functions will be examined. COIs are resolved as SAT, UNSAT, or unresolved. UNSAT or unresolved COIs will be re-evaluated during FOT&E. Figure 9 shows the flow as to how COMOPTEVFOR plans OT&E for the Navy.

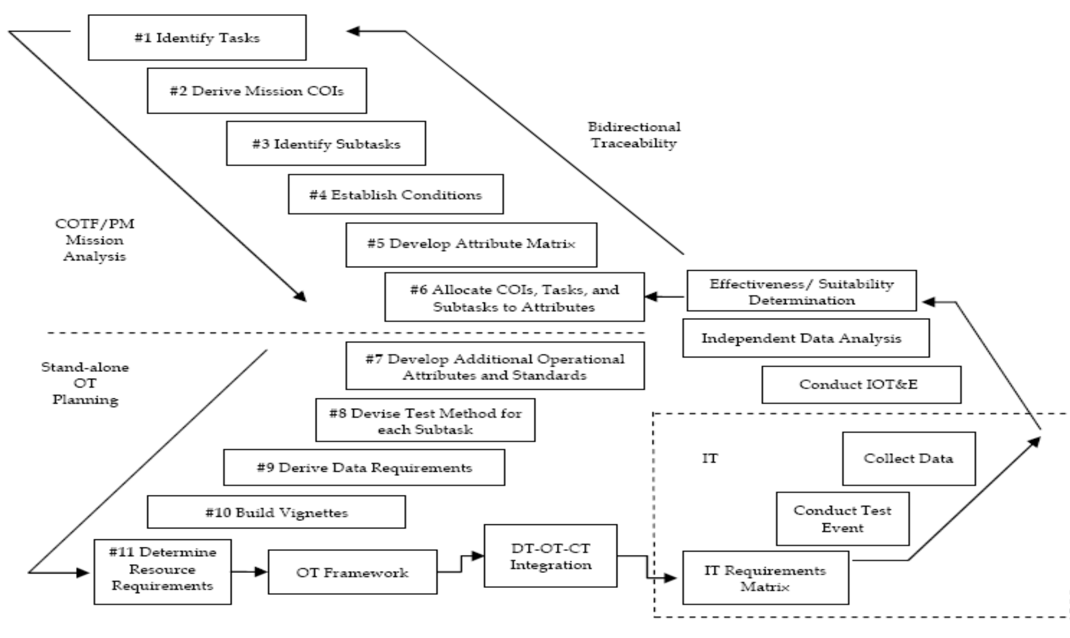

Figure 9. Mission Based Test Design and Integrated Test (MBTD/IT) Process

Process for how COMOPTEVFOR plans OT&E for the Navy, taken from COMOPTEVFOR Instruction 3980.1, 2008.

COMOPTEVFOR, the Program Manager (PM), and other key participants must complete and agree on the product of a mission analysis for the system [COMOPTEVFOR, 2006]. Mission Based Test Design (MBTD) planning process entry point is between Milestone A and Milestone B, but a post Milestone B entry is fine. Mission analysis enables direct traceability of any system enhancement, risk area, or deficiency discovered during testing to a mission or missions. During steps 1-6 of the MBTD, COMOPTEVFOR and the PM conduct a mission analysis where they identify the mission COIs of a system. The mission COIs are identified by conducting an analysis of available documents such as the Operational Requirements Document (ORD), Capabilities Documents, and the Concept of Operations (CONOPS) to identify the mission areas for the system under test. They analyze each mission area to define tasks required to support the mission. Once the subtasks are identified they then establish conditions for each subtask and allocate standards to each task. The tasks and subtasks are correlated to specific capabilities/requirements. Steps 1-6 of Figure 9 provide the Operational Test Director (OTD) with the prerequisites for stand-alone OT planning (Steps 7-11 of Figure 9). At this point they develop additional operational attributes and standards. Test procedures are then written for each standard or qualitative capability considering the tasks, subtask and conditions associated with that capability. Using the test procedures, data requirements are derived, test scenarios built, and test resource requirements are determined. The OTD will then look for opportunities for DT/OT integrations where they can plan to conduct EOAs and OAs. Data collected during EOA and OA is then analyzed before IOT&E. During IOT&E, tests are conducted, data is collected and analyzed. Once the analysis is complete an effectiveness and suitability determination is made. The key takeaways of Figure 9 are steps 1-11. The mission analysis (Steps 1-6) is important because this is where all of the tasks, subtasks, capabilities, and requirements that a system under test will have to meet. Using the outputs of the mission analysis provides the OTDs the information needed for them to plan and execute OT&E (Steps 7-11).

d. Phases of Operational Test and Evaluation

OT&E can be conducted throughout the acquisition life cycle of a system. Before any OT can be conducted, documentation for major systems and those designated y the Director, Operational Test and Evaluation (DOT&E) for oversight must be sent to the Office of the Secretary of Defense (OSD) for approval before the testing can be conducted or the systems can be cleared to proceed Beyond Low Rate Initial Production (BLRIP) [Guidebook, 2010]. Figure 10 shows how OT&E relates to the Milestone process.

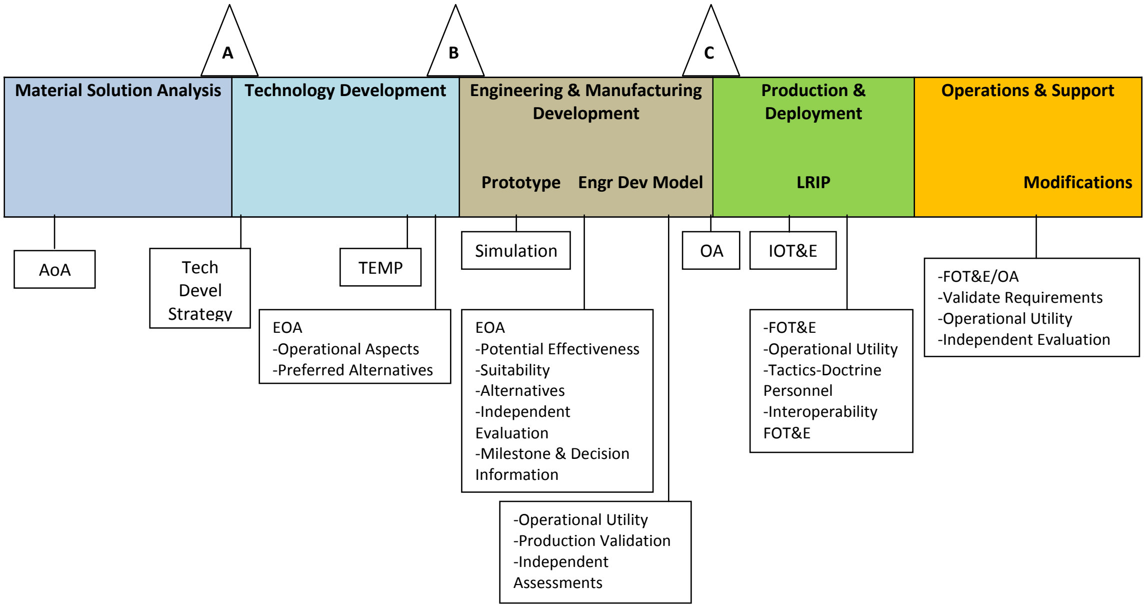

Figure 10. OT&E Relationship to the Milestone Process

Process for how COMOPTEVFOR plans OT&E for the Navy, taken from COMOPTEVFOR Instruction 3980.1, 2008.

During material solution analysis and technology development an Early Operational Assessment (EOA) can be conducted. EOAs are focused on investigating the deficiencies identified during the mission area analysis. OTAs involve themselves during these assessments so that they can validate the OT&E requirements for future testing and identify issues/criteria that can only be resolved through OT&E. This helps initiate early test resource planning. An early assessment can provide data to support a decision on whether the technology is sufficiently mature to support entry into the next developmental phase [DAU Guidebook, 2010]. In addition, EOA can be difficult since testing is done on mock-ups or using models/simulations. Documents are also reviewed and both contractor/government data are evaluated. This leads to inputs being provided into the Test and Evaluation Master Plan (TEMP). Special logistics problems, program objectives, program plans, performance parameters, and acquisition strategy are areas of primary influence to the operational tester during this phase and must be carefully evaluated to project the system's operational effectiveness and suitability [DAU Guidebook, 2010].

Additional EOAs or Operational Assessments (OA) may be conducted during the Engineering and Manufacturing Development phase. OAs are conducted to facilitate identification of the best design, indicate the risk level of performance for this phase of the development, examine operational aspects of the system's development, and estimate potential operational effectiveness and suitability [DAU Guidebook, 2010]. The data collected during these OAs can be reviewed and used to determine whether or not a system is ready to move into the development of the Engineering Development Model (EDM). EOAs and OAs are conducted with DT&E testers, contractors and OT&E testers

During the Production and Deployment phase (P&D), equipment that has been formally certified by the Program Manager as being ready for OT&E is tested [DAU Guidebook, 2010]. Initial Operational Test and Evaluation (IOT&E) is then conducted by user organizations in a field exercise to examine the organization and doctrine, integrated logistic support, threat, communications, command and control, and tactics associated with the operational employment of the system. After the Full Rate Production (FRP) decision, Follow-on Operational Test and Evaluation (FOT&E) is conducted to refine effectiveness and suitability estimates, assess performance not evaluated during IOT&E, evaluate new tactics and doctrine, and assess the impacts of system modifications or upgrades of issues found during earlier EOAs, OAs and IOT&E. FOT&E is conducted by the users in a operational environment. Overall the OTA is required to provide reports of OT&E results in support of Milestone B and C, in addition to the IOT&E report required for the Full Rate Production Decision Review (FRPDR) [DAU Guidebook, 2010].

e. Summary of Operational Test Planning Process Research

COMOPTEVFOR is an independent agent for OT&E in the Navy’s acquisition process whose mission is to “independently and objectively evaluate the operational effectiveness and suitability of new and improved war fighting capabilities” [COMOTEVFORINST 3980.1, 2008: 1-1]. OT&E is to be conducted in as near a real operational environment as possible with fleet personnel operating and maintaining the system under test. As systems are passing Developmental Test and Evaluation (DT&E) yet failing OT&E, it is important to understand the key concepts pertaining to developmental testing. DT&E is planned and conducted by the Design Agent (DA) responsible for the development of the system and Program Executive

Office (PEO) in case of the Navy who assigns a Government agency to conduct DT&E, such as the Naval Surface Warfare Centers (NSWC), Naval Air Warfare Centers (NAWC) and Naval Underwater Warfare Centers (NUWC). These tests can be conducted at a contractor's facility, a government facility or out in the field. One finding showed that the viewpoints between DT&E and OT&E are different. They both differ in the way tests are conducted, in what is being tested, and in the evaluation criteria. Table 2 reflects the key differences.

Table 2. DT&E and OT&E Differences

This table, taken from COMOPTEVFORINST 3980.1, summarizes the differences between Developmental Test and Operational Test.

How Tests are Conducted	
DT&E testing is properly conducted: • In a controlled environment that minimizes the chance that unknown or unmeasured variables will affect system performance • By technical personnel skilled at "tweaking" to maximize performance • Against simulated threats tailored to demonstrate various aspects of specified system technical performance	OT&E testing is properly conducted: • In an operationally realistic environment (e.g., high seas, temperature extremes, high density electromagnetic environments) under conditions simulating combat stress and peacetime conditions • With Fleet operators and maintenance personnel • Against threats which replicate, as closely as possible, the spectrum of operational characteristics • Using Fleet tactics
Testing Subject/Topic	
DT&E tests a weapon or a "blackbox," whatever the development program involves. (Seldom does a development program involve a complete weapon system)	OT&E tests total weapon systems. If a missile is being developed, OT&E does not test only the missile itself, but rather the missile system, which includes the firing platform; that platform's detection, classification, and targeting systems; the people who man it; logistical support; interfacing equipment; etc.
Evaluation Criteria	
DT&E – Technical criteria are parameters measured during controlled DT&E tests.	OT&E – Operational criteria are the CNO-provided minimum acceptable operational performance requirements (older programs) or measures of effectiveness/suitability (newer programs), or thresholds, which quantify the Critical Operational Issues (COI).
Measurement and Frequency	
DT&E • The DA generally knows what he/she wants to measure (some particular parameter: launch velocity; the number of g's pulled as the missile acquires; time to climb; etc.). • DT&E tests are structured to hold many things constant, isolate others, and allow measurement of one or two parameters of interest. • It is generally possible to verify data statistically through replication of tests.	OT&E • It is often not possible to specify measurements. • The objective is often simply to create combat conditions as closely as possible and record data as events unfold. • For aviation OT&E, with highly time-compressed test events and a high cost for OT&E, it is mandatory that OTDs know exactly what parameters of their system must be examined to resolve the specified COI. • OT&E cannot enjoy the luxury of isolating a variable. Methods of data capture must be devised during operational evolutions or during post-operation analysis. • It is often not possible to replicate data because interactions during tests are unique.

One recommendation to improve the test planning process would be for OT&E personnel to work with the DT&E personnel so that DT&E can be conducted in more of an operational test setting and allow for the planning of test phases that provide the necessary data to satisfy common needs of the DA and the OT&E agency. This would have the effect of reducing the differences between DT&E and OT&E cited above, and possibly allow system deficiencies to be discovered earlier in the process during DT&E.

Another possible improvement in the test planning process is in the tracking and review of Critical Operational Issues (COIs). COMOPTEVFOR develops the COIs for each program and publishes them in the Test and Evaluation Master Plan (TEMP). The COIs are linked to CNO requirements established in the Operational Requirements Document (ORD), Analysis of Alternatives (AoA), Initial Capabilities Document (ICD), Capability Development Document (CDD), and Capability Production Document (CPD). COIs define the operational effectiveness and operational suitability for a given system. They are assessed and will be resolved as SAT, UNSAT or unresolved. COIs need to be defined correctly, otherwise incorrectly defined COIs may remain throughout the test planning and test execution. Another recommendation would be for a formal role in the Systems Engineering Technical Review (SETR) for the OT community in which COIs are indentified and validated with the users and traced to the system requirements at several reviews throughout the development phase.

3. Operational Test Failure Research

a. Research Methodology and Objectives

There were two principal objectives to this task. First, research was conducted for historical information that could give some insight as to why some programs fail operational testing. This was accomplished via a search to find publically available literature applicable to operational testing and examining them to identify possible issues or challenges programs in general have experienced. The second objective in this task was to identify actual programs that had recently experienced problems during operational test and examine them to determine potential sources of failure. This was accomplished by requesting documentation from programs via contacts held by the authors and contacts provided by the project sponsor, ASN (RDA) CHSENG. The overall goal with this combined approach was to locate and study previously performed research on this subject (or similar subject) to identify potential root causes, and then compare them to specific programmatic documentation to find any similarities or differences.

To accomplish the first objective of this task, an extensive search of publicly available papers, articles, and reports was complete. These included but were not limited to:

- Government Accountability Office (GAO) reports
- Senate Armed Committee reports.
- Defense Science Board reports
- Various topic papers from the NPS Library

Most of the literature found was very general and not program specific, but it provided good insight to the historical performance of programs undergoing operational testing. From this research several conclusions could be made regarding the sources of OT failures. These findings and conclusions will be discussed in the following sections.

b. Operational Suitability

First, while several programs were shown to have failed OT due to a lack of operational effectiveness (failure to meet performance requirements, functionality, etc.), multiple sources identified a lack of operational suitability as a major cause of failures that is not being adequately addressed by programs. Operational suitability includes requirements such as reliability, availability, maintainability, and training. These operational suitability failures are clearly illustrated in the "Report of the Defense Science Board Task Force on Developmental Test Evaluation" [Defense Science Board Task Force, 2008]. This paper gave a good overview of the historical performance of various programs during OT from all three services from 2001 to 2006. Figures 11, 12 and 13 are copied directly from Figures 1-3 of the DSBTF Report dated May 2008.

Program	Service	ACAT	IOT&E Result		Reason
FY 2001					
F-15 TEWS	USAF	II	Effective	Not Suitable	Reliability, Maintainability, Availability
V-22 Osprey	Navy	1D	Effective	Not Suitable	Reliability, Availability, Maintainability (RAM), Human Factors, BIT
Joint Direct Attack Munitions (JDAM)	USAF	1C	Effective only with legacy fuses	Not Suitable	Integration with delivery platforms
M2A3 Bradley Fighting Vehicle	Army	1D	Effective	Suitable	
FY 2002					
Joint Primary Aircraft Training System (JPATS)	USAF	1C	Effective with deficiencies	Not Suitable	RAM, Safety, Human Factors
Cooperative Engagement Capability (CEC)	Navy	1D	Effective	Suitable	
Multiple Rocket Launcher System (MLRS)	Army	1C	Effective	Suitable	
MH-60S	Navy	1C	Effective	Not Suitable	RAM, excessive administrative and logistic repair time impacted RAM
FY 2003					
B-1B Block E Mission Upgrade Program	USAF	1D	Effective	Not Suitable	16% decrease in weapons release rate, reduction in accuracy of Mark 82 low drag weapons, 14% hit rate on moving targets
Sea wolf Nuclear Attack Submarine	Navy	1D	Effective	Suitable	Several requirement thresholds were not met but overall system effective and suitable

Figure 11. DoD IOT&E Results FY 2001-2003

This figure, from Defense Science Board Task Force, 2008, shows the Initial Operational Test & Evaluation results from FY2001 to FY2003.

Program	Service	ACAT	IOT&E Result		Reason
FY 2004					
Evolved Sea sparrow Missile	Navy	II	Effectiveness unresolved	Suitable	Testing was not adequate to determine effectiveness.
Stryker	Army	1D	Effective	Suitable	
Advanced SEAL Delivery System (ASDS)	Navy	1D	Effective with restrictions	Not suitable	Effective for short duration missions; not effective for all missions and profiles. Not suitable due to RAM.
Tactical Tomahawk	Navy	1C	Effective	Suitable	
Stryker Mortar Carrier-B (MC-B)	Army	1D	Effective	Not Suitable	RAM and safety concerns.
FY 2005					
CH-47F Block I	Army	1C	Effective	Not Suitable	RAM; communications system less suitable than CH-47D; did not meet Information Exchange Requirements for Block I.
F/A-22	USAF	1D	Effective	Not Suitable	RAM; needed more maintenance resources and spare parts; BIT
Joint Stand-Off Weapon-C	Navy	1C	Not Effective		Not effective against moderately hardened targets; mission planning time was excessive.
Guided-MLRS	Army	1C	Effective	Suitable	
High Mobility Attack Rocket System (HMARS)	Army	1C	Effective	Suitable	
V-22 Osprey	Navy	1D	Effective	Suitable	
EA-6B (ICAP III)	Navy	II	Effective	Suitable	

Figure 12. DoD IOT&E Results FY 2004-2005

This figure, from Defense Science Board Task Force, 2008, shows the Initial Operational Test & Evaluation results from FY2004 to FY2005.

Program	Service	ACAT	IOT&E Result		Reason
CY 2006					
Common Missile Warning System (CMWS)	Army	1C	Effective	Suitable	Effective and suitable in the OIF/OEF environment but needs further testing outside of the OIF/OEF environment.
Deployable Joint Command and Control (DJC2)	Navy	1AM	Effective	Not Suitable	Operational Test Agency, COTF, reported effective, not suitable. BLRIP not complete.
Integrated Defensive Electronic Countermeasures	Navy	II			Test suspended due to reliability problems.
Surface Electronic Warfare Improvement Program (SEWIP) Block 1A	Navy	II	Not Effective	Not Suitable	Block 1A Upgrade does not make the AN/SLQ-32 EWS operationally effective and suitable but does enhance ability to protect ships
C-130J	USAF	1C	Effective single ship; Not effective in formation	Suitable with shortfalls	Effective single ship; not effective in formation air land / air drop; not effective in non-permissive threat environment. Shortfalls in suitability due to maintainability issues
Small Diameter Bomb (SDB) Increment 1	USAF	1D	Effective with limitations	Suitable with limitations	Limited effectiveness and suitability due to bomb rack reliability and deficiencies in software used to predict optimum fuzing solutions. Oct 2006 flight operations suspended

Figure 13. DoD IOT&E Results FY 2006-2008

This figure, from Defense Science Board Task Force, 2008, shows the Initial Operational Test & Evaluation results from FY2006 to FY2008.

It can be seen that the majority of the failures in OT between 2001 and 2006 were due to a lack of operational suitability. These were mostly identified as reliability shortfalls, maintainability issues, or interoperability problems. The lack of operational suitability was also identified as a major contributor to OT failures by Dr. Charles McQueary, the Director for Operational Test and Evaluation, in a 2007 interview:

> Test results since 2001 show that almost 50 percent of DoD's programs in oversight are unsuitable at the time of initial operational test and evaluation--IOT & E--because they do not achieve reliability goals [McQueary, 2008: 4].

The research suggested several underlying causes for the operational suitability failures. The first is the inadequate early investment of programs into a robust operational suitability program. This could result in OT failures due to inadequate, unrealistic, or even omitted operational suitability tests or simulations performed early in the program that could potentially identify shortcomings prior to comprehensive operational testing [Defense Science Board Task Force, 2008; McQueary, 2008]. In particular, without a robust operational suitability program, modeling and simulation techniques often used in lieu of early testing may not adequately measure operational suitability requirements. Operational suitability can be a particularly difficult area to model and simulate, and physical testing can prove to have unforeseen effects on systems not shown during simulations.

Secondly, some research suggested that deficiencies in training methods for both the operational use and the maintenance of the systems may be masked during early developmental testing. Contractors are often present during early testing and are readily available to fix any problems that come up in early tests due to inadequate user training. During OT, contractors are usually not available to solve problems, and training deficiencies become much more apparent [Schrobo, 2010].

Finally, many systems are entering OT with operational suitability deficiencies that point to inadequacies in the Systems Engineering Technical Review (SETR) process. All programs must demonstrate they meet certain stated operational suitability requirements in order proceed through the project phases, yet in some cases the SETR process is either not identifying deficiencies in the system or is allowing the system to proceed to OT regardless [Defense Science Board Task Force, 2008].

c. Interoperability and Integration

Interoperability and integration was another major source of OT failures identified in the research [GAO, 2008; DeLaurentis, 2009]. Several potential sources of failure were identified, many of which are similar to the issues operational suitability suffered.

First, it was recognized that incorrect or inadequate requirements may be identified during the program’s requirements process. This may be due to the difficulty of working with large System of Systems (SoS) that have many different Technology Readiness Levels (TRLs) amongst its components, especially if a legacy system is incorporated. TRLs are not adequate as a metric to measure system integration, and may mislead the program in assuming that any interoperability challenges are minor and easily handled [Sauser et al, 2009]. Incorrect or inadequate requirements may also be due to the lack of control the SoS engineer may have over the component systems; while incorrect or incomplete information about the component systems may be used to formulate unrealistic interoperability requirements [DeLaurentis, 2009].

Second, it is recognized that there are several root causes identified that were associated with interoperability, in particular with regards to early testing and/or simulation. Similar to what can occur with operational suitability, early interoperability testing and simulation could be either inadequate or unrealistic, or not being performed at all. Unfortunately in large SoSs, early demonstrations of interoperability are usually limited to simulations, which are inadequate and/or unrealistic for interoperability tests. This makes early program testing unfeasible. In these cases, unless the early simulations were accurate in modeling the SoS, deficiencies in interoperability will likely not be discovered until comprehensive operational testing.

Finally, the fact that many systems are entering OT with interoperability deficiencies, points to inadequacies in the Systems Engineering Technical Review (SETR) process. Assuming the interoperability requirements for the program are correct and realistic, the SETR process is either not identifying deficiencies in the system or is allowing the system to proceed to OT regardless.

d. Testing Methodologies

While reviewing general testing methodologies frequently identified within the researched literature, an issue was discovered on how to properly implement early “operationally realistic” testing. Performing early testing in areas such as effectiveness, interoperability and suitability is cited many times as a method of alleviating failures in OT; however, it has been stressed that such early testing must be as “operationally realistic” as possible in order to properly identify deficiencies in the system. As discussed earlier, inadequate or unrealistic tests or simulations performed early in the program will not prevent failures from occurring during OT. Unfortunately, it is often the case that inadequacies in the early testing are not discovered until such OT failures occur.

One methodology that needs to be stressed is the involvement of OT personnel early in the program [McQueary, 2008]. Early involvement of OT personnel can identify requirements that are unrealistic or impossible to test for. By engaging test personnel early and often, a program can ensure that the early testing and simulations they perform are as adequate and realistic as possible, and catch any system deficiencies before they enter OT.

e. Program Research

To accomplish the second objective in this task, the authors identified actual programs that had recently experienced problems during operational test and obtained operational test documentation from them to review. Several of the authors had contacts with applicable programs; others were provided by the project sponsor, ASN (RDA) CHSENG. The documentation received from all sources was reviewed and evaluated. Note that much of the program documentation that was received was classified; therefore, no specific (technical) causes of OT failures will be discussed in this report. Appendix B lists references for all COMOPTEVFOR reports used during this research.

Information was provided for a total of 6 separate programs. All of the programs reviewed encountered major problems during OT; the general causes of their failures are summarized in Table 3.

Table 3. Summary of Reviewed Programs

This table summarizes the systems that were studied and the types of failures that were identified.

	Performance/ Functionality	Survivability	Interoperability	Reliability	Training	Documen-tation
Mark XIIA Mode 5 IFF	●	●	●	●	●	
SSDS MK 2 MOD 2			●		●	
Cooperative Engagement Capability	●		●	●		●
AN/WLD-1 Remove Minehunting System			●	●	●	

The review of the OT reports and other provided documentation identified similar trends and issues found during the literature research. Interoperability and reliability were cited as the most frequent deficiencies, with training deficiencies not far behind. The IFF, SSDS and CEC programs both cited major problems in interoperability during OT [COMOPTEVFOR (MK XIIA), 2009; COMOPTEVFOR (SSDS), 2008; COMOPTEVFOR (CEC), 2001], while the IFF, RMS, and CEC programs found major deficiencies in reliability, both with regards to hardware and software [COMOPTEVFOR (MK XIIA), 2009; COMOPTEVFOR (RMS), 2007; COMOPTEVFOR (CEC), 2001] .

The program and test community documentation research matched the results of the open literature research very well. While some programs did fail OT due to performance or functionality deficiencies, the majority of programs reviewed had greater problems with interoperability and operational suitability (reliability and training in particular).

f. Summary of Open Literature and Program Documentation Research

Based on the results of the open literature and program documentation research, several general conclusions could be made regarding the causes of OT failures. First, while many programs fail OT due to operational effectiveness deficiencies, the bulk of the systems cited in the literature and the specific programs that were reviewed have seen failures in OT due to a lack of operational suitability or interoperability. These are mission critical areas of concern; however, when compared to standard performance goals these areas can be nebulous, difficult to test or simulate in a realistic way, and may be prone to being disregarded due to programmatic pressures.

Secondly, for all areas (effectiveness, suitability, and interoperability), the inclusion of OT personnel early in the process is important to ensure adequate, realistic testing or simulation is performed prior to OT to discover any deficiencies. Any simulations that are performed in lieu of early testing must also be validated to ensure deficiencies are being properly identified. And finally, there may be issues with the SETR process. In some cases, deficiencies found during early testing or simulations have not been identified in the SETR process. Or if they have, programs somehow are proceeding to OT regardless.

C. PROJECT RESCOPE

1. Bounded Problem Statement

After considering the advice provided by the panel to the authors at the first IPR, it was decided to reduce the scope of the project by only considering OT failures that occurred in a single mission critical area. The open literature and program/test documentation research performed in the Process Review and Problem Identification Phase identified two major mission critical areas where OT failures were likely to occur: operational suitability and interoperability. Enough literature and example programs had been identified to support a focus in either area; however it was noted that improving the operational suitability of systems had already been the focus of several government studies to date that had provided their own conclusions and recommendations. In an effort to avoid repeating previous works, OT failures due to a lack of interoperability were chosen to be the focus for the remainder of the project.

The definition of "interoperability" was very important to gain this focus on the project. It was determined by the authors that a comprehensive definition of interoperability would need to be agreed upon for use during the remainder of the efforts. Research into the available literature revealed a wide variety of interoperability definitions [Carney, 2005; Morris, 2004; Brownsword, 2004; Ford, 2010]. Furthermore, it was discovered that the definition of interoperability often overlapped definitions of the related concept of "integration," creating confusion between the meanings of the two terms. Clarification of the terms was also requested from the project sponsor. The sponsor suggested the definitions of: "Interoperability is putting two or more systems together in any way, seamless or not and that connection allows performance of a new requirement for the systems or an enhanced requirement in one of the existing systems. Integration is simply putting two or more components together in a seamless way so the system operation meets required performance" [McKinlay, 2010].

Taking into consideration the researched definitions [Carney, 2005; Morris, 2004; Brownsword, 2004; Ford, 2010], the recommendation from the sponsor [McKinlay, 2010] and the definition called out in the Department of Defense Joint Publication [DoD JP 1-02, 2008]; it was determined that the definition in the *Department of Defense Dictionary of Military and Associated Terms* [DoD JP 1-02, 2008] would be the best definitions to use for this project. The authors wanted to comply with the standard military definitions such that this meaning would be common across military applications and understandable to engineers and analysts working on military systems. These definitions are sufficient for the purpose of this project because they provide for a common understanding for the elements that make up a System-of-System. The definitions provided in JP 1-02 and used in this project are:

Interoperability

The condition achieved among communications-electronics systems or items of communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users.

Integration

The arrangement of military forces and their actions to create a force that operates by engaging as a whole.

The expected deliverables of this project remained the same: recommended changes to the Systems Engineering (SE) processes in the Defense Acquisition System in order to increase the percentage of programs that successfully pass OT&E and therefore decrease the cost and schedule delays associated with programs failing OT&E. However, with the decreased scope to focus on only one mission critical area, the recommended changes would now only focus on improving interoperability performance during OT&E.

2. Requirements of the Bounded Problem

Once the scope of the project had been narrowed, it was necessary to revisit the initial requirements to review their applicability and add additional requirements that were discovered during the first phase of the project. The following requirements were indentified early in the Review and Problem Identification Phase and were described in detail in Section A above:

A. Develop a Method to Track Mission Critical Requirements

B. Explore a Mission Thread with Respect to Mission Critical Requirements

C. Develop a Conceptual Approach to Improving OT Results

D. Improve OT Success Rate

E. Reduce Rework Costs

These requirements still apply after reducing the scope of the project to focus on the interoperability mission critical area. Requirements C, D and E could remain as written, however the first two requirements were refined as:

A. Develop a Method to Track Interoperability Requirements
B. Explore a Mission Thread with Respect to Interoperability Requirements

Additionally, a number of deficiencies were identified by the authors as described in the research section and these deficiencies must be taken into consideration in the design of any solution. These requirements were added to form an expanded requirements list of the bounded problem:

A. Develop a Method to Track Interoperability Requirements
B. Explore a Mission Thread with Respect to Interoperability Requirements
C. Develop a Conceptual Approach to Improving OT Results
D. Improve OT Success Rate
E. Reduce Rework Costs
F. Improve Visibility of System Performance Throughout the Process and Earlier Detection of Problems
G. Improve Alignment of Developmental Testing to Operational Testing
H. Improve Alignment of OT&E Critical Operational Issues and System Design Requirements
I. Minimize Time and Cost Required to Implement the New Process

3. Value System Design

The value of a new process for the various stakeholders is a function of the ability of the new process to minimize cost, improve schedule, and improve the performance of the system in addition to meeting all required regulations. Additionally, the ease and speed of implementing the changes will increase the customer value by allowing the benefits of the new process to be achieved earlier. There are several components of each of these five primary factors as shown in Figure 14.

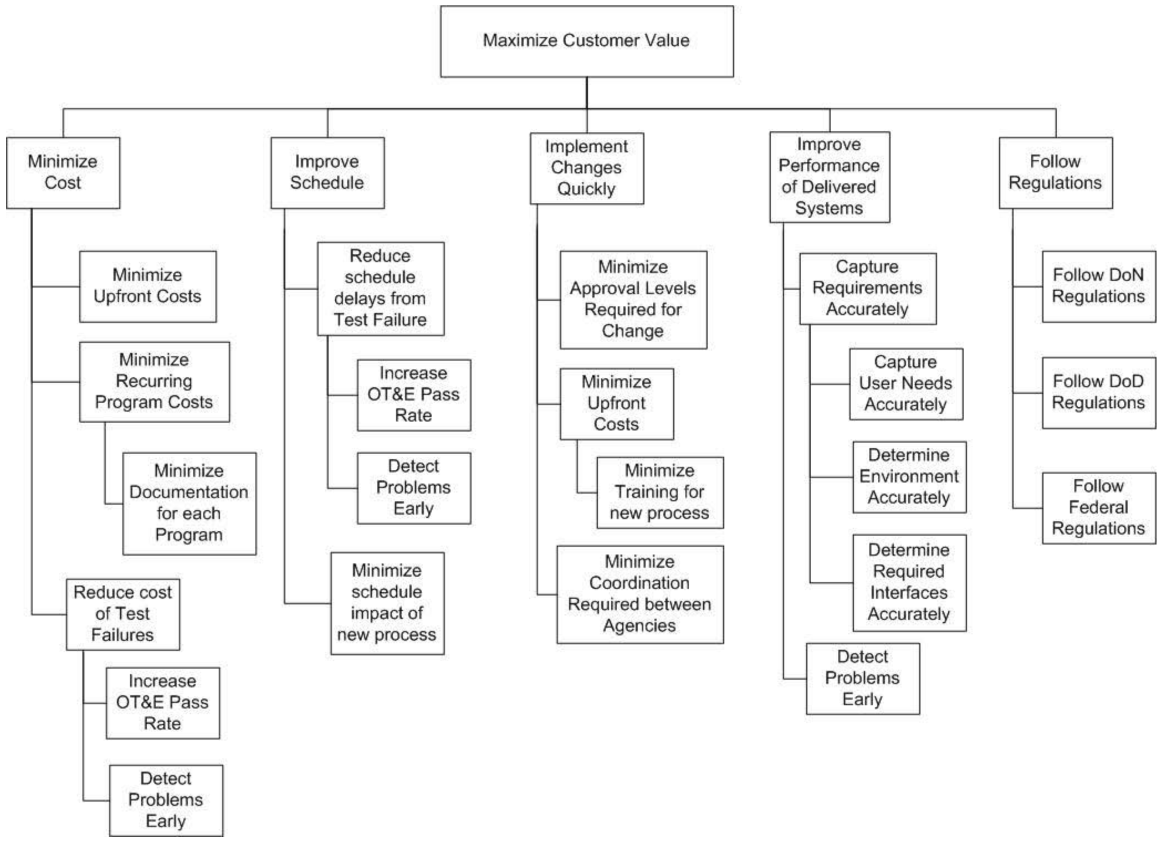

Figure 14. Value System

This figure shows the hierarchy of values for this process based upon a study of the stakeholder needs.

Each stakeholder would assign different preference weightings on the relative importance of each of these factors based upon their point of view and underlying role in the process. For example, the war-fighter would likely put maximum importance upon the performance of the system and would also place significant importance upon schedule performance since delays in system delivery will deny the war-fighter the benefits of the new system. Alternatively, the program office is primarily focused upon meeting the schedule and cost requirements in addition to meeting all regulatory guidance. That is not to say that the program office places no importance on system performance; however, they must balance the needs of the war fighter with the fixed constraints of budget and regulations.

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III. ANALYSIS OF ALTERNATIVES

Following the completion of the first phase of the project and the subsequent re-scope to focus on OT failures due to interoperability, the down selection or Analysis of Alternatives (AoA) phase was begun. The term AoA is used throughout the remainder of this report and is synonymous with the term down selection. Several tasks were completed during this phase. Alternative solutions were developed by utilizing a multi-step brainstorming process. Alternative solutions were compared and the one with the greatest potential to be successfully developed and integrated into the existing SE process was selected for further development in the Analysis of Alternatives Phase. The results of these tasks are discussed in more detail in the paragraphs below. Last, a representative system that had recently encountered problems during OT was selected for use during the remainder of the project as a baseline system.

A. CREATING DESIGN ALTERNATIVES

1. Generation of Alternative Solutions

In order to begin the Analysis of Alternatives phase of the project, the authors conducted brainstorming sessions. The focus was to come up with ideas that could affect the Systems Engineering process, resulting in successful demonstration of interoperability requirements during operational testing.

Each brainstorming session generated and discussed various ideas for solutions, ensuring that each member understood the concepts. Sources of ideas included the research conducted during the first phase and also real-world experiences of the authors. The ideas were refined throughout various discussions and documented. While some ideas are not as conventional, practicable or feasible as others; all ideas were accepted during this process to promote creativity and ensure as many possible solutions were considered as possible. Each idea was assessed by the group to ensure it had the potential to fully meet the requirements outlined in the previous chapters. As the ideas developed more fully, this assessment continued throughout the down selection process, aiding in the decision to eliminate some of the proposed idea.

At the completion of the brainstorming, a single list of potential solution concepts was created. These ideas were then reviewed and compared. The authors took this opportunity to modify some ideas, combine similar ones and improve the description of others based on similar ideas provided. The ideas varied greatly, using various approaches that affected the Systems Engineering process at different phases; however all ideas addressed methods to reduce interoperability failures in OT. Once these potential solutions were finalized and compiled, the next step was for the authors to rank the relative effectiveness and potential cost of each solution.

2. Initial Solution Comparison

While most of the suggested processes were worth considering, it was decided that a much smaller number of ideas should be selected and refined for inclusion in the Analysis of Alternatives. To accomplish this, the initial solutions were subsequently reviewed, categorized, and consolidated based on two criteria factors: cost and effectiveness. Cost at this step is defined as the additional financial burden of implementing and sustaining a potential solution in the process. No dollar values were calculated; rather, the relative cost of each solution was predicted as compared to the other solutions. Similarly the relative effectiveness or positive impact on the OT&E pass rate was predicted for each solution as compared to the other proposed solutions.

This initial evaluation was a qualitative measure that was used to drive the decision making process. With little detail developed for each solution at this point, the originator(s) of each solution explained each potential solution and the group discussed the benefits for each and the effectiveness it would have on decreasing OT&E failures. The authors once again relied on personal lessons learned, previous technical experience, expert technical knowledge, and information gathered as a part of the research phase to make these qualitative selections. No actual costs or effectiveness measures were generated at this point, but rather the 63 ideas were compared amongst each other, searching for a reasonable "bang for the buck." It was determined that at such a high level as this initial comparison, cost and the effectiveness of reducing OT failures would be the most important factors for the stakeholders. Figure 15 shows these relative comparisons plotted on two axes: Effectiveness vs. Cost. Of the 63 original ideas, some were determined to be duplicative and were combined with the redundant counterparts while others were determined to be unachievable or unrealistic. However their usefulness for sparking creativity and generating new lanes of thought and ideas during the brainstorming process made them relevant up until this point. This resulted in 41 ideas being considered to be relevant and were graphed. A full listing of the ideas that were generated during the brainstorming sessions can be found in Appendix C.

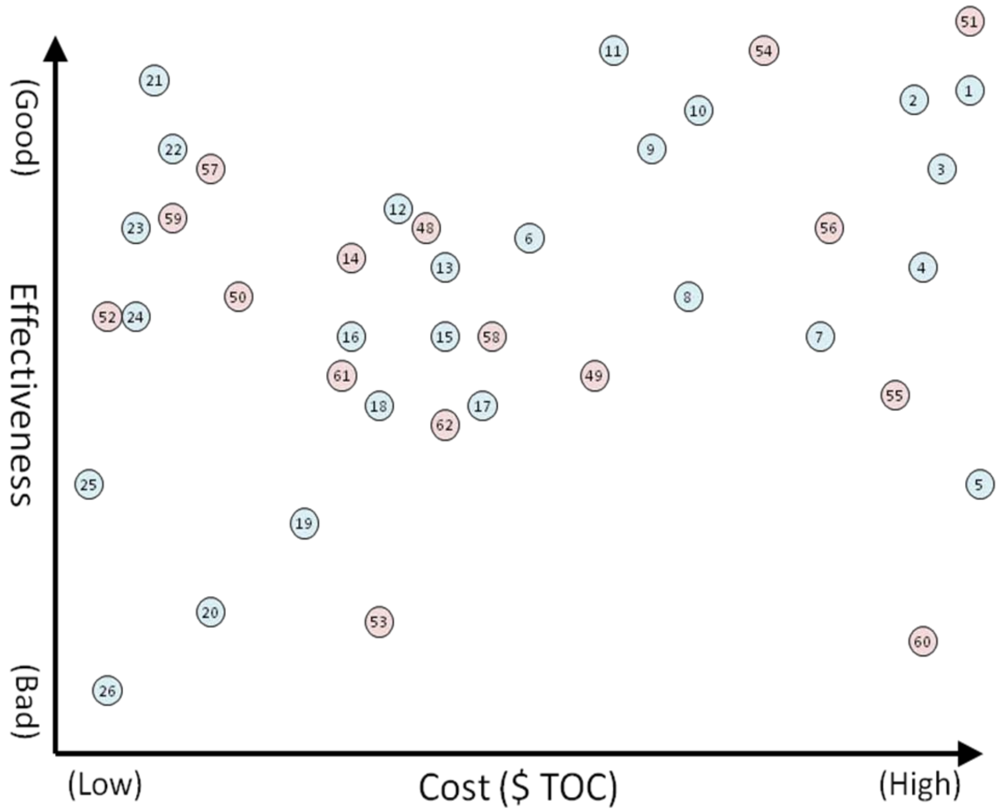

Figure 15. Scatter Plot of Solutions, Effectiveness Vs Cost

Each of the ideas was graphed based upon the expected effectiveness of each change and the projected total lifecycle cost impact.

3. Down Selection of Refined Solutions

Once the original list of 63 ideas had been consolidated to 41 distinct options and these options graphed for relative effectiveness and cost, the authors then selected a subset of concepts that had a high probability of success and effectiveness while managing total ownership cost. Location on the graph was not the exclusive selection criteria; rather, it was a means of screening out options that clearly did not have a high rate of return relative to the expected implementation cost. After reviewing the 41 options individually, each author had an opportunity to provide input into the first down selection; either from the list or new options conceived during the review process. There were a total of eight proposals put forth by various authors for further consideration; these are listed in Table 4.

Table 4. Solutions for Improving Interoperability

This table summarizes the down-selected solutions that were determined by the authors to have a high probability of success and manageable total ownership cost.

Solution #	**Description**
1.	Incorporate backwards compatibility in standards for OT
2.	DT exit criteria to include OT pass criteria
9. & 10.	Standardization of DT simulation and modeling
13.	Use of mission threads for interoperability tests
15.	Create a new color of money for testing
16.	Consider Interoperability at all milestone reviews
21.	Develop Interoperability Readiness Levels (IORL)
57.	Reevaluate the passing criteria for interoperability

As shown in Table 4, potential solutions #9 and #10 were combined as one process. Most of the processes selected have a relatively high expected effectiveness rating while the cost ratings range from low to high meaning that the anticipated cost to implement these proposed improvements varies significantly.

After reviewing the suggested solutions, the authors then discussed each of these options to determine if there was sufficient interest in pursuing each solution and to further reduce to a manageable number of solutions (five or less). To achieve this, a democratic process of elimination was used. Each of the authors chose three proposals they would like to see considered in the AoA based on engineering judgment. It was quickly evident that five of the eight proposals had interest from at least 40% to 90% of the group, while the remaining three were only selected by one or two of the authors. These three with only limited support were eliminated, and no further reduction was required.   Table 5 summarizes the final five processes that were selected for AoA.

Table 5. Final Alternative Solutions

This table summarizes the final alternative solutions that were selected for the Analysis of Alternatives.

Solution #	Solution Description	Effectiveness	Cost
2	DT exit criteria to include OT pass criteria	Very Effective	High
9 & 10	Standardization of DT simulation and modeling	Very Effective	Medium
13	Test to Mission Thread at interoperability OT	Effective	Medium
16	Consider interoperability @ all milestone reviews	Effective	Low
21	Develop Interoperability Readiness Levels	Very Effective	Low

4. Refinement of the Alternatives

At this point the final down selection could be made in the AOA. While the full development would only be completed on the final alternative selected, all of the authors did not fully understand each other's ideas at this point to make a final decision. Therefore each of the five alternatives was further defined, by the originating author. This was each author's opportunity to advocate their option as the best alternative to the body of authors. The following five alternative descriptions were used as frame of reference to choosing the one alternative that would be developed; they were not intended to be fully developed solutions and are provided here solely to illustrate another step in the progression toward the final solution.

a. DT Exit Criteria to Include OT Pass Criteria

The first alternative was focused on preventing programs from entering Operational Test and Evaluation (OTE&E) despite known problem areas in the Critical Operational Issues (COI). This option utilizes the TEMP to define COIs to which the system is tested to and evaluated against. During the early stages of development the TEMP has not been fully developed, thus the effectiveness of this approach is limited during early phases of a program. However as the TEMP is refined it is possible to align the DT exit criteria to the OT pass requirements by including Operational Testing pass criteria during Development Testing. OT and DT viewpoints are often completely different as discussed in Chapter II of this report, specifically Table 2; however, this does not mean they cannot work together. OT and DT usually differ in what is being tested, the way tests are conducted, the test measurements and the evaluation criteria. DT generally involves testing using a black box concept or a component as a part of the basic system with little to no testing of the complete system; in contrast to OT which is always at the system level. Under this concept, the final testing in DT would include testing of the complete system.

The current process for DT only tests technical criteria under a controlled environment. DT should be able to measure the quality of a basic combat condition. The current process measures particular parameters (i.e. the number of g's pulled as the missile acquires; missile launch velocity; etc...). In addition to technical specifications, DT should test performance capabilities (continuing with the same missile example, the successful tracking of the target by radar, etc). DT is performed by the Development Contractor and can be witnessed by Independent Verification and Validations (IV&V), and/or any other designated representatives. Exit criteria or successful completion of DT testing requires that all the test documentation has been approved, all test scripts have been executed and trouble reports are generated for each failure or anomaly, all trouble reports have been resolved all changes made as a result of trouble reports have been tested, and the test report has been reviewed and approved. DT is mainly conducted at the development contractor's facility and usually does not have physical interface with external systems. By including OT pass criteria to DT exit criteria; it will require early involvement of the Operational Test Community (OPTEVFOR) to ensure the interoperability requirements are included in the DT&E process.

For this solution, the development agent and OPTEVFOR will work closely to develop the T&E Master plan at the early program development cycle. The Critical Operational Issues (COIs) that relate to operational effectiveness and operational suitability need to be defined and examined to determine the system's capability to perform its mission. The system integrator will implement and incorporate the COIs into the development test (DT) plan. If there are interoperability issues identified during the DT, the issues need to be documented and changes to system detailed design may be required. A simple functional flow block diagram of this process is shown in Figure 16.

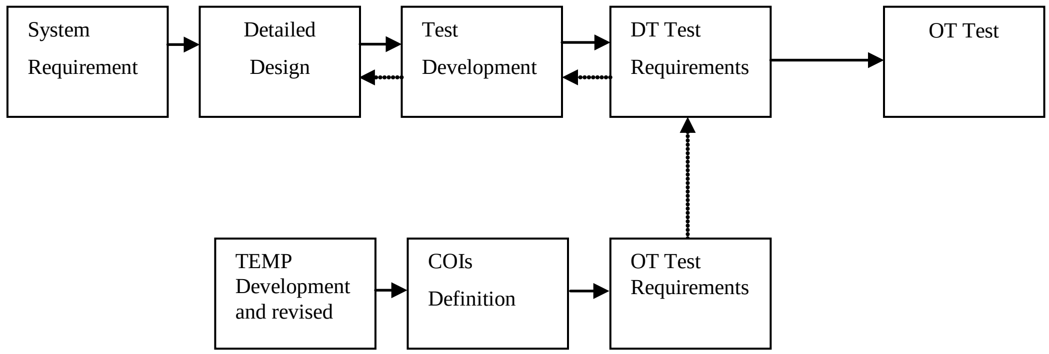

Figure 16. Basic Process Diagram for the "DT Exit Criteria to Include OT Pass Criteria" Option

Functional Flow Block Diagram of the "Exit Criteria to Include OT Pass Criteria" Alternative.

Implementing OT passing criteria into DT will increase the cost of the program in order to conduct the basic operational test. This would also require additional personnel, training and test equipment (hardware and software), as well as a considerable increase in coordination with other systems or organizational entities. This increases both the DT schedule and cost, while potentially decreasing the amount of money and time spent at OT. However, by preventing re-work and re-testing and delivering a quality product when scheduled, this concept could potentially save money and time over the life of the program.

Program schedules would be affected by implementing these changes in the process. However, these schedules could be affected even worse if the product doesn't meet the basic requirements. If the process is included in the schedule from the beginning of the project, the overall impact would likely be minimal. An advantage would be that the longer schedule would be known from the beginning and unexpected delays due to OT failure would be significantly less likely.

Implementation of this change would be difficult. In order to test in a basic operational environment it would require coordination with other systems. Deciding who is paying what would make the implementation difficult. Other systems schedules would need to be taken into consideration.

Implementing this process would have a positive impact on the final product. It would improve the OT schedule and success. The final product would be more reliable and less likely to encounter delays as a result of failing OT. This would lead to cost savings and product satisfaction.

b. Standardization of DT Modeling and Simulation

The standardization of Developmental Testing (DT) and Modeling and Simulation (M&S) is a second possible solution to this problem. M&S should be used during DT as a method for predicting system performance, identifying technology and performance risk areas, and the ability to support determining system effectiveness and suitability. Currently, with DoD programs failing to detect critical interoperability failures prior to operational level testing after successfully completing DT, there is a need for standardization of DT and M&S procedures and pass criteria. The use of quality M&S within the DT process could greatly enhance the achievement of effective and efficient test and evaluation of the system all the way through to OT&E. M&S is currently used within programs to demonstrate system integration risks, supplement live testing with M&S stressing the system, assist in planning the scope of live tests and data analysis, and prediction of system performance and possible risk areas. None of the current M&S strategies are standardized and most model and simulations are tailored for their specific system, but the following list from the Defense Acquisition Guidebook [DAU, 2010] contains some areas that could be considered for an overall standardized M&S method that leads to a successful DT:

- Document the intended use of models and simulations
- Describe the data standards and verification, validation, and accreditation standards with which the models and simulations and associated data must comply
- Identify the modeling and simulation data needed to support T&E
- Define the methodology for establishing confidence in the results of models and simulations
- Provide descriptive information for each model and simulation resource: Title, acronym, version, date, support organization (the organization with primary responsibility for the model or simulation),
- State assumptions, capabilities, limitations, risks, and impacts for the models and simulation
- Project the schedule and availability of M&S for T&E support

M&S capability encompasses many software tools, middleware, networks, security features and encryption capabilities that will have to be standardized to some degree. Without standardization, the credibility of M&S becomes an issue. If M&S cannot provide trustworthy insights into the system then the program will be ill-served and the M&S investment will be wasted.

Costs and the development schedule are two other areas of consideration that need to be examined when looking into DT and M&S standardization. The associated schedule and costs with implementing a comprehensive set of standards for M&S within the DT cycle could prove to be extensive. Estimates could be determined from previous standards and process implementations as well as the projected time taken to complete those processes. Putting standards in place for M&S and DT can have lasting effects for system integration and system interoperability. The potential for cost saving during the test cycle can best be captured qualitatively. M&S standardization will trim down DT cost and schedule by introducing complete and proven models and simulations, however it is likely that not all aspects of the standard will be applicable to every system and therefore some unnecessary costs will be incurred. If standardized M&S methods are used across all programs this could lead to cost and schedule savings, however time and funding will be required to develop and validate the standards prior to implementation.

To improve the systems engineering process, M&S enables better planning of live test events, representing system attributes that cannot be examined realistically in live testing. However, without standardizing the M&S process, the system may suffer increase of cost, inadequate discipline in planning or applying M&S, incoherent plan and no information sharing among community.

To achieve a successful DT which eventually leads to a successful OT, the M&S process should be standardized in the following areas:

- Document the intended used of models and simulation
- Standardized Verification, Validation, and Accreditation (VV&A) process to ensure development of correct and valid simulation
- Identify the M&S data needed to support DT
- Define the methodology for establishing confidence in the results of models and simulations

- Provide descriptive information for each model and simulation resource
- State assumptions, capabilities, limitations, risks, and impacts for the models and simulation
- Project the schedule and availability for DT support

A simple functional flow block diagram of this M&S process is shown in Figure 17.

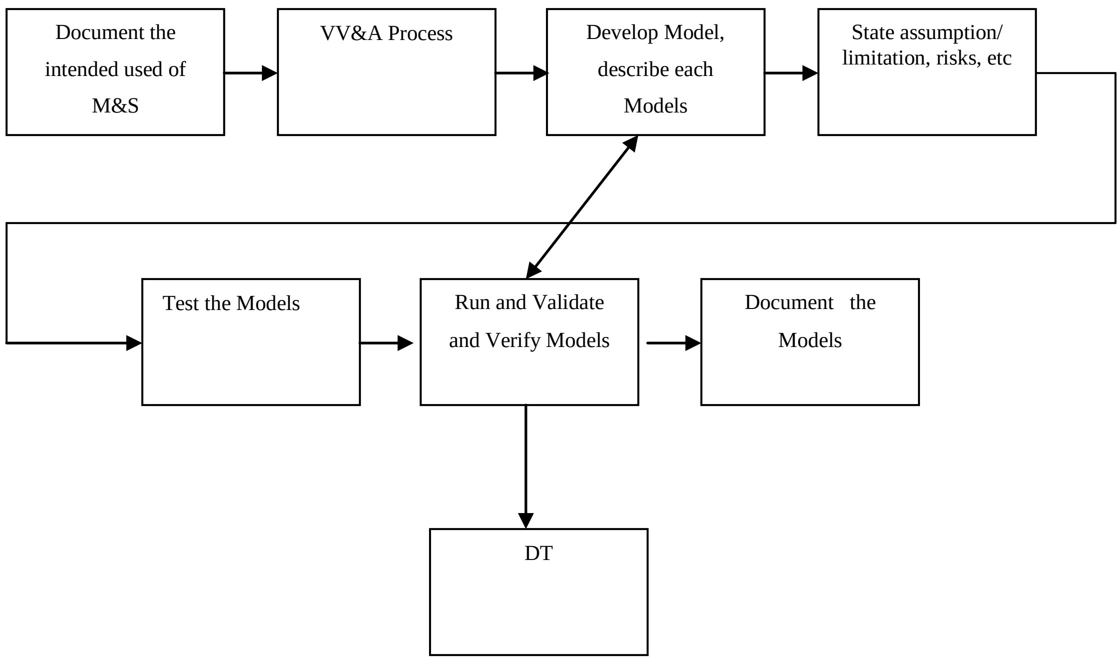

Figure 17. Basic Process Diagram for the "Standardization of DT Modeling and Simulation" Option

Functional Flow Block Diagram of the "Standardization of DT Modeling and Simulation" Alternative.

Implementation of standard M&S methods and processes during DT will be a moderately difficult task to accomplish. New and existing methods will need to be blended to ensure flexibility and completeness are captured in the M&S process to make certain all programs will have confidence in the new standardized approach. New and current M&S documentation should be modified and streamlined for concise understanding of how M&S will integrate with the DT cycle. Further, there is always risk involved with developing standards. As standards are rewritten they are hardly ever loosened, but rather tend to become more and more stringent with time. This could eventually lead to time and money wasted testing to standards that have become unrealistic (outside the mission thread requirement) or archaic (outdated and irrelevant).

c. Test to Mission Thread

The term mission critical thread is being used more and more often throughout the DOD. The Joint Chiefs of Staff Instruction (CJCSI) 6212.01E states: "The joint critical threads are determined by the sponsor's analysis of the system's required operational capabilities and other Key Performance Parameters." The CJCSI 6212.01E goes on to give a formal definition of a Joint Mission Critical Thread as "an operational and technical description of the end to end set of activities and systems that accomplish the execution of a joint mission" [CJCSI 6212.01E, 2008]. For the purposes of developing this option the authors have chosen to use this CJCSI 6212.01E definition of a mission critical thread.

Mission threads should be developed early in the acquisition process. Mission threads could be taken from a previously developed list or developed specifically for the system under development; either way the mission threads must reflect the operational requirements of the system. These mission threads must be designed specifically to quantify a system's response to a series of scenarios. These threads can then be applied as a guide for building the system architecture, where it can help identify the architectural risk early in the process. When applied to the SoS, mission threads can be used as inputs for building the SoS architecture, and can also serve as a tool for system in-progress design review and system architecture evaluation. The mission threads will need to be applied to the interoperability tests performed during system development. As acquisition progresses, mission threads will be applied to testing, gradually increasing the number of systems involved. While it may push the schedule to the right, it will greatly reduce the risk of severe delay due to integration issues.

As the system matures and begins to interact with other systems the mission thread should be reevaluated to encompass the mission threads of these respective systems. In this manner the system and its mission thread evolve to encompass a larger and larger view with the last capturing the SoS prior to entering OT. Figure 18 shows a functional flow block diagram of this process.

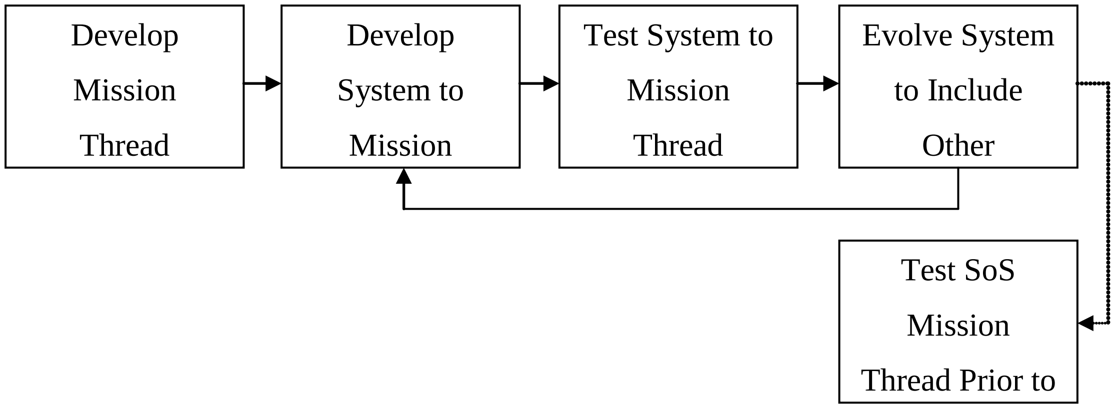

Figure 18. Basic Process Diagram for the “Test to Mission Thread” Option

Functional Flow Block Diagram of the “Test to Mission Thread” Alternative.

The biggest challenge facing the implementation of mission threads is the fact that each system is normally operated and managed independently. Each system has its own program office responsible for its own system development. However, each system may interact with different joint programs, resulting in a complex combination of systems. The combination of the multiple mission threads must be tested during OT in order to have interoperability for the entire SoS evaluated. The mission threads test will be required at a system level and would need to be started as early as the architecture design phase. Then as the integrated system matures, the combined mission threads will be verified through simulations or tabletop exercises at each milestone. Failures will need to be corrected before moving onto the next stage of the process. An example of a mission thread for a combat system might be to engage (acquire, track, and destroy) 10 incoming threats, each of these threats would be defined in detail as part of the mission thread. This high level approach is much different from a technical requirement such as display 200 simultaneous air targets or process data at a rate of 60Mb/sec. Completing the mission critical thread is based on mission completion, not on meeting a system specification.

The cost and schedule of the program may increase when mission thread testing is involved in the early phase of the process. However, it avoids the risk of an even greater impact to cost and schedule later in the program. The problems that were not detected until systems integration or deployment will cause significant issues in cost, schedule, and performance.

d. Consider Interoperability at Milestone Reviews

It is understandable that most systems are used as part of a larger system. It is important that each system can be fully integrated into a system of systems (SOS). A successful integration of systems involves the performance of all systems working together to achieve the desired tasks. The integration requires that each system inter-operate with one another to meet the designed capability of the system of systems. The interoperability of systems must be considered early and applied continuously across the system of systems life cycle.

Considering interoperability at each milestone review is one such way to ensure that all systems work together to achieve the desired tasks. It allows system engineers to periodically evaluate the interoperability of the system. This evaluation is carried out as part of the milestone reviews. The generalized process will need to be tailored for each program and each review. For instance, during Milestone A much of the consideration will be based on the conceptual design of the system, while at Milestone C interoperability will be assessed based on the results of testing. The general process for evaluating interoperability consists of:

- assess the system
- evaluate interoperability results
- take appropriate action
- proceed to the next milestone

During the milestone review, a panel of experts will assess the system to determine systems, components, and sub components to evaluate for interoperability. They will then assess the interoperability of these components and identify any that have a low interoperability. The program manager will then be responsible for addressing any identified interoperability issues, such as those demonstrating a low interoperability.

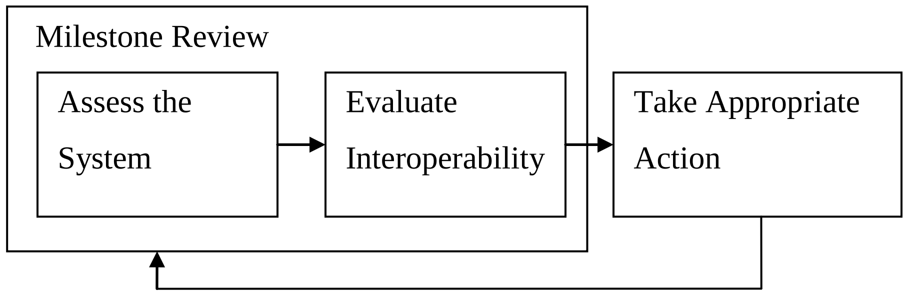

Figure 19. Basic Process Diagram for the "Consider Interoperability at Milestone Reviews" Option

Functional Flow Block Diagram of the "Consider Interoperability at Milestone Reviews" alternative.

By considering interoperability at each milestone review, one can gain a sense of the level of interoperability of the system. This will allow the program manager to act accordingly. Allowing for the detection of low levels of interoperability at each of the milestones enables systems to avoid the high costs of failing OT. Thus considering interoperability at each milestone review has the potential to have significant cost savings.

It would be relatively easy to implement a process to consider interoperability at each milestone review given the fact that subject matter experts are on hand during the milestone reviews. As such this approach would be cost effective to implement and moderately effective at preventing OT failures.

e. Define and Apply Interoperability Readiness Levels (I/ORLs)

The last potential solution would be to develop and implement a system of Interoperability Readiness Levels (I/ORLs) to quantify the maturity of the system interfaces. Implementing I/ORLs is a way to use metrics to assess the maturity of a system's interoperability before proceeding to Operational Testing (OT). Using metrics allows for a quantitative judgment of a system's readiness for OT, removing some of the subjectivity of humans. This allows for more consistency in determining when a system is ready for OT.

Assessing a system with differing pieces of integrated technology based on I/ORLs reflects an evaluation of integration and readiness; it gauges the maturity of the interfaces or interoperability of systems. I/ORLs can be applied to connections between legacy systems, legacy and new systems, or between integration of new systems. Each interface will have a unique I/ORL value, thus it is possible for a system to be assigned multiple I/ORLs. Further, assessing a system based on I/ORLs can be performed on technology insertion or on new system development.

To gain a frame of reference for the creation of interoperability readiness levels (I/ORLs), the authors started with open literature research. This research yielded several articles on the subject of integration readiness levels (IRLs). The reference frame provided in *A Systems Approach to Expanding the Technology Readiness Level within Defense Acquisition* [Sauser, et al, 2009] provides a conceptual basis from which the authors could develop IRLs. The integration readiness levels summarized in Table 6 illustrate the basic concept of an Integration Readiness Level system which is similar to an Interoperability Readiness Level system. If this option is selected a more appropriate set of I/ORLs would be developed by the authors after the AOA is complete. In practice a team would assess the system based on a criteria of agreed upon levels, if the system scored at a level below the agreed upon level, the system would not proceed to OT but rather continue further development.

Table 6. An Example of Integration Readiness Levels (IRLs)

This table summarizes the Integration Readiness Levels that were identified by Sauser, 2009.

IRL	Definition	Description
9	Integration is **Mission Proven** through successful mission operations.	IRL 9 represents the integrated technologies being used in the system environment successfully. In order for a technology to move to the TRL 9, it must first be integrated into the system and then proven in the relevant environment; thus, progressing IRL to 9 also implies maturing the component technology to the TRL 9.
8	Actual integration completed and **Mission Qualified** through test and demonstration in the system environment.	IRL 8 represents not only the integration-meeting requirements, but also a system-level demonstration in the relevant environment. This will reveal any unknown bugs/defects that could not be discovered until the interaction of the two integrating technologies was observed in the system environment.
7	The integration of technologies has been **Verified and Validated** with sufficient detail to be actionable.	IRL 7 represents a significant step beyond IRL 6; the integration has to work from a technical perspective, but also from a requirements perspective. IRL 7 represents the integration meeting requirements such as performance,

IRL	Definition	Description
		throughput, and reliability.
6	The integrating technologies can **Accept, Translate, and Structure Information** for its intended application.	IRL 6 is the highest technical level to be achieved; it includes the ability to not only control integration, but to specify what information to exchange, to label units of measure to specify what the information is, and the ability to translate from a foreign data structure to a local one.
5	There is sufficient **Control** between technologies necessary to establish, manage, and terminate the integration.	IRL 5 simply denotes the ability of one or more of the integrating technologies to control the integration itself; this includes establishing, maintaining, and terminating.
4	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.	IRL 4 Many technology-integration failures never progress past IRL 3, due to the assumption that if two technologies can exchange information successfully, then they are fully integrated. IRL 4 goes beyond simple data exchange and requires that the data sent is the data received and there exists a mechanism for checking it.
3	There is **Compatibility** (i.e., common language) between technologies to orderly and efficiently integrate and interact.	IRL 3 represents the minimum required level to provide successful integration. This means that the two technologies are able to not only influence each other, but also to communicate interpretable data. IRL 3 represents the first tangible step in the maturity process.
2	There is some level of specificity to characterize the **Interaction** (i.e., ability to influence) between technologies through their interface.	IRL 2 Once a medium has been defined, a "signaling" method must be selected such that two integrating technologies are able to influence each other over that medium. Since IRL 2 represents the ability of two technologies to influence each other over a given medium, this represents integration proof-of-concept.
1	An **Interface** between technologies has been identified with sufficient detail to allow characterization of the relationship.	IRL 1 This is the lowest level of integration readiness and describes the selection of a medium for integration.

To conduct the recommended assessment, one must select a review at which the assessment will take place. This review may be conducted a single time; however it is recommend that multiple reviews be conducted. Regardless of the number of reviews selected the process will be the same each time. First a review is selected in which the necessary subject matter experts are available. The system is then assessed to determine its I/ORL value in a manner similar to that presented in Table 6. These I/ORL ratings are then evaluated to determine if the system is progressing at an acceptable rate with respect to interoperability. Based on the results of this evaluation appropriate action may be taken to improve interoperability functionality. If multiple reviews are conducted, relative progress may be tracked. To gain a visual understanding of these high level functions, a top level functional flow block diagram has been provided in Figure 20. The detailed definitions of an I/ORL will be provided in Chapter IV of this report.

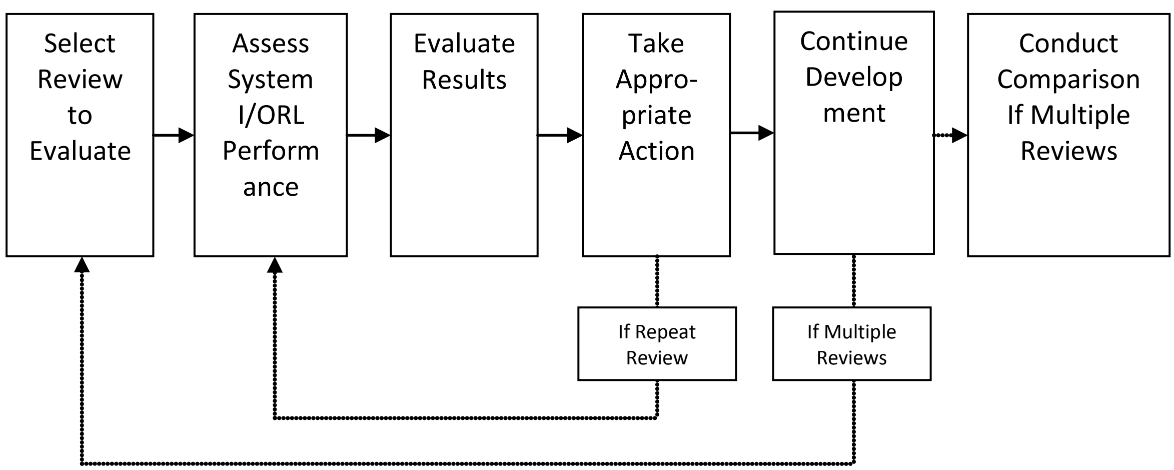

Figure 20. Process Diagram for "Define and Apply I/ORLs" Option

Functional Flow Block Diagram of the "Interoperability Readiness Levels" alternative.

Implementing I/ORLs on a system is an assessment of the system. It does not require development or testing. As such, the cost to implement this assessment is small. The impact to cost is based on the time it takes to evaluate the system against a set of I/ORLs and the administrative cost to document this evaluation. During the course of an acquisition cycle stakeholders and subject matter experts (SMEs) meet on a regular basis for development and other assessments. Assessing a system for interoperability can be performed during any or several of these existing meetings rendering the cost minimal. Implementing I/ORLs can potentially save a significant amount of money. By preventing a system with immature interfaces from proceeding to OT and failing, money spent on unnecessarily testing an immature system could be saved.

Implementing I/ORLs, can impact schedule but the impact can be minimal. As noted, the I/ORL assessment can be implemented during one of the many existing pre-Milestone C meetings. The expected impact on the schedule would be one or two days per meeting. If these few days save the time it takes for the system to go through OT testing and fail, the result could be a savings in schedule.

Implementing this change, functionally, is not difficult. Systems are routinely assessed during development. I/ORLs can be one additional standard by which to measure a system. The I/ORL assessment can be performed during one or many of pre-Milestone C events. It can be performed once or several times to see a progression of interoperability maturity. One event in particular in which an I/ORL assessment can be performed is during a Post-Critical Design Review Assessment which ends Integrated System Design during Milestone B.

Implementing I/ORLs can improve OT success. Assessing a system based on I/ORLs can prevent the system which is not sufficiently interoperable from proceeding to OT, saving the system from failing. This assessment can inform on specific areas of development needing further development. In the end this would make a system having undergone an I/ORL assessment more stable and dependable.

B. PUGH MATRIX

The method selected for down selecting from these five alternatives to a single proposed solution was a Pugh Matrix. Evaluation criteria were developed based on the process requirements developed in the previous phase, the authors evaluated each alternative against these criteria and the results of the individual Pugh Matrix responses were tabulated. The results of the Pugh Matrix were discussed and validated by the authors and were used as the major tool for the group selection of the final alternative to the current SE process that would be developed in detail during the third phase of the project

1. Pugh Matrix Comparison Criteria

Concurrent with the refinement of the five alternatives discussed previously, the authors developed the evaluation criteria for assessing and ranking these five alternatives. The simple cost versus effectiveness comparison was determined to be insufficient. Nine criteria were developed in all based upon the requirements and value system that were developed in the previous phase and documented in Chapter II of this report. Effectiveness was divided into the increase in the percent of OT passed as well as how early in the program an issue was likely to be detected with the given alternative. Additionally, cost was analyzed more closely and encompassed not just financial cost but also schedule cost and risk. These costs were also addressed both as upfront cost for implementing the new system and the reoccurring costs that would negatively or positively impact each program.

The nine criteria:

- Change in OT % Pass: This rates each alternative's increased or decreased chance of passing OT over implementing Alternative 1.
- Change in the program phase in which problem detection occurs: This rates when each alternative allows the detection of issues prior to OT. How much sooner are those problems predicted and mitigated or avoided compared to Alternative 1?
- Upfront cost of implementing the new process (upfront $): This is a comparison of the estimated costs to develop the new SE process compared to Alternative 1. Exact cost is not required, this is a relative comparison. Is the alternative to be more or less expensive to implement that Alternative 1? This is the one-time financial costs for starting the new process.
- Per program (reoccurring) costs for the new process (per program $): This is a comparison of the estimated costs of using the new SE process compared to Alternative1. Exact costs are not required, this is a relative comparison. Is the alternative likely to be more or less expensive for each project to use then Alternative 1? This is the recurring costs of the new process that will affect each program.
- Approval Level (getting the new process approved for DOD use) (upfront risk and time): This is the comparison of each alternative with Alternative 1's time and risk of getting approval for the new process. For example, one alternative might be at the USD (AT&L) while another may only be at the NSWC CO level. (Approval of the new process is only needed once, not for each program.)
- Coordination required between agencies to implement the new process (upfront time): This is a comparison of the one-time "time" expense required for developing the new processes (Alternative compared to Alternative 1.)
- Time to develop, train, and implement the new process (upfront time and money): This is a comparison of the one-time "time" and financial cost of developing training and

transition to the new process across program offices (complexity of change required for the alternative compared to Alternative 1.)

- Impact to individual program schedules (per program, time): Comparison of how the alternative affects each program schedule compared to the effects of Alternative1.
- Change in documentation for each program (per program time and $): Comparison of the increase or decrease in time and financial cost of documentation of the alternative compared to Alternative 1.

2. Pugh Matrix Data Acquisition

Figure 21 is a representative sample of the Pugh Matrix completed by each member of the team; Table 7 is the legend used by the team members in developing their Pugh Matrices. The authors choose to do individual Pugh Matrices so that each group member had an equal say in the further development of the project.

Pugh Matrix Comparison Criteria	DT Exit Criteria to include OT Pass Criteria (Alternative 1)	Consider interoperability @ all milestones reviews (Alternative 2)	Test to Mission Tread at interoperabability OT (instead of requirements) (Alternative 3)	Develop Interoperability Readiness Levels (IRLs) (Alternative 4)	Develop Standards of all DT Testing and Simulations (Alternative 5)
Change in OT % Pass	0	-	-	0	-
Change in the program phase in which problem detection occurs	0	+	- -	+	0
Upfront cost of implementing the new process (upfront $)	0	+	0	-	-
Per program (reoccuring) costs for the new process (per program $)	0	+ +	+ +	+ +	+
Approval Level (getting the new process approved for DOD use) (upfront risk and time)	0	+	-	-	-
Coordination required between agencies to implement the new process (upfront time)	0	0	-	-	- -
Time to develop train and implement of the new process (upfront time)	0	-	-	-	- -
Impact to individual program schedules (per program, time)	0	+ +	+ +	+ +	+
Change in documentation for each program (per program time and $)	0	0	0	0	0

Figure 21. Sample Pugh Matrix from one of the fourteen group members.

The authors evaluated each option using a Pugh Matrix and the nine criteria identified above.

Table 7. Pugh Matrix Legend

Each option in the AoA was evaluated for each of the nine criteria based on these rating criteria.

Symbol	Definition
+ +	Major improvement compared to Alternative 1(Include OT pass criteria in DT exit) (significant decrease in time, cost, performance or risk)
+	Some improvement compared to Alternative 1(Include OT pass criteria in DT exit)(some decrease in time, cost, performance or risk)
0	No difference from current process (doing nothing)
-	Some increased burden/loss compared to Alternative 1(Include OT pass criteria in DT exit)(some increase in time, cost, performance or risk)
- -	Major increased burden/loss compared to Alternative 1(Include OT pass criteria in DT exit)(significant increase in time, cost, performance or risk)

Since it is assumed that our alternative will be an improvement over the current system, there was no "do nothing" alternative. This is important because the use of a "do nothing" alternative will always score higher than any changes when it comes to any upfront developmental costs (there is no cost for making no change) and may often have some reduced reoccurring financial, schedule and risk costs within each program. This could give the "do nothing" alternative a favorable outcome in any AOA. However, the problem being addressed is rarely solved by "doing nothing" and an AOA is generally not performed unless a change is thought to be necessary. Therefore DT Exit Criteria to include OT Pass Criteria (Alternative 1) was chosen as the baseline alternative. The other four alternatives were compared to this and each group member used their engineering and project management judgment to determine if the other alternatives were "better" or "worse" then Alternative 1.

3. Pugh Matrix Analysis

With each member completing their own Pugh Matrix, the total +, 0, and – were summed in Figure 22, Pugh Matrix Results. When analyzed, there is no single criterion that stands out as being irrelevant; had any one criterion been equal or nearly equal across the five alternatives then considering that particular criterion would not have provided any substantial decision making capability when choosing between the alternatives. It was quickly noted however, that the two highest ranked alternatives were closely related. That is to say that the highest rated alternative, "Define and Apply I/ORLs," could possibly fulfill the second highest ranked alternative. Further, each system was analyzed with all 14 group members' data, as well as without the highest and lowest score provided to each system by any one group member (middle 12 group responses). Similar to judging at Olympics and other competitions, this method allowed the group to reduce any biases that may arise from a member who may have authored or been endeared to any one alternative. No significant bias appeared to be present, as the score of each alternative changed by no more than four + or -, out of a possible fluctuation of up to 36 + or -.

Criteria	DT Exit Criteria to include OT Pass Criteria	Consider interoperability @ all milestones reviews	Test to Mission Tread at interoperability OT (instead of requirements)	Develop Interoperability Readiness Levels (IRLs)	Develop Standards of all DT Testing and Simulations
Delta in OT % Pass	0	-2	11	5	-8
Delta in phase of problem/issue detection	0	3	8	10	1
Upfront cost of new process (upfront $)	0	3	-1	3	-4
Per program (reoccuring) cost (per program $)	0	10	5	9	0
Approval Level (upfront risk and time)	0	7	1	-2	-4
Coordination required to implement change (upfront time)	0	3	-6	3	-7
Time to develop, train, implement the new process (upfront time)	0	-2	-2	1	-7
Impact to program schedule (per program, time)	0	6	3	10	4
Change in documentation for programs (per program time and $)	0	-4	0	2	-10
System Sum (the entire group)	**0**	**24**	**19**	**41**	**-35**
Average for each Alternative (the entire group)	0	1.71	1.36	2.93	-2.50
System Sum (drop the highest lowest vote)	0	28	21	42	-31
Average for each Alternative (drop highest and lowest)	0	2.33	1.75	3.50	-2.58

Figure 22. Pugh Matrix Results

This figure summarizes the results of the AoA.

C. SELECTION OF PREFERRED ALTERNATIVE

Once the Pugh Matrix results were tabulated, the authors discussed the results based upon the value system discussed in Chapter II. The majority of the discussion focused on the three alternatives with the highest “score” in the Pugh Matrix: “Define and Apply Interoperability Readiness Levels (I/ORLs)” had 41 pluses, “Consider Interoperability at all Milestone Reviews” had 24 pluses and “Test to Mission Thread at Interoperability OT” had 19 pluses. The Mission Thread alternative had the most pluses in the two measures of effectiveness, but at a much higher anticipated cost. Initial discussions with the project stakeholders, specifically with an ASN (RDA) CHSENG staffer, had identified a concept based on Mission Threads as being desirable. As this alternative most reflected the original Project Proposal, it was a hard decision to choose another path, however, the authors discussed the Pugh Results and agreed with the analysis that this alternative would be harder to coordinate between organizations and would have a greater negative impact on each program's schedule and budget than the other two alternatives. These impacts would be due to the change in requirements development process up front as well as a change in how OT process and procedures are developed, carried out and documented. On the other hand, I/ORLs and the evaluation of interoperability at each milestone were projected to require less significant changes to the current OT process.

The remaining two alternatives were viewed by the authors to be similar, as it was agreed that the implementation of I/ORLs would likely involve the evaluation of I/ORLs at key technical reviews and would therefore be inputs to the milestone decisions. It was also felt that specifying that interoperability be assessed at each milestone was difficult without developing a system by which interoperability of a system would be quantified. Therefore, the authors concluded that developing I/ORLs was the best alternative and every effort would also be made to meet the basic objectives of "Considering Interoperability at each Milestone Review".

IV. DETAIL PROCESS DESIGN

Upon completion of the Analysis of Alternatives, Detailed Process Design began. A more detailed functional analysis kicked off this phase in which functions were defined. After expanding on the functional analysis, synthesis of the process commenced. I/ORL Development and Process Design comprised the synthesis portion of the detailed process design; in an iterative fashion, I/ORL Development and Process Design further refined the system. Consequently, a more thorough discussion on activities in the functional analysis is presented in this chapter. During this phase it became apparent that the preferred solution of "Develop Interoperability Readiness Levels" implies one activity only, yet, this process involves much more than simply developing I/ORLs. A more suitable name for this solution is "I/ORL Assessment Process" which reflects the use of Interoperability Readiness Levels as a mechanism to assess the maturity of the design of a system with regard to how well it interoperates with other systems in support of mission critical threads, and as a means to predict a system's ability to pass operational testing with regard to interoperability.

A. DETAILED FUNCTIONAL ANALYSIS

To assess interoperability readiness levels, it was determined that I/ORLs would need to be evaluated at multiple reviews. A more detailed approach to evaluating a program's I/ORL involves evaluating interoperability at each review leading up to a milestone review. The top level of the detailed process to developing I/ORLs considers how this process will be implemented and includes the functions of:

- Evaluate I/ORLs at selected reviews
- Assess system I/ORL performance
- Evaluate interoperability results
- Take appropriate action
- Continue development
- Conduct milestone reviews

This functional analysis is reflected in Figure 23. These actions will be discussed briefly in the following sections with more detail in Sections B and C.

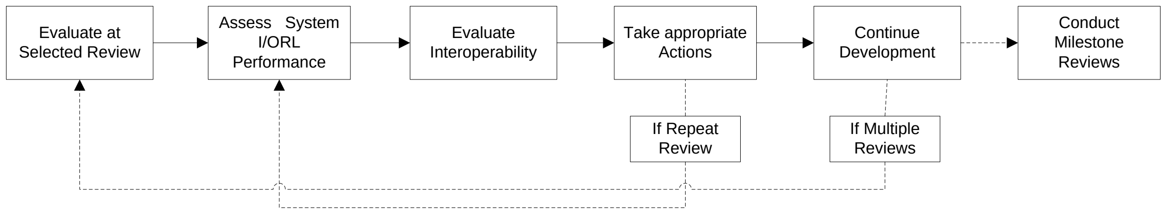

Figure 23. Functional Analysis of Interoperability Readiness Level Process

This figure summarizes key functions in the I/ORL Process.

1. Evaluate at Selected Reviews

Several reviews take place during the development of a system as prescribed by the SETR [SETR, 2009]. Interoperability should be considered at many of these reviews. However, some reviews are not technical and interoperability is not a factor in these reviews. The authors considered all of the reviews leading up to milestone reviews and selected the reviews in which interoperability should be considered. Figure 24 summarizes the selected reviews leading up to milestone reviews.

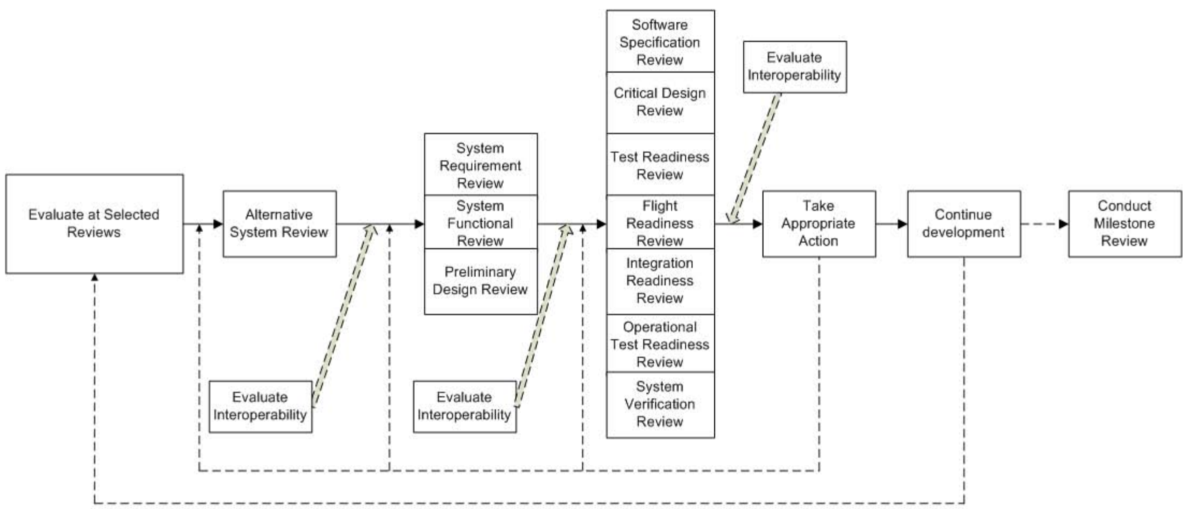

Figure 24. Selected Technical Reviews for I/ORL Evaluation

The Evaluate at Selected Reviews reflects a choice of technical reviews in which I/ORLs should be considered.

2. Assess System I/ORL Performance

In order to assess the system performance I/ORL levels were selected and described, and a quantitative value was assigned to each level. Lower values reflect less mature interoperability levels and increasingly higher values reflect progressing maturity in a system's ability to pass information at interfaces. This is the scale against which interoperability will be measured; interoperability of each interface of a system must be considered and assessed.

3. Evaluate Interoperability

Once interoperability assessment data are available, values are evaluated. I/ORL values are measured against a threshold and objective level designated for a particular review. The values have been assigned based on the purpose of the review. An objective is a quantitative level that should be met. A threshold is a minimum value, a level that must be met.

4. Take Appropriate Action

Upon evaluating interoperability, appropriate action must be taken. This action can be one of several depending on the evaluation. If an I/ORL value meets the objective, it proceeds through the system development process as usual. If the I/ORL obtains a value between the objective and threshold value, a system interoperability performance review must be performed. If the system fails to meet the threshold value it must undergo a mini re-view or repeat the review in order to rectify interoperability issues.

5. Continue Development

The system must proceed with development per their tailored system's engineering process. The system must continue to consider interoperability as it progresses with maturing interoperability readiness.

6. Conduct Milestone Review

A milestone review is conducted as usual with the inclusion of interoperability consideration. Findings from the I/ORL reviews performed at technical reviews leading up to a milestone review are considered, this may include I/ORL evaluations and mitigations. Further, concurrence on issues and I/ORL decisions should be obtained during the milestone review.

B. I/ORL DEVELOPMENT

I/ORL Development began with examining all of the reviews outlined in the SETR handbook [SETR, 2009]. Reviews containing an interoperability component were selected. The authors then created an I/ORL standard outlining I/ORL levels, values, and descriptions. Finally threshold and objective values were assigned to relevant reviews based on outputs of each review gleaned from the SETR handbook.

1. Applicable Reviews

I/ORLs are intended to assess the state of system interoperability using the systems engineering process within the existing DoD framework. Consequently, reviews from the SETR handbook were chosen. After inspecting the reviews in the SETR handbook the authors arrived at a list of reviews that should include an I/ORL assessment. Table 8 reflects the selected reviews, their purpose, and a brief explanation on why interoperability should be considered at the chosen review.

Table 8. Technical Reviews for I/ORL Assessment

This table shows the technical reviews in which an I/ORL assessment is applicable.

Review	Purpose	Rationale
Alternative System Review (ASR)	Reviews results of Material Solution Analysis phase and assesses technology development plan and preferred system concept.	This is an early technical review, interoperability should be considered from the early stages of development in order to successfully pass operational testing.
System Requirements Review (SRR)	Assesses technical readiness to enter Engineering & Manufacturing Development Phase.	This review establishes requirements and assesses the developing system to ensure a likely expectation that the ultimate system will be operationally effective; interoperability must be considered in requirements for successful interoperability.
System Functional Review (SFR)	Assesses System Functional Baseline and readiness to begin functional allocation.	This review is a technical assessment to establish that the system functional baseline will likely be deemed operationally effective, interoperability must be considered in functional specification for success.
Preliminary Design Review	Assess System Allocated Baseline and readiness to begin	This review is a technical assessment to establish that the physically allocated

Review	Purpose	Rationale
(PDR)	detailed design.	baseline will likely be deemed operational effective, interoperability must be considered in the physical architecture for successful passing of information at interfaces.
Software Specification Review (SSR)	Assesses completeness of software specification.	This review is a technical assessment to establish that the software requirements baseline of the system and its preliminary design will likely be deemed operationally effective, interoperability must be considered in software for successful passing of data.
Critical Design Review (CDR)	Assesses System Product Baseline and supports Design Readiness Review.	This review is a technical assessment to establish that the build baseline likely be deemed operational effective, interoperability must be considered in the design in order to successfully pass operational testing.
Flight Readiness Review (FRR)	Assesses system readiness to initiate and conduct flight tests and flight operations.	This review is a technical assessment to establish that the configuration used in flight testing will likely be deemed operational effective, interoperability must be considered at this review for success.
Integration Readiness Review (IRR)	Assesses readiness of software systems.	This review is an assessment to ensure that the hardware and software are ready to begin integrated configuration item testing, interoperability must be considered in the configuration for successful completion of operational testing.
Operational Test Readiness Review (OTRR)	Assesses system readiness to proceed into Operational Test and Evaluation (OT&E).	Interoperability maturity must be considered to ensure that the system can proceed into OT&E with a high probability that the system will successfully complete operational testing.
System Verification Review (SVR)	Assesses system compliance with functional baseline.	This review is an assessment to ensure that the system under review can proceed into Low Rate Initial Production; interoperability must be achieved for the system to proceed to LRIP.

While most of the reviews outlined in the SETR are applicable to interoperability and subsequently an I/ORL assessment, some reviews are neither technical nor appropriate for I/ORL consideration. Table 9 reflects the reviews excluded from I/ORL assessment with a brief explanation as to their rejection.

Table 9. Technical Reviews Excluded From I/ORL Assessment

This table shows the technical reviews in which an I/ORL assessment is not applicable.

Review	**Purpose**	**Rationale**
Initial Technical Review (ITR)	Supports technical basis for initial cost estimates and POM budget submissions.	This review focuses on cost and budget versus technical issues.
Integrated Baseline Review (IBR)	Assess risk areas in contract. Produces Performance Measurement Baseline to ensure technical scope of work is realistically and accurately scheduled, has proper resources, utilizes correct techniques, and employs appropriate management processes.	This review focuses on earned value management versus technical issues.
Test Readiness Review (TRR)	Assesses system readiness to begin Developmental Test and Evaluation (DT&E).	This review coincides closely with the CDR, there will be a desire to test any unfavorable results before addressing them.
Production Readiness Review (PRR)	Assesses system to enter production.	This review is conducted after Milestone C and operational testing.
Physical Configuration Audit (PCA)	Assesses the as-delivered system for compliance with the produce baseline and supports full-rate production decision.	This review is conducted after Milestone C and operational testing.
In-Service Review (ISR)	Assesses the in-service technical health of a fielded system from a risk, readiness, and resources perspective.	This review is conducted after Milestone C and operational testing.

Once the appropriate reviews were selected, the authors developed I/ORL values and their meaning.

2. I/ORL Values

I/ORLs are to be used similarly to Technology Readiness Levels (TRLs) throughout the SETR process [SETR, 2009]. After selecting reviews in which to assess I/ORLs, meaningful I/ORL values were assigned. It should be noted that a reference frame for IRLs is available in *A Systems Approach to Expanding the Technology Readiness Level within Defense Acquisition* [Sauser, 2009]. However, Sauser, et al, inappropriately applied mathematical operation on non-ratio scale numbers in their paper. A discussion of the issues with the methodology applied by Sauser, et al, can be found in *The trouble with the System Readiness Level (SRL) index for managing the acquisition of defense systems* [Kujawski, 2010]. The authors wanted to ensure we did not duplicate that error. Therefore, the authors decided to develop our own I/ORL level designations to tailor them to our process. In order to keep the process simple and consequently practicable, levels of 1 to 9 were chosen. A value of 1 is considered the least mature as it pertains to interoperability, and a value of 9 is the most mature as it pertains to interoperability.

It is important to note that the authors are choosing to describe the acronym I/ORL as Interoperability Readiness Level versus IRL as Integration Readiness Level example presented in the AoA section. The authors chose to use "interoperability" as it aligns more closely with the issues in this project. Further, the authors are expanding upon the example presented in the AoA and are tailoring I/ORLs to the issue of systems failing operational testing. As a result, the interoperability readiness levels appointed by the authors are outlined below:

I/ORL 1

1) *The physical interfaces and software scope of the preferred system solution are sufficiently understood to begin development with low technical risk.*
2) *The Program has determined which legacy and other development systems the new system must interface with.*

Any other systems that interface with the developing system must be identified. This includes systems that physically connect to the new system as well as software and data sharing communications. The details of the connections do not have to be explicit. This I/ORL simply states that a connection will be needed. Completing this I/ORL will aid in the development of a full list of mission critical interoperability requirements which will be evaluated individually during successive reviews.

I/ORL 2

1) *A design/technology maturity risk analysis has been completed. Interoperability issues that could impact cost, schedule or system performance have been identified.*
2) *An AOA is complete and addresses interoperability between the new system's interfaces and other applicable systems that require interoperability with the new system.*

An assessment of current technology is complete; the risk analysis provides the Program Manager with valuable insight into whether the new system will be fully interoperable with existing systems. Schedule and funding changes can be made early to address any high risk system interfaces. The AOA is used to determine if the various interfaces are being used optimally; there may be alternative configurations that are succinct then the originally planned new System of Systems. The AOA can further reduce risk by ensuring the optimal system interoperation configuration is chosen and may identify unnecessary redundancy, reduce the quantity of interfaces or maximize the efficiency of the interfaces that interoperate.

I/ORL 3

1) *The hardware interface specification is sufficiently detailed to include requirements such as MIL-STD, ISO, IEEE, etc.*
2) *The software interface specification is sufficiently detailed to include requirements such as programming languages, protocols, and standards.*

I/ORL 3 does not evaluate the new system's interface but rather focuses on the documentation of the interface requirements and design generation. All of the connections, physical and electronic must have documented standards. A large portion of this I/ORL is completing sufficient research on the other systems that the new system's interfaces will interface with in order to determine what standards those systems already use/require and ensure that the standards required for the new system's interfaces are backwards compatible. Further, any upgrades required to legacy systems that are based on obsolete standards should be identified at this point, for early development.

I/ORL 4

1) *The interoperability of the interface shall be demonstrated using its respective standards.*

I/ORL 4 represents a transition from a conceptual interface to one that has been realized and is a combination of research and testing. The objective of this evaluation is to demonstrate that the interface is mature. It is not intended that development of any portion of the system be finished at this point. This is just a technology demonstration or documentation of technology demonstration performed elsewhere using this technology to demonstrate that interoperability is achievable without regard to the test conditions, thus this can be done in the lab or in the field.

I/ORL 5

1) *Interface design is complete and has undergone an independent review for interoperability deficiencies.*

As a system approaches its product baseline each interface must be complete and have undergone a review for interoperability deficiencies. As a prerequisite of this review the interface shall have been reviewed by an independent party, not the SE team or contractor developing the new system, to ensure interoperability has been addressed. This evaluation is critical to ensuring that time and money is not wasted on building a design that is incomplete or unachievable.

I/ORL 6

1) *Interface test article components have successfully completed Developmental Test and Evaluation for interoperability.*

The individual components have been developed and have successfully completed DT&E (bench or lab testing); DT&E must include evaluation of the interoperability requirements of the interfaces being tested. The interfaces are ready for integration into larger sub-systems and eventually into the full system.

I/ORL 7

1) *All interfaces have been tested between the new system and the legacy system(s) it interacts with.*
2) *Interface interoperability with all other systems has been verified through simulated operational scenarios.*

I/ORL 7 must be accomplished prior to entering OT&E. Modeling and Simulation may be used to verify that interoperability of the entire system should work during actual testing. Furthermore, each interface has been verified through interoperability testing to ensure it functions properly with other system's components, such as completing fit testing for physical interconnections, completing radio communication checks for systems with RF or wireless communications, and connecting computers in the new system to those in legacy systems to ensure data transfer is correctly established, etc.

I/ORL 7F ***(only for system requiring flight based testing)***

1) *Interoperability with all other interface has been verified through ground based verification testing.*

I/ORL 7F is an additional requirement for I/ORL 7 for any system that will undergo flight based testing, either as an aircraft, new flight system, rocket, weapons system on an aircraft, etc. I/ORL 7F is intended to eliminate interoperability failures during flight testing, which could potentially lead to loss of the test system, air frame or human life in the event of a failure and crash. Completing I/ORL 7F is accomplished by simulating the entire flight test on the ground. It ensures that all interfaces and sub-systems of the new system are functioning properly with each other as well as other systems. It ensures that all communications lines with other systems are functional. While numerous ground tests are currently performed prior to flight testing, achieving I/ORL7F ensures that interoperability is addressed and something is not overlooked before the system is actually engaged in flight operations off of the ground.

I/ORL 8

1) *All interoperability issues discovered during OT&E have been mitigated (or none were present). The system and its interfaces are now mission qualified.*

I/ORL 8 is achieved by either having no interoperability issues during OT&E or by documenting the steps taken to mitigate any interoperability deficiencies. Interoperability issues that are below requirements, but do not cause system failure; such as slower than required (desired) data exchange rates, or physical connections outside of expected tolerance must either be corrected or the program manager may accept the deficiency and reduced capability from the initial requirements. I/ORL 8 is an important milestone for the system as I/ORL 8 indicates that there are no remaining interoperability issues that have not been corrected or accepted and the system is ready for use on the battlefield.

I/ORL 9

1) *The system has been proven to be interoperable during operational use (Mission Proven)*

I/ORL 9 is achieved once a system is deployed and has demonstrated successful mission completion (either actual or a training mission) in the fleet/field. Any deficiencies discovered in the field/fleet previously not experienced during other testing have been mitigated or accepted (just as in I/ORL 8). If OT&E is completed in the field/fleet and not at a test command or test range then the system may achieve I/ORL 9 simultaneously with I/ORL 8 once any interoperability issues discovered have been mitigated. An I/ORL is intended to signify that the system and all its interfaces have been proven to be interoperable.

3. I/ORL Values for Reviews

After selecting reviews in which to assess I/ORLs, and those values were developed, I/ORL levels were assigned to applicable reviews. For each applicable review an objective I/ORL value and a threshold value was assigned. The objective value is the level that should be met at a particular review. A threshold value is the minimum value that the interface must meet at the review. These values are based on the outcome of the review as described in the SETR handbook. If this value is not met, the system cannot proceed without further action. The process or appropriate action to take after failing to meet a threshold value is described in the Process Design section.

Some reviews have a hard minimum I/ORL requirement or threshold that must be met with no objective beyond that. Consequently these reviews have the same threshold and objective value in the table. The applicable reviews, exit criteria as they pertain to interoperability, objective, and threshold values are outlined in Table 10.

Table 10. I/ORL Values for Each Review

This table shows the I/ORL levels and values needed at each review [SETR, 2009].

Review	Exit Criteria	Threshold	Objective
ASR	-Is/Are the preferred system solutions(s) sufficiently detailed and understood to enable entry into Technology Development with low technical risk? -Is the system software scope and complexity sufficiently understood and addressed in the Technology Development plan to enable low software technical risk? -Are the risks known and manageable for Technology Development?	1	2
SRR	-Are the system requirements sufficiently detailed and understood to enable system functional definition and functional decomposition? -Is the architecture adequately structured to support both explicit and implied system attributes? -Are the risks known and manageable for design and development? -Are the Family of System/System of Systems	2	3

Review	Exit Criteria	Threshold	Objective
	(FoS/SoS) requirements properly allocated and approved? -Did the Technology Development phase sufficiently reduce development risk?		
SFR	-Are the system functional requirements sufficiently detailed and understood to enable system design to proceed? -Are adequate processes and metrics in place for the program to succeed? -Are the risks known and manageable for design and development?	3	3
PDR	-Does the status of the technical effort and design indicate OPEVAL success (operationally suitable and effective)? -Has the system allocated baseline been established and documented to enable detailed design to proceed with proper configuration management? -Are adequate processes and metrics in place for the program to succeed? -Are the risks known and manageable for DT/OT?	3	4
SSR	-Inputs, processing, and outputs are defined and accepted for all functions -All interfaces between the software configuration item and all other configuration items both internal and external to the system are defined and accepted as stable. In particular, interoperability requirements are fully identified and defined, accepted, and correlated to mission requirements and scenarios. -All interface-level data elements are defined and accepted, including data type, size, format, units, range of values, accuracy and precision -SW development processes are fully defined in the SDP or equivalent document (e.g., Software Standards and Procedures Manual (SSPM)), and are accepted as appropriate for coding and unit test. -Risks are identified in a Risk Database and have mitigation plans in place that are compatible with the SW development schedule.	4	4
CDR	-Does the status of the technical effort and design indicate OPEVAL success (operationally suitable and effective)? -Has the system product baseline been established and documented to enable hardware fabrication and software coding to proceed with proper configuration	5	5

Review	Exit Criteria	Threshold	Objective
	management? -Are adequate processes and metrics in place for the program to succeed? -Are the risks known and manageable?		
IRR	- The IRR is considered complete when all draft RFAs are signed off, and an acceptable level of program risk is ascertained.	6	6
FRR	-The FRR is considered complete when all draft RFAs are signed off, and an acceptable level of program risk is ascertained.	7 & 7F	7 & 7F
OTRR	-The OTRR is considered complete when all requirements for Navy Certification of Readiness for OT are complete. -For programs employing software, there are no unresolved priority 1 or 2 software problem reports (SPR), and all priority 3 problems are documented with appropriate impact analyses.	7	7
SVR	-Does the status of the technical effort and system indicate operational test success (operationally suitable and effective)? -Are adequate processes and metrics in place for the program to succeed? -Are the risks known and manageable? -Are the system requirements understood to the level appropriate for this review?	8	8

C. I/ORL PROCESS DESIGN

Once the authors had generated the definition of the I/ORLs at each level, the process for assigning and evaluating I/ORLs was generated. In developing this process, the authors researched the history of interoperability measurement and keyed in on the most widely used interoperability measurement systems. The most notable one was the i-Score methodology [Ford, 2007; Ford, 2008]: an interoperability measurement technique for generating a system-wide interoperability value based on a numerical analysis of mission threads. While i-Score approaches interoperability from a different perspective, the authors leveraged certain core concepts in the I/ORL system.

The overall process that was generated was split into two major phases: work done before the milestone review process and work done at each of the milestone reviews. The steps included in each of the phases are shown in Figures 25 and 26.

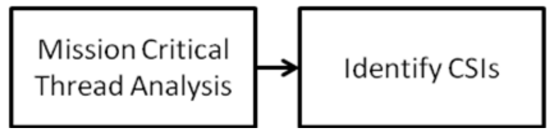

Figure 25. I/ORL Process Steps – Pre-Review

These are the key steps that occur prior to the Milestone Review.

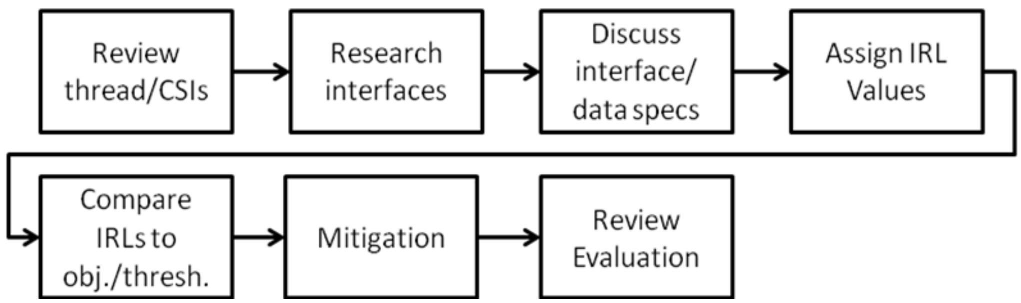

Figure 26. I/ORL Process Steps – Each Review

These are the key steps that occur at each Technical Review.

Detailed descriptions of the steps involved with assigning and evaluating a system for I/ORLs are listed in the sections below.

1. Identify and Analyze Mission Critical Threads

Prior to conducting the analysis of Interoperability Readiness Levels (I/ORLs), it is important to understand the critical interfaces of a system. To outline those critical interfaces, one must first analyze the critical mission threads that are involved with accomplishing the mission.

The team's concept of initializing the necessary mission thread and defining the necessary interfaces are shared with i-Score's methodology, [Ford, 2007]. The i-Score methodology diagrams an operational thread, and from this diagram identifies the systems that require interoperability. These systems are then numerically assessed for interoperability and recorded in a matrix, which is used to generate a score. The team's method varies from the later part of their process, but share a similar methodology for identifying interfaces.

Before any mission threads are analyzed, a review team consisting of key stakeholders and program managers must identify the critical mission threads out of the many mission threads that may exist for the system. This narrows down the scope of the analysis to something more manageable while still maintaining a high degree of fidelity. The review team should use the following or similar definition of mission criticality as their guide for selecting the appropriate threads for analysis. The following definition is provided in Joint Chiefs of Staff Instruction (CJCSI) 6212.01E:

> An operational and technical description of the end to end set of activities and systems that accomplish the execution of a joint mission [CJCSI 6212.01E, 2008].

The review team for the mission and the system involved must make a joint determination that the thread in question meets the above definition.

Similar to the i-Score methodology's Step 1 [Ford, 2007] of diagramming the operational thread and defining the set of supporting systems, the mission threads involved with the system are evaluated for mission criticality then diagramed for analysis. This involves all of the various steps in the functional flow of the system to accomplish that mission thread. Once completed, the functional flow elements must be traced back to their individual system components and the interfaces between components must be identified. This method is different from the i-Score methodology in that our process tracks the interfaces between systems, not the actual systems themselves. The interfaces outlined here are the interfaces associated with the mission thread.

The interfaces between mission functions, components, and organizations are then cross-referenced with the mission thread to determine their criticality towards the mission thread. If an interface is not deemed critical, then that interface will not be considered at this level of review. The interfaces that are deemed critical will then be identified as Critical System Interfaces (CSIs). These interfaces will be then documented as the interfaces at which the I/ORLs of the system will be evaluated during each review. All other interfaces are recognized and should be scrutinized prior to each milestone review, but the I/ORL determination will only be made on the CSIs to focus the attention on the aspects that are important to mission success.

2. Identify Required Personnel / Research

After the Mission Critical Threads and their respective CSIs are identified, the respective Subject Matter Experts (SME) / organization representatives for each of the critical system interfaces meet with an unbiased third party (either government or contractor) to assess the validity of the mission thread and interfaces. This team of SMEs and 3rd party representatives will eventually assign the I/ORLs prior to the System Engineering Technical Review. Each SME or organization representative must review the mission thread and interfaces, and be ready to discuss each aspect of the interface.

3. Review Mission Threads and CSIs

As the systems move through the acquisition cycle, the critical threads may change as well as the various system interfaces that are involved. This means that the above analysis for determining the CSIs should be revised prior to each I/ORL determination in support of milestone reviews. It is not necessary to start the mission thread analysis from scratch, but verifying that all of the analysis is still applicable in light of any major system changes should be completed. Each SME/ organization representative must discuss the interfaces in order to approve, remove, or add to the given critical system interfaces.

4. Discuss Interfaces

Each of the CSIs must then be analyzed for interoperability problems. While there are many different ways to accomplish that, a list of suggested evaluation criteria is described in Table 11.

Table 11. Suggested Evaluation Criteria

This table describes the suggested evaluation criteria for I/ORLs

Topic	**Criteria**
Physical Interfaces	Ensure physical connections are adequate.
Data Type	Ensure data from one system/organization is compatible with the other system/organization.
Data Amount	Ensures that the amount of data transferred can be utilized/stored properly within the other systems.
Bandwidth	Ensure systems can accommodate the rate at which data is received.
Hardware/Software Requirements	Ensure hardware and software is compatible.
Data Security	Ensure data is correctly secured.
Human System Interface	Ensure usability with software / hardware.

Physical interfaces would be discussed during the meeting to ensure the connections between the systems are correctly designed and compatible. This is to ensure that the interface is adequate to meet the requirements of data transfer.

The type of data is an important factor to consider during these discussions to ensure that the data transferred from one system is compatible with another system. SMEs will provide data requirements for their system and ensure that the system will receive all the information required to complete its own task. It is important to consider the quality of data type that is transferred and if the data type will always be readily available. Data translators can be discussed if required.

The amount of data must be considered by each system. Systems must account for the amount of data being transferred to ensure that the systems are capable of storing and utilizing the amount of data received.

Bandwidth must be considered to ensure each system can accept the rate at which data flows. The systems must consider the rate at which data is transferred at, and the rate at which data is received.

Hardware and software are often built as separate elements. This topic must be discussed to ensure the hardware meets the required specifications to adequately run the software. As software development proceeds, requirement changes forces alteration of the code. This step will ensure hardware adapts to these software alterations.

Data security must be considered during these meetings as well. The data be within the correct classification, and ensure that the data is not leaked into an improper classification.

Human System Interfaces is important when considering how different organizations interface with software or hardware. These interfaces must be considered in order to create, perform, and support the mission thread.

Any issues must be recorded and discussed during the risk mitigation steps. Mitigations steps for these issues will be created after identifying the appropriate I/ORL levels for the system. At this point, each of the CSIs will have an individual I/ORL value assigned for evaluation at the associated milestone review.

5. Compare TRL/I/ORL Values to Prescribed Threshold and Objective Values

As a system progresses through its various reviews, a program that is on track should progress in a predicable manner. Given assigned threshold and objective I/ORL values for each review, each interface of the system can be evaluated to see if it is on or behind schedule for its I/ORL requirements.

Should a system or any of its components fail to meet the required threshold at a given review, it will need repeat the review or conduct a mini re-review. The decision to repeat the review or conduct a mini re-review will be up to the individual program; however it should consider the degree to which the system failed to meet the thresholds.

In the event that the I/ORL review yields results between the objective and threshold values the program manager will need to demonstrate a risk mitigation plan. The purpose of this is to address potential trouble areas in more detail before they delay the system. This approach highlights potential system interoperability issues allowing them to be resolved earlier in the system development.

Components or systems that exceed the objective I/ORL requirement for a given review do not require further action. These systems or components will be evaluated at the next review. Ultimately it is desirable that all components in a system meet or exceed the objective throughout development. This decision criteria is summarized in Figure 27 below.

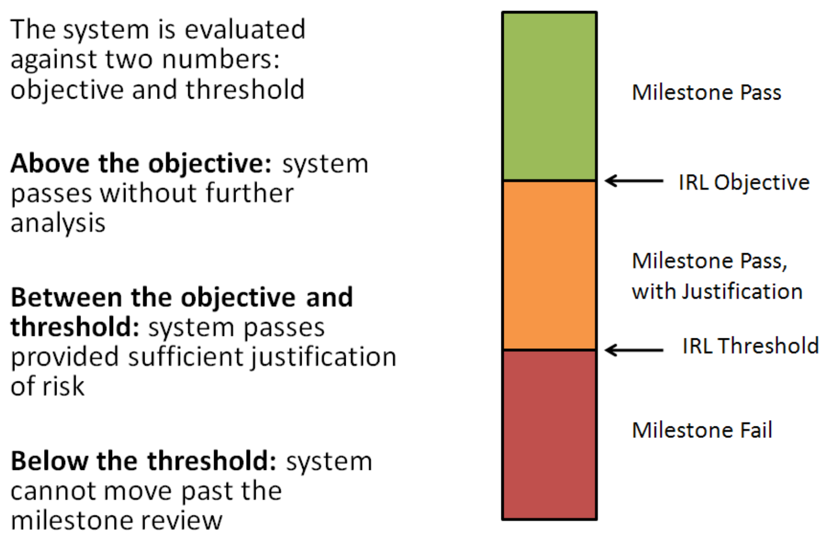

Figure 27. Milestone Evaluation Criteria

These are the decision criteria for I/ORLs at Each Milestone.

6. Perform risk mitigation on interfaces that do not meet objective values

For interfaces that fail to meet the objective values for the assigned review a system interoperability performance review will need to be performed. The objective of this review is to develop a mitigation plan to improve the I/ORL levels of interfaces that failed to meet the objective I/ORL values. It also provides a means to track the cost and schedule impact of interfaces that failed to meet the objective I/ORL values. This is shown in Table 12.

Table 12. System Interoperability Performance Review

This table describes two examples of the I/ORL evaluation process A3 shows an example of an interface that is lower than the objective and greater than the threshold. To pass, it must be at the objective or above the threshold with a mitigation step.

System or component interface	Description	I/ORL value	I/ORL threshold	I/ORL objective	Mitigation	Cost	Schedule	Anticipated I/ORL value	Pass
A1	Example 1	4	2	4					Yes
A3	Example 2	3	2	4	Establish common standards	$20K	3 weeks	4	Yes
B7	Example 3	1	2	4	Define interface, ID com-munication requirements	$60K	5 weeks	4	No

In the first block the system or component interface is identified. This identification is intended to be a shorthand notation that is used to track a particular interface. The second block provides a description of the interface. This is intended to augment the information in the first block and provide sufficient information to understand the function of the interface. The third block is the current I/ORL value for the given interface. The fourth block, I/ORL threshold, denotes the minimum required I/ORL value at the given review and is intended as a reference value. An interface can still pass the review if it is above the threshold value; however, it must have a mitigation plan approved by the SETR review board in order to pass. The fifth box is the objective I/ORL value for the given review. Together, boxes three through five provide a picture of how well the system's interface has been developed. The sixth box is intended to provide a mitigation strategy. It will be the responsibility of the PM to develop a strategy to improve the I/ORL of this interface. The objective of the mitigation plan is to outline how the given interface will improve its interoperability. The seventh box is intended to capture the costs associated with the mitigation plan. This will be used to track the cost of improving interoperability and may be useful for justifying changes to the budget. The eighth box captures the impact to the schedule as a result of implementing the proposed mitigation. Boxes seven and eight measure the impact of considering interoperability throughout the design and development process, while it may appear to that this process has the potential to add significant costs and delays, one must consider the impact of not addressing these issues early. The ninth box provides an anticipated I/ORL value, this is the I/ORL value that the PM anticipates achieving after completing the mitigation described in box seven. The last box, box ten, indicates if whether the given interface passed the review. An interface will pass a review provided the I/ORL value (box 3) is greater than the threshold I/ORL value (box 4) and a mitigation plan (box 6) with a favorable anticipated I/ORL value (box 9) are provided. Should an interface fail to meet this, it will be marked as failing, meaning that further development is required prior to the system passing the review.

As discussed previously, components or systems with interoperability failures will need to repeat the review or conduct a mini review of the interoperability failures. The decision to repeat the review or conduct a follow-up review will be up to the individual program; however it should consider the degree to which the system failed to meet the thresholds and the risk associated with the interface.

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V. PROCESS VALIDATION

To determine the effectiveness of the I/ORL design, the authors developed a two-pronged methodology. The first method used was a tabletop exercise designed to demonstrate the functional details of the I/ORL Process as it tracks the interoperability of a fictitious system. Although a tabletop exercise will not show general applicability to all systems, it will demonstrate the functionality of the approach presented in this paper. The second method is a mathematical simulation designed to track the effectiveness of the I/ORL Process if applied across the Navy and DoD. The application of I/ORLs and the progression of the system as it moves through the SE process is abstracted, but overall effectiveness can be determined.

A. TABLE TOP EXERCISE

The authors simulated the I/ORL Process on a system using a Table Top Exercise (TTX), illustrating how the I/ORL Process could be performed at System Engineering Technical Reviews. This validated the process and improved on gaps within the process. The TTX included real-world scenarios and role-plays that demonstrated knowledge of policies and procedures of the I/ORL. The TTX consisted of developing scripts to guide the exercises, separating the team into role players, and executing the I/ORL Process. Further, the team identified shortcomings in the I/ORL Process, created solutions, and applied improvements to a following TTX.

1. Development of the Table Top Exercise

A TTX is a discussion-based walkthrough of a proposed process [Radow, 2007]. It is a method used to review and test a plan, allowing for interjection of unexpected scenarios or events in order to vet many aspects of the proposed process. A TTX facilitates process improvement and training.

a. Selection of Reviews

As Chapter IV of this report describes, the I/ORL Process is to be performed at 11 reviews, which are outlined in the SETR [SETR, 2009]. Ideally the new I/ORL Process would be validated via a TTX on all of these reviews; however, the team selected a subset of reviews due to time constraints: ASR and OTRR. These reviews are in different phases of maturity for a system under development and allowed for "lessons learned" to be implemented in at least one subsequent review.

b. Selection of a Program

The authors investigated actual DoD systems and fictional systems on which to exercise the I/ORL Process. By choosing an actual system, it would allow the team to compare the data from the TTX to real data, showing how the process can actually improve a system's chances of passing OT. Upon investigating actual DoD systems, the authors discovered that data was not readily available, in part due to the classification of data. As a result, the authors turned to hypothetical systems to use for the TTX. Due to a theoretical system's flexibility, it gave the authors the ability generate and find data more readily and constrain a system's complexity; however, it meant the loss of the ability to compare the system to real data. A list of pros and cons in comparing an actual system to a theoretical system is presented in Table 13.

Table 13. Comparison of Actual versus Theoretical System for TTX

This table describes the benefits and shortfalls of using a theoretical system rather than an actual system for the Table Top exercise.

Actual System		**Theoretical System**	
Pros	**Cons**	**Pros**	**Cons**
Comparable to real data	Requires extensive knowledge on a system	Information readily available	Unable to verify data in an actual system
	Not all information is readily available	System can be constrained	
	Information may be classified	Faster to obtain data	
		More flexibility in finding data	

Based on the pros and cons, the authors decided to use a theoretical system. The system used was the Advanced Combat Integrated Helmet (ACIH) [ACIH, Garcia et al.], which is a helmet with integrated communications, night vision, thermal vision, navigation, and mapping tools. It includes many internal and external interfaces used for communication, and uses many commercial off the shelf (COTS) components, which facilitated information gathering. As this system is fictional, data for the ACIH could be quickly generated. An executive summary of the ACIH is provided in Appendix D.

c. Creating Artifacts

Artifacts are required to assess I/ORLs and to perform a SETR review. For implementing the TTX at the reviews, the team noted entrance criteria outlined in the SETR [SETR, 2009] and other additional documents/graphics to determine the necessary artifacts. The artifacts created for the ASR includes: an AoA, High Level Operational Concept Graphic (OV-1), Risk Assessment/Risk Management Plan, requirements, a notional schedule, and a Technology Development Plan. The artifacts created for the OTRR includes: Operational Requirements Document (ORD), Operational Test Plan, DT&E Results and test report, and Training Plan. These artifacts are provided in Appendix D.

d. Planning for the I/ORL Process TTX

All participants of the TTX were of members from the overall project team. The TTX team was separated into the following three categories with their respective responsibilities:

- Scripter/Facilitator
  - Design the table top exercise scenarios and script
  - Lead discussions
- Role Players
  - Perform the process using procedures and protocols
  - React to situations
- Observers
  - Take notes on the events
  - Provide overall suggestions for improvements

These key participants were required to review the I/ORL Process and perform the necessary steps as outlined in Chapter IV of this report. Participants were reminded that the goal was to assess the I/ORL for each interface in the context of executing the mission thread. The role players required for the ACIH TTX were:

- SETR Lead/Board
  - Responsible for conducting the review and is the decision authority for the pass/fail judgment of the interfaces.
  - SETR Handbook documents exactly how the SETR lead is identified for each review.
- System Integrator
  - The System Integrator is responsible for integrating the system to ensure readiness for OT. They will ensure the system is ready for integration testing by providing

feedback to the SMEs at each iterative review. They can also provide testing results to the SMEs to help assess I/ORLs at certain reviews.
  - Within the Army, the System Integrator would be identified from Program Executive Office Soldier (PEO Soldier). The System Integrator role can also be contracted out by the PEOs.
- System/Element SMEs
  - SMEs are identified from the owners of the system. SMEs can either be Government or contractor personnel. Example organizations include: In-Service Engineering Agent, Developer, Contracted support, etc.
  - ACIH Mission Thread Specific: Display, Core HW/SW, and Audio/Video
- Operational Test Agency Representative
  - The representative is responsible preparing the Operational tests. The representative will also ensuring the system is testable during the OT process by providing feedback to the SMEs at each iterative review.
  - The representative would come from COMOPTEVFOR
- 3rd Party Representative
  - The representative would be responsible for fostering SME discussion and to support the assigning I/ORL values as an unbiased 3rd party.
  - The representative is assigned by the program office and can be either a contractor or government personnel.

Due to time constraints, the TTX was designed to explore only one mission thread. The team selected the ACIH System Mission Thread pertaining to audio and visual communication. This thread integrates various audio, visual, and system components within the helmet to a core computing system. The helmet will enable the user to communicate with other ground troops and headquarters both visually and verbally through direct air transmission and/or via satellite communication, increasing the user’s situational awareness. This thread must include the organizations responsible for fielding the equipment, and the organizations responsible for ensuring the logistical infrastructure to support the use of the helmet throughout the lifecycle. This thread was chosen because many of the components used within the thread are COTS, allowing the team to easily find data.

e. Goals of the TTX

The TTX addressed the following questions about the I/ORL Process:

- How effective is the new process at ensuring programs pass Operational Testing?
- What areas in the I/ORL Process are missing or require more definition and clarification?

2. Performing the Table Top Exercise – ASR

The team performed the I/ORL Process using the ASR as the first review; however, some procedures were not executed as expected. This resulted in the team discussing issues and generating solutions following the exercise.

a. Performing the I/ORL Process

The team began the I/ORL Process by defining the given Mission Critical Thread. The SMEs attempted to discuss what interfaces were relevant. The following is a list of interfaces selected:

- Audio and video needs to be encrypted
- Communications prevent jamming
- Coverage to satellite/SATCOM
- Encryption key needs to change
- The software should interface all individual components together and provide communication
- Requirement for 3 dimensional display

As the Mission Critical Thread was not clearly defined by the team, the team improperly identified interfaces for the system. The team complicated matters further by discussing where the program should be in respect with the ASR, versus using the given artifacts to help identify interfaces. While the items in the list above are not actually interfaces, the discussions that ensued occasionally highlighted actual interfaces, such as the hardware-to-hardware interface between the helmet and the satellite, and the software-to-hardware interface between the core software and other various components.

With the team in technical discussions on these identified "interfaces", the team began assigning I/ORL values to each interface based on the I/ORL Values as defined in Chapter IV of this paper. These values were then compared to the I/ORL threshold and objective value requirement for the review. If an I/ORL did not meet its objective as outlined in Table 10, a risk mitigation plan was generated. The assessed values and required mitigation steps were later presented to the SETR Lead and OTA Representative for approval. The results are presented in Table 14.

Table 14. ASR TTX Results

This table shows the assessed I/ORL values for the ACIH System during the ASR TTX.

Interface	**I/ORL Objective**	**I/ORL Threshold**	**I/ORL Assessed Value**	**Mitigation Step**	**Pass/Fail**
Encrypt audio/video data	2	1	2	N/A	Pass
Anti-jamming	2	1	1	Do more research	Pass with mitigation
Satellite communications	2	1	2	N/A	Pass
Power	2	1	2	N/A	Pass
Software	2	1	2	N/A	Pass
3D Display	2	1	2	N/A	Pass

b. Assessing the ASR TTX

Once the TTX was completed, the assigned facilitators and observers discussed their comments on the exercise. Issues noted upon completion of the TTX for the ASR included an unclear definition of Mission Critical Threads, unclear definition of an interface, and a failure to identify critical interfaces. Additionally, I/ORL ranking levels were vague and no procedure existed for ranking I/ORLs. Finally, cost applicability and goals of reviews needed to be outlined. The following solutions were generated to clarify the process based on lessons learned from the ASR:

Mission Criticality Thread Representation

Issue: A major issue from the table top exercise was detailing how to represent the mission thread topic. The exact definition of mission criticality was not understood and the method in representing the mission thread in a manner to help the I/ORL Process caused confusion among the team.

Solution: In order to remedy this issue, appropriate diagrams are required to define and accurately represent the mission critical thread. A flow chart can be used as an important tool to describe the mission thread. It can visually show how mission threads flow from start to finish. This allows the team to identify critical system interfaces to be used in the I/ORL Process. These interfaces can then be assessed during criticality assessment. The flow chart becomes a valuable tool in representing the mission thread to help identify the interfaces. A top level flow chart can become the main diagram, which can further refined as other diagrams such FFBDs and IDEF0s emerge.

<u>Interface Definition</u>

Issue: During the table top exercise, it was realized that interface definition was not clearly characterized.

Solution: To address the lack of an interface definition that was identified during the table top exercise, the team must define interfaces associated with the mission thread and assess the I/ORL. Defining each interface of a system prior to and during the interface design process is essential to the success of system interoperability. Interface definition includes defining external interfaces with other systems, defining interfaces of system end items with each other, and defining interface objectives.

The mission thread flow chart and other available diagrams can be used to help identify interfaces. These interfaces can be human, hardware, and software aspects of a system. These interfaces can be categorized as software-to-software, software-to-hardware, and hardware-to-hardware.

<u>Critical Interface Identification</u>

Issue: Key players failed to identify critical interfaces as part of the I/ORL Process.

Solution: While all interfaces are important in the SE process, certain interfaces must be distinctly considered to carry out the I/ORL Process. The critical interfaces should be highlighted and brought to attention in the program review. The focus on critical interfaces prior to the review will allow the system designer and developer to closely plan and lay out the system interfaces to satisfy the mission requirements. Early consideration and planning of critical interfaces will make certain that system interoperability is integrated into the design and development of the system.

Prior to the review, a team of engineers are required to identify critical interfaces for a critical mission thread in order to test the I/ORL Process. The engineers identified the applicable interfaces for the critical mission thread but failed to identify the interfaces that have the most impact in the thread, the critical interfaces. They did not assess the interface criticality prior to assigning the I/ORL objective and threshold. The mistake was discovered when the engineers had difficulty assigning I/ORL values to an interface that was not critical in the I/ORL Process.

If the non-critical interfaces had been identified earlier, the team would have recognized that the interfaces did not have significant roles in the process.

I/ORL Ranking

Issue: The definitions for each I/ORL as described in Chapter IV of this report are not universal and it is difficult to apply to various interfaces.

Solution: One way to clarify the I/ORL descriptions and make them more universal is to provide a brief, high-level summary of the I/ORL ranks to be used in addition to the detailed explanations. It is important to note that the brief descriptions are useful for clarification of I/ORL values, however, the complete definition of an I/ORL must be used when making as assessment. This summary of I/ORL values is outlined in Table 15.

Table 15. High-Level Description of I/ORL Values

This table describes the brief, high-level summaries developed for each of the I/ORL values.

I/ORL	High-Level Description
9	In Operational Use
8	Passed OT&E
7	Component Interoperability Successful & Operational Scenarios Simulated
6	Passed DT&E
5	Component Design Complete & Reviewed for Interoperability Deficiencies
4	Technology Demonstration of Interfaces
3	Interfaces Requirements Documented
2	AoA Addressing Interoperability Complete
1	Identification and Exploration of Interfaces

Another solution to help clarify I/ORL levels is to develop a training program. Although the I/ORL Process is fairly simple, understanding I/ORL definitions is not trivial. A curriculum could be established that expands on these definitions and provides examples on how to use them. This could be offered via the Defense Acquisition University as an online class.

Having more tools available to aid in understanding will allow those involved in the I/ORL Process to more accurately assess I/ORL values for interfaces. This in turn will help the interfaces and consequently the system to perform better during operational testing.

I/ORL Ranking Procedure

Issue: No procedure was provided in the I/ORL Process for ranking I/ORLs.

Solution: A clearly defined process for ranking or assigning values to interfaces would assist the team in the I/ORL Process. By outlining the ranking procedure, evaluators have a clear "means of attack" and can more accurately assess I/ORL values for interfaces. Ultimately this will help the system interfaces to be more robust during operational test and evaluation.

Once data is available to determine the maturity of critical interfaces, I/ORL values are assigned to each interface as part of the I/ORL Process. In order to assign I/ORL values in a consistent way, a ranking procedure must be developed. The process for ranking I/ORLs is outlined briefly below:

- **Review Interoperability Assessment Data:** Prior to a review, subject matter experts have determined Critical System Interfaces as outlined in Chapter IV of this report. These are the interfaces on which an I/ORL assessment is to be made. SMEs will provide technical specifications required to assess the CSIs. Personnel responsible for assigning I/ORL values must review this data.
- **Understand I/ORL Values:** Evaluators are responsible to ensure they understand the meaning of I/ORL values. These values are described in Chapter IV in the section titled "I/ORL Values". Additionally, Table 15 is provided with increasing I/ORL values and hence maturity is presented. Both sets of data can be used to understand the meaning of each I/ORL value. Evaluators should attend training if it is available.
- **Discuss Maturity of Interface:** All parties involved in assigning interfaces must thoroughly discuss critical interfaces. The team must fully confer about the I/ORL data in order to fully comprehend the level of maturity of each interface.
- **Assess Maturity of Interface:** Once discussion has occurred evaluators must assess the interoperability data presented by SMEs. Evaluator should assess the maturity or interoperability of each interface bearing in mind the I/ORL values and their meaning.
- **Assign I/ORL Values:** Upon assessing the interoperability maturity of an interface, evaluators assign an I/ORL based on the designated values in Chapter IV.
- **Repeat For Each Interface:** Repeat this process for each interface until I/ORLs have been assigned to each CSI.

Cost Application

Issue: The process of allocation of cost with respect to system interfaces and their interoperability within the overall system design from programmatic, life cycle cost (LCC), and implementation viewpoints was unclear.

Solution: There are many factors in the SE process and cost should always be a consideration during this process. The I/ORL Process can be used to help focus on interoperability areas that are known to, or could present possible cost application risks to a system's design and development. Program engineers and budget analysts need to consider the various stages of the I/ORL Process and evaluate the cost associated with ensuring that the interoperability of the system is in line with the system's respective stage of development.

Implementation of bringing an interface to the appropriate I/ORL level can present a severe strain on the overall budget of a program if programmatic cost and LCC are not kept in check. Programmatic costs can seem small at first, but these costs must be reviewed and vetted through the whole program to capture the true nature of how much it might cost to mitigate a potentially low I/ORL during a review cycle. This cost does not just stop with trying to mitigate an interface to the next appropriate interoperability readiness level, but can extend well beyond the system engineering and design phase. The cost application should be considered even into the out years with the entire life cycle cost for the program due to modifications made during the early development stages.

The table top exercise demonstrated with the ranking of interfaces with I/ORLs where the interfaces were not at the threshold I/ORL value for the associated review; cost considerations to get the interface to the threshold level should be thoroughly investigated by the PM. The PM must then weigh all the factors involved to determine the way forward. This type of exercise can give great insight into how the design team and program managers should work hand in hand during early development to ensure the right systems and interfaces are getting the correct attention, and the system is progressing at a suitable pace so as to avoid interoperability failures later in the operational testing phases.

Goals of Review

Issue: The Alternative System Review (ASR) is a technical review that demonstrates the preferred concept is cost effective, affordable, operationally effective and suitable; and can be developed to provide a timely solution at an acceptable level of risk. The ASR ensures that the resulting set of requirements satisfies the customers' needs and expectations, the system's concepts align with the external environment, and the system under review is mature enough to proceed into the Technology Development phase. These are the textbook definitions as defined in the Defense Acquisition Guidebook (DAG) but the goals are not clear in terms of interfaces (hardware and software) or Interoperability Readiness Levels (I/ORLs).

Solution: The ASR provides an agreement on the proposed material solutions, hardware and software architectural constraints or drivers to address all key performance parameters (KPPs). As assessment of the full system software concept, a comprehensive rationale for the proposed material solutions, a comprehensive assessment of the relative risks, and a comprehensive risk assessment for the Technology Development phase are performed. The ASR also provides results of trade studies, technical demonstrations, joint requirements, refined thresholds and objectives, and a draft system requirements document all in terms of cost effectiveness, affordability, and providing an acceptable level of risk. During the ASR, key system components and interfaces (both physical and functional) need to be identified across the entire system and interface design. As seen during the TTX, I/ORLs need to be assigned to system interfaces where I/ORL objectives and thresholds are identified. During the ASR, I/ORL values are assessed to the interfaces and if the I/ORL threshold is not met then mitigation steps are identified. This will help identify any issues in regard to interfaces and system requirements prior to going to the Technology Development phase. Changing requirements or interfaces later in the program development will usually produce cost increases and schedule slips. The overall goals of the ASR should be entrance criteria for a system going into the Technology Development phase and System Requirements Review (SRR).

3. Performing the Table Top Exercise – OTRR

This review ensures that the production configuration system can proceed into Initial Operational Test and Evaluation (IOT&E) with a high probability of success. The interoperability goals of the OTRR are to verify interoperability of the system with all other systems has been verified through laboratory testing, simulated operational scenarios, ground based testing, and under operational environmental testing (desert urban environment in the day or night using military special forces executing a planned representative task or rescue mission) (I/ORL 7).

a. Performing the I/ORL Process

The I/ORL Process was performed by the team while leveraging off the lessons learned from the ASR TTX. The OTRR focused on Developmental Test and Evaluation (DT&E) results of the ACIH program, a provided artifact. The team reviewed the goals of the OTRR to ensure the team shared a common general understanding of the objectives and to ensure a successful outcome of the review.

Before starting the TTX, the team regenerated the Mission Critical Thread definition and the respective Critical System Interfaces. The Mission Critical Thread definition was supported by a diagram, presented in Figure 28.

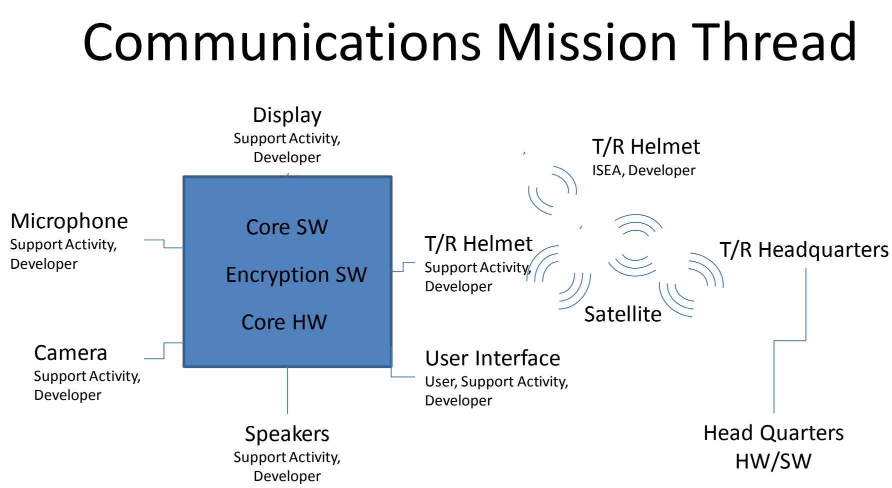


Figure 28. Communications Mission Thread for the ACIH System

This figure depicts the communications mission thread for the fictional ACIH System. The left side of the diagram represents the main internal components of the ACIH required for the mission thread and organizations that support the ACIH. The right side of the diagram represents the external components that the ACIH must be interoperable with: satellite, T/R Headquarters, and other Helmet T/Rs.

Using this diagram, the team was able to identify interfaces within the mission thread and discuss which interfaces were critical. The following is a list of the CSIs:

- Microphone-to-Core SW/HW
- Speakers-to-Core SW/HW
- Core-SW/HW-to Display
- Core SW/HW-to-Transmit/Receive (T/R)
- T/R-to-Satellite
- Satellite-to-T/R Headquarters
- User Interface-to-Core SW/HW
- User-to-User Interface
- Support Activity-to-HW Equipment
- Support Activity-to-Software
- Support Activity-to-Developer

- OS-to-Encryption SW
- User-to-Headquarters

The interfaces above identify the various hardware and software components within the helmet that must be interoperable to ensure the fulfillment of the mission thread. Also identified are the various organizations/people vital to using, developing, and maintaining the hardware and software throughout the helmet's life cycle.

Experience from previously completing the ASR TTX essentially provided training the team required. This resulted in a smoother execution of the process. The team referred to the process and artifacts more, and utilized the revised I/ORL procedure to help assign I/ORL values. This resulted in less confusion in assigning I/ORL values, and allowed the team to effectively find issues with the system.

Upon completing the improved I/ORL Process, the team generated interface assessments, evaluated these assessments, and issued a Pass or Fail designation. Results are presented in Table 16.

Table 16. OTRR TTX Results

This table shows the assessed I/ORL values for the ACIH System during the OTRR TTX.

Interface	**I/ORL Objective**	**I/ORL Threshold**	**I/ORL Assessed Value**	**Mitigation Step**	**Pass/Fail**
Microphone-to-Core SW/HW	7	7	7	N/A	Pass
Speakers-to-Core SW/HW	7	7	6	Re-evaluate requirement for audio frequency/Find cause of low frequency and conduct additional testing	Fail
Core-SW/HW-to Display	7	7	6	Re-evaluate requirement/Investigate display component	Fail
Core SW/HW-to-Transmit/Receive (T/R)	7	7	7	N/A	Pass
T/R-to-Satellite	7	7	6	Investigate 45 second delay issue.	Fail
Satellite-to-T/R Headquarters	7	7	6	Investigate 45 second delay issue.	Fail
User Interface-to-Core SW/HW	7	7	7	N/A	Pass

Interface	I/ORL Objective	I/ORL Threshold	I/ORL Assessed Value	Mitigation Step	Pass/Fail
User-to-User Interface	7	7	6	Perform DT user-to-user interface before OTRR	Fail
ISEA-to-HW Equipment	7	7	7	N/A	Pass
ISEA-to-Software	7	7	7	N/A	Pass
ISEA-to-Developer	7	7	7	N/A	Pass
OS-to-Encryption SW	7	7	7	N/A	Pass
User-to-Headquarters	7	7	6	This issue is dependent on other issues to be resolved.	Fail

As shown within the results, the TTX was successful in identifying critical system interfaces not ready for Operational Testing. By identifying these failures ahead of time, the I/ORL Process will have prevented a failed Operational Test.

b. Assessing the OTRR TTX

The TTX for OTRR benefitted greatly from the initial ASR TTX. However, while performing the TTX the team discovered a few minor issues; one dealing with the tracking table used during the review, and the other concerning timing of events.

Additional Column: Mitigation Step Accept/Disagree

Issue: While the team performed the second phase of the TTX, the team discovered one minor issue in the table used to keep track of the interfaces. When the SETR Board was deciding whether or not the mitigation step was acceptable or not, there was no column to input their decision.

Solution: An additional column is required to keep track of whether or not the mitigation step is acceptable to the SETR Board. This is an important option for the SETR Board in case the suggested mitigation step is unacceptable due to cost, schedule, or relevance. The mitigation step can be updated and accepted at the review or at a later time.

Time Between I/ORL Assessment and the SETR

Issue: During the discussions of mitigation steps with the SETR Lead and the OPTEVFOR Representative, one concern that was brought up was that the time between the I/ORL assignment meeting and the actual technical review was not defined in the process. The concern was brought up when minor ACIH issues from the first phase (I/ORL Meeting) were discussed in the second phase, questioning whether issues found would be fixed by the time the review occurs.

Solution: While the amount of time between the assessment meeting and the review is ultimately determined by the program manager based on the status of the program, the team suggests the meeting be held anywhere from a month to two weeks before the actual review. This will allow enough time to mitigate any small issues found during the assessment meeting. However, any major issues costing the program additional funds and/or affecting the schedule of the system must be approved by the SETR Board.

4. Summary of Table Top Exercise Results

The goal was to perform the TTX at different sections of the System Engineering Process and gradually improve the process as the authors progressed through the reviews. The I/ORL Process was assessed by going through an ASR and OTRR for a fictitious program. Upon completion of validating the I/ORL Process via a TTX, several valuable lessons emerged from this exercise.

a. The Need for Training

The I/ORL Process is most effective when participants fully understand the process and are able to use their knowledge and skills to apply it to a program. All involved personnel should have a common understanding of the I/ORL Process to collectively apply it to a system. It is important that the participants are provided with training and guidelines to increase their understanding and improve the application of the process.

The need for training was highlighted by the difference in performing the I/ORL Process between the ASR and the OTRR. In the ASR, the team neglected to identify critical interfaces. The lack of understanding the I/ORL Process among key participants led to confusion and lengthy program reviews. Performing the ASR effectively provided the team training. With a greater understanding of the process and I/ORL values, the team executed more efficiently. The OTRR TTX demonstrated that improvement in understanding the I/ORL Process enhanced and expedited execution.

b. Skipping a Review Can Lead to Problems

Performing the TTX proved challenging due to the fact that the team only performed two reviews to validate the I/ORL Process. The team noticed that issues found within the OTRR TTX would have been caught in earlier reviews. If the TTX consisted of more SETR reviews earlier in the system lifecycle, these issues would likely have been caught earlier, resulting in fewer issues at OTRR.

This TTX lessons learned can be applied to the I/ORL Process. It demonstrates the need to apply the I/ORL Process to all the relevant reviews throughout the lifecycle of a system. If the I/ORL Process is skipped, it is possible that the system will progress through reviews with some immature interfaces. This could in turn lead to a system failing operational testing.

c. The I/ORL Process Worked

After conducting the OTRR, the team found critical interfaces that were not at the proper I/ORL in order to proceed. The team found that the I/ORL Process worked well with regard to identifying interoperability issues before the system proceeds to formal Operational Test. If these issues had not been caught by applying the I/ORL Process to the system, the system would have proceeded into OT&E and would likely have failed at some point. This would have had a major impact on cost and schedule for the program and would have ended in considerable amounts of follow-on testing in order to verify and secure the proper corrections

By performing the TTX at two reviews, the team validated that the I/ORL Process is effective at ensuring that programs will likely pass operational testing. Further, the team identified areas in the I/ORL Process that require more definition and clarification, and areas that were missing.

B. MODELING AND SIMULATION

The second part of the validation is a mathematical and computer model designed to demonstrate the high-level effectiveness of an I/ORL implementation. The model stochastically simulates the interoperability work done throughout the SE process by assigning I/ORL values to system components and compares the assigned value to the required values at each of the decision gates. If the system does not meet the prescribed I/ORL threshold for the technical review, the system is reworked to meet the threshold at an additional cost that is assessed according to the development phase.

If the system reaches operational test and does not meet the prescribed I/ORL threshold, the system is deemed to have failed. This process is automated and repeated for a large number of systems and the number of failures is counted as well as total cost of failures incurred to the program.

To generate a meaningful comparison, the simulation performs two parallel models: one of the current SE process and one of the modified I/ORL Process. Prior to each review, the interoperability is increased for each system in both models. For the new process, if the system does not meet the I/ORL threshold values, it is reworked until it matches the threshold.

Ultimately, the model takes random inputs simulating the size of the program and data outlining the effectiveness of the current SE process, and outputs relative OT pass rates and cost impacts. The simulation compares the results of the two processes to draw conclusions on the effectiveness of adding the I/ORL measurement process. See Figure 29 for a generic flow diagram for the simulation:

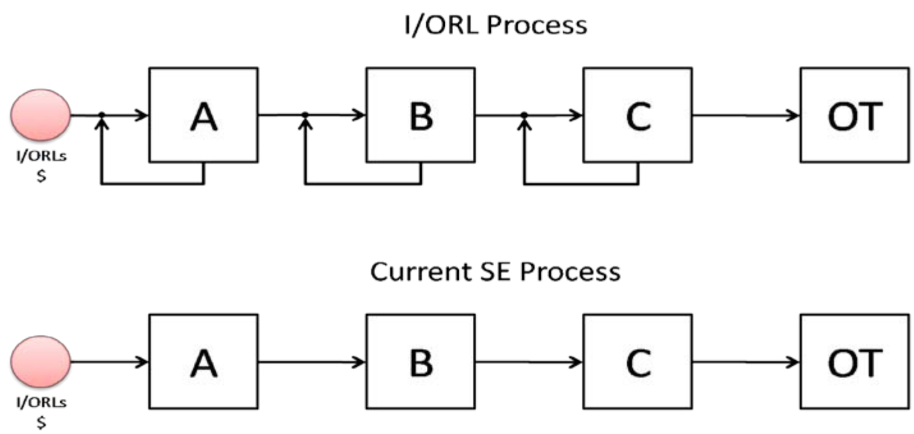


Figure 29. Flow Diagram for Modeling and Simulation

This diagram shows the basic model structure. Each system (represented by the red dot), moves through a series of decision gates. As the system moves across each arrow in the diagram, the system is being worked on and the interoperability improves. In the I/ORL Process, the system is evaluated at each of the technical reviews (A, B, and C in the above diagram), and, if the system does not meet the review requirements, it is reworked until it does. During the current SE process, the interoperability is not rigorously and consistently evaluated against a defined criteria and the system never incurs any rework. At OT, the system has its interoperability field tested and it is determined to either pass or fail.

1. Model Assumptions

Given both the time constraints and available data, the authors made the following assumptions to facilitate the model creation process. The authors made the determination based on engineering judgment that none of the assumptions made would significantly alter the conclusions drawn by the model in a negative manner.

- The maturity of an interface's design can accurately be represented by a single number reflective of the interface's interoperability
    a. Interoperability can be modeled as a real number despite I/ORLs only being integers.
    b. For the purposes of this model, the maturity of an interface design is represented by a single number on an interval scale, which is a constraint on those values not included in the I/ORL definitions provided earlier.
- As a system design matures, the work done between technical reviews is represented by an increase in the I/ORL level. That increase will not always be the same for each interface and nor from system to system. Therefore, a random number generator was included in the I/ORL model between simulated reviews to represent design maturation in a realistic way. Furthermore this assumes that
    - There is an equal probability to be above or below the mean
    - Interoperability work is well behaved, i.e. the standard deviation is significantly smaller than the mean
- The total amount of interoperability work is the same between each review
- The cost incurred to correct a design flaw is a fixed cost based on the milestone at which the problem was discovered
- The amount of interoperability tracking in the current SE process is minimal

2. Model Structure

The model is a procedural program written in the MATLAB language. MATLAB was chosen for its familiarity to the authors and due to its ease of processing array operations. The full code is included in Appendix E.

The model is designed to run a series of evaluations on a single system and record the results. That process is repeated a number of times (~10,000) and statistics are gathered from the results. As mentioned above, the model runs two concurrent models, one for the current SE process and one for the modified SE process, on an identical system.

The model sequence is broken down into the following phases:

- Data Initialization
- Interoperability Work
- I/ORL Measurement
- Review Decision
- Interoperability Rework
- Operational Test Evaluation
- Data Storage

The description of each phase follows.

a. Data Initialization

During the data initialization phase, the simulation configures the variables for a new system. This involves zeroing and recreating the interoperability arrays and other variables used in the simulation. Since the constants do not change from run to run, they are defined up front and just referenced each time.

During data initialization, the system generates anywhere from 5-20 interfaces to track using a uniform distribution. The interface parameters are stored in an array structure and modified using MATLAB's array operations throughout the simulation. Given the probabilities involved, the quantities of interfaces for each system will alter the overall OT pass rate. Through a series of test cases, the authors demonstrated that the effect of increasing the number of interfaces was minimal. In addition, model parameters were calibrated based on the number of interfaces to match literature data, so if at a later point in time it is determined that the interface number should be adjusted, other model parameters can be adjusted to maintain model validity.

b. Interoperability Work

The simulation keeps track of the interoperability of each of the system's interfaces throughout the acquisition process. During an actual implementation on a real program, the details of the interfaces are critical to the evaluation of the I/ORL levels, but for the purposes of the model those details are abstracted away. The model keeps track of interface quality independent of any details of the system/subsystem to which it is attached. These interface interoperability values are stored in two separate arrays throughout the model: one for the current system and one for the new I/ORL system.

Prior to each review, each of the critical interfaces had their interoperability increased based on a random amount. The amount of interoperability is a distinct, normally-distributed random variable. Although it is unique for each of the interfaces for the system, the amount of interoperability increase between technical reviews is identical between the current process and the new I/ORL Process (i.e. interface 1 current = interface 1 new, interface 2 current = interface 2 new, etc.). As mentioned in the assumptions, the math behind the model fundamentally assumes that interoperability is a number on an interval scale. This assumption was made by the authors because the level of interoperability was an abstraction of a measurement of design maturity, and that measurement was defined to be on an interval scale. It should be noted that because the system is interval does not imply linearity (i.e. the amount of effort, cost, schedule, etc. to go from an interoperability value of 1 to 2 may not be the same as from 2 to 3).

c. I/ORL Measurement

Once the new interoperability values are generated, the simulation models the measurement error for assigning the I/ORL values. The process model used is a simple probabilistic model for assigning correct values, false positives, and false negatives. If a correct result is generated, the system rounds the I/ORL value and uses that. If either a false positive or false negative result is generated, the I/ORL value is rounded and the result is either added to or subtracted from the actual interoperability. Note that this process is distinct for each of the system interfaces.

d. Review Decision

The I/ORL values are then compared to the threshold values for the technical review in question. If the measured value for a given interface is above the threshold, it passes and if it is below it fails and heads for rework. The technical reviews evaluated are ASR, SRR, SFR, PDR, CDR, IRR, FRR, and OTRR.

e. Interoperability Rework

Each system interface that fails a review has its interoperability reworked at an additional cost proportional to its developmental status. Since the cost data associated with the failures tracks a fully fixed problem, the amount of rework done is assumed to be exactly equal to the work necessary to pass. In other words, any interface that is reworked at a technical review has an interoperability equivalent to the threshold.

If a system is reworked as described above, additional cost is incurred to the program. This cost is review-based and is determined by a table lookup. The cost is incurred on a per interface basis (i.e. the cost to fix two interfaces is twice as expensive as the cost to fix a single interface) and does not factor how much rework needs to be done (i.e. if the system is deficient by .01 or .1 interoperability units, the cost is the same). Note that given a false negative result, the system could be sent back into a rework state (and thus incur cost) even though there is no problem to fix.

f. Operational Test Evaluation

At this point, the system is now ready to enter operational test. If all of the system's actual interoperability values are above the threshold of 7, the system passes operational test. While the perceived I/ORL value is used to determine if the system is ready to enter OT&E, the system's actual interoperability is being tested during the OT&E phase and therefore is used as the pass criteria. If a single interface is deficient, the system is considered to have failed for the purposes of the simulation and is sent to the final rework phase. Similar to the rework stage, if a system fails operational test, rework costs are incurred based on the number of interfaces that failed OT.

g. Data Storage

During the data storage phase the results are synthesized and stored for future analysis. After the simulation is complete, the total number of failures are tallied and descriptive statistics for the current and new systems are printed to the screen. The statistics of key importance are the average minimum I/ORL value for each of the systems, the OT pass rate, and the total cost overrun which could be correlated to schedule slip.

In addition to the table, a histogram is generated summarizing each of the systems. The histogram shows the differences in minimum I/ORL value for the current process and the one proposed by the authors. Figure 30 is a screen capture of a typical model result.

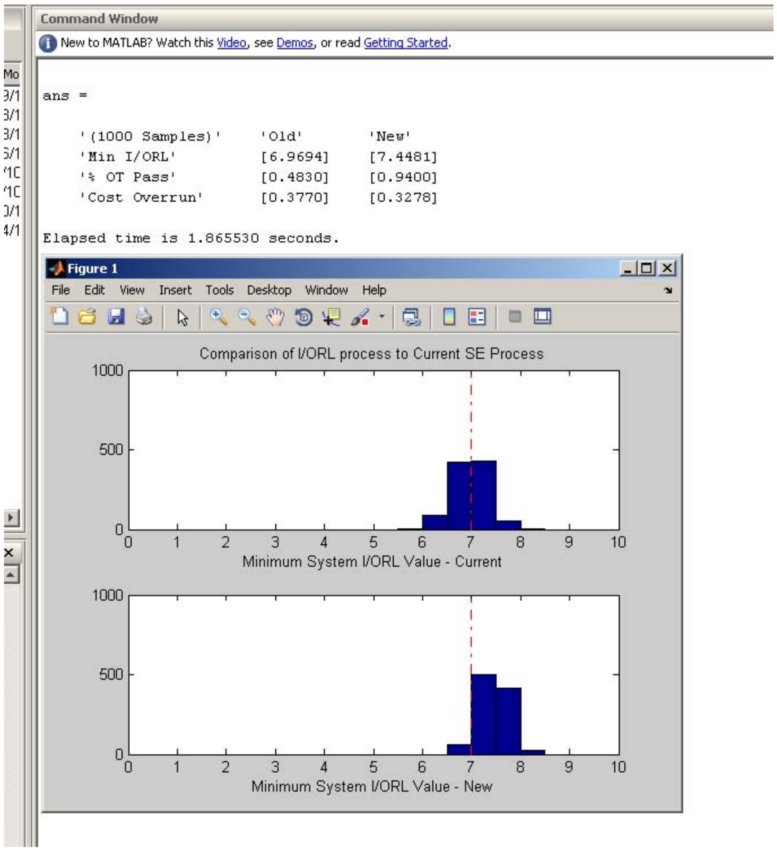


Figure 30. MATLAB Model Output

This figure displays the model output from MATLAB. The simulation outputs two primary pieces of data. The first is a table that displays the three primary model statistics: the average minimum I/ORL value for the systems, the OT pass rate, and the percentage cost overrun. The second output is a histogram of the minimum I/ORL value for each of the systems (blue) compared to the minimum I/ORL pass criteria (red).

3. Verification, Validation, and Accreditation

Once the model structure was created, the underlying parameters had to be gathered such that the model generates valid results. The three fundamental pieces of data that the authors determined were necessary to validate the model were interoperability work done between each review phase, costs of reworking an error, and the accuracy with which a team can apply I/ORLs.

Because of a lack of access to the necessary data, the authors ended up "reverse engineering" a majority of the unknown parameters. To accomplish this, the authors gathered data on the high level SE process results (for example OT pass, cost overruns, etc.) and adjusted the underlying model parameters until the model output matched.

a. Interoperability Work

As mentioned previously, the simulation tracks an abstract interoperability value for each of the interfaces in the system. In between each of the reviews, the interoperability of the system interfaces increases: this increase is termed “interoperability work.” For the sake of simplicity, this interoperability work is defined to be a random number for each interface at each review based on a positive normal distribution with a particular mean and standard deviation.

There were many particular random distributions to choose from, but, as mentioned in the assumptions, there were a series of characteristics that drove the decision. The first was that the distribution would be well behaved. The authors made the assumption that most programs would only enter a milestone review if all of their interfaces were deemed passing or, at the very least, near passing. This obviously is not always the case, but that variation is accounted for by the randomness in the distribution. The next one was that there would be an equal probability for the work to be above or below the mean. The last factor in choosing the distribution of choice was ease of programming. The authors wanted to make sure that the simulation could be run a statistically significant number of times to provide good results. Given these assumptions, the authors chose a normal distribution. Given more time and research, other alternatives could be found that better fit the assumptions and literature research on interoperability.

To determine the mean and standard deviation of the random interoperability work done, a literature search was conducted but few direct sources could be found. The method that the authors ultimately decided upon is to manually create the model parameters to fit existing data. Because the model compares the current SE process to the new I/ORL system, the output of the current SE process portion of the model should match data from existing processes. These parameters were then used for the I/ORL system as well to determine the relative change. Leveraging the work done by Eric Honour on the effectiveness of the SE process, the authors matched the model results to failure rates found in large engineering projects [Honour, 2004]. By assuming that an equivalent amount of work is done between each of the reviews, the parameters were adjusted until the failure rate for the current SE process, as calculated by the model, matched the literature.

The values that were ultimately chosen were a mean of 1.115 and a standard deviation of .215. When these values are implemented in the model, the majority of the interfaces on a given system demonstrated sufficient design maturity to pass each review, but it is relatively common for one or more to fail and have to be reworked at each review.

b. Rework Costs

The most important parameter for determining the cost-effectiveness of the I/ORL system is the improvement to the cost and schedule of the programs involved. The theory dictates that catching problems early in the SE process is more cost effective and saves time, and the I/ORL Process is designed to track problems such that they can be taken care of early.

The authors were familiar with the general rule of thumb that as the system moves through the different phases of systems engineering (requirements definition, detailed design, developmental test, operations, etc.), the cost of finding and making changes increases an order of magnitude between each review. The authors determined that if actual data could be acquired (rather than rough approximations), it would give the model the necessary inputs to accurately calculate the total normalized program cost.

The authors returned to Eric Honour's work on the *ROI of Systems Engineering* which compiled a list of past studies to provide an accurate approximation for the relative cost differences between the costs of changes at different phases of a software engineering project [Honour, 2007]. Unfortunately, Honour only provides relative rankings of the data and does not provide a reference for the absolute cost of a change, so it is only of limited use on its own.

To accommodate this, the authors developed a baseline for the relative data. Rather than trying to determine the absolute cost of one of the changes at a particular review and extrapolating for the remainder, the authors decided to use a similar approach to the OT pass rate and match total cost overrun for the model's output for the standard SE process to actual data. Upon revisiting the *Value of Systems Engineering* work, Honour's graphs indicated that the cost overrun of an average system was about 40-50%, so the authors scaled each of the relative costs to generate a total average cost overrun of 40-50% [Honour, 2004].

The authors were also interested in finding schedule slippage information in addition to the cost data. Unfortunately, no schedule slippage data was available as a function of time. Although this assumption does not hold for all systems, one can assume that the bulk of the costs will be labor and thus the average schedule slippage savings would be approximately proportional to cost savings.

c. I/ORL Application Accuracy

With any system of evaluation, the accuracy at which that system can be applied is paramount to its success and effectiveness. Obviously there is no actual data on I/ORLs, so the authors began looking for the effectiveness of TRLs, assuming that the results would be reasonably similar. Unfortunately, data outlining the application accuracy of TRLs was unable to be found. To tackle this problem, the authors developed three potential options:

- Assume 100% accuracy
- Assume a rough accuracy (<100%) and document the assumption
- Generate an accuracy model based on well-founded Human Reliability Analysis equations.

The first option, while the easiest, was not a viable option given that, without measurement inaccuracy, systems would never fail OT&E. In other words, if the evaluators always knew ahead of time that a system would fail OT&E, the system would never enter OT&E, and thus never fail.

The third option would provide the most validity, but it would also be the most complex model to generate. It would give the authors the ability to compare the accuracy rates of experienced versus inexperienced operators, at different reviews, etc., but fundamentally those effects were deemed to be minor, if any, when the simulation was run for upwards of 10,000 data points.

Therefore the second option was the only one that was feasible given the project's constraints. The authors were not comfortable inventing numbers without some basis behind them, so a literature search was conducted. No papers were found for the effectiveness of technical evaluation methodologies, but there is a broad and extensive field studying the accuracy of medical diagnoses. While this was not generally applicable for the application in question, it did give validity that the numbers chosen were accurate within an order of magnitude [Bagnato, 2004].

Ultimately the accuracy of the measurement was defined to be 80% accuracy with a false positive rate of 15% and a false negative rate of 5%. These numbers do not change the ultimate validity of the model and, as more data becomes available, the analysis can be modified to incorporate more accurate findings.

4. Model Results and Conclusions

The model was run for 100,000 cycles and the following results were generated.

Table 17. I/ORL Model Statistics

(100,000 Samples)	Current SE Process	I/ORL Process
Minimum I/ORL	6.9554	7.4565
% OT Pass	46.13%	93.73%
Rework Costs	44.26%	37.97%

The minimum I/ORL values is the lowest I/ORL value of all of the systems' interfaces at OT averaged over all of the number of runs; the % OT pass is the percentage of the time that the systems had all of the interfaces above the 7 I/ORL limit for passing OT; and rework costs is the average of the total amount of additional costs generated because of failures to meet the required thresholds.

Table 17 indicates two major facts about the model. The first is that the model results for the current systems engineering process matches data gathered from real systems in the actual DoD acquisition process. This gives the authors significant confidence that the model itself is valid.

Given that the first point indicates that the model is valid, the second point is that the proposed process is significantly better than the current SE process at developing systems that pass OT on the first try. Assuming that the technical review decisions are abided by, systems in the new process will pass more than 90% of the time on the first OT attempt. The system should also reduce the total cost overrun for the programs implementing I/ORLs by an average of 6.29% of program cost. Although these cost savings seem minor, there is the potential to save millions of dollars across DOD in the course of a fiscal year. Additionally the model does show that I/ORLs will improve the chances that systems will meet their interoperability goals the first time.

5. Model Areas of Improvement

Although the authors deemed the model sufficient to make a decision on the overall effectiveness of the I/ORL Process, there are many areas in which the simulation can be improved.

a. Programming Efficiency

MATLAB was the programming language of choice due to the experience of the authors and the ease of use. MATLAB is an interpreted scripting language and by default that is less efficient than compiled languages. Moving the model to something less processor intensive will allow for a greater number of data samples and thus better statistical accuracy.

In addition, increased efficiency would allow for greater model complexity without sacrificing the required statistical accuracy. This would allow the model to make fewer assumptions and therefore provide a more accurate understanding of the true effects.

b. Improved Data Sources

As mentioned in the previous section, the authors had difficulties finding data to exactly match the model structure. If improved sources can be found, the model's code found in Appendix E can be refined to provide more accurate results.

c. Study Effects of Program Size

As discussed in the section on model assumptions, the amount of interoperability work done between technical reviews was assumed to be a normal distribution with a fixed mean and standard deviation. Although the model was validated based on a normal distribution, there may be a better distribution that would provide more realistic results.

By setting the number of interfaces, the program can simulate a large or small program moving through both the current SE and modified I/ORL Processes. The authors feel that an interesting avenue of study for future work may be to analyze the effects of program size on the model's outputs for OT pass rate and rework costs. I/ORL methods may work well for large engineering programs, but their effects may not be as cost effective on smaller programs with fewer interfaces to track.

d. Explore other distributions for interoperability work

The authors made a simplifying assumption that the interoperability work done to the system interfaces could be modeled by a normal distribution. There are many other distributions that could have been chosen instead, and choosing a better distribution may be able to improve the quality of the results.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This project originated with a need to determine why systems are failing OT. Mission criticality was a recurring topic throughout the preliminary research. The sponsor had other groups studying various aspects of mission criticality; the authors were specifically asked to determine if OT failures could be reduced, through the application of mission critical threads. This project was not a typical SE design process as there is no physical hardware or software to design; rather, a Systems Engineering approach was applied directly to improving the Systems Engineering process.

The project was focused and narrowed as it progressed from one stage to the next. There was not sufficient time or resources for the Capstone Team to address every cause of OT failure. The data available for systems failing OT indicated that every system that failed, did so for multiple reasons, the most prevalent being interoperability, followed by reliability and training. Interoperability was prevalent in each of the OT failures, with concurrence of the Sponsor and the Capstone Advisor; interoperability became the sole focus of the new process's detailed design. Many processes were proposed by the authors, but ultimately the implementation of I/ORLs was determined to be the most appropriate method of addressing interoperability issues in mission critical threads. An I/ORL rating and application process was developed by the authors; it was then validated and improvements made through computer based modeling, as well as a pair of table top exercises.

Based on the modeling and the table top exercise, the authors believe that the current DoD Systems Engineering process could benefit from the implementation of I/ORLs. The modeling estimates a savings of approximately 6.29% over the current System Engineering process. This seems like a reasonable result for implementing I/ORLs. Further, the new process does not eliminate the need for rework; rather it identifies deficiencies earlier in the design process so they can be corrected before further development occurs. Additionally, the proposed process has the potential to reduce the amount of failures during OT&E (often highly visible) and allow for earlier assessments and adjustments to programs. Such adjustments might be reorganization, reevaluation of requirements, increased funding, and / or cancellation of a failing program.

Expectedly the hardest aspect of the process to model is the human factors. Factors such as a lack of or varied understanding of the processes and definitions, personal biases and opinions, political agendas, and human error are just some of the aspects that are difficult to model. These human factors were considered and assumptions were included in the computer-based model, as discussed in the I/ORL Application Accuracy Section of Chapter 5. The human factors were more clearly evident during the Table Top Exercises. Valuable data was collected for further refinements to potentially improve both the current process, as well as the proposed addition of the I/ORL process. The complexity of the SE process, along with the volume of sources (government, academia, and commercial) providing guidance, interpretation and instruction, leads to variations in the human understanding of the SE process. The authors concluded that a simplified SE process, with clear concise and standardized definitions would help to improve the process, with or without the implementation of I/ORLs.

All of the research and new process design and validation were then used to answer the Research Questions posed at the beginning of the project development:

Research Question 1. How are mission critical elements identified and managed using the existing acquisition and SE processes?

Mission critical elements are not currently being identified in the Systems Engineering process, and allocations or dependency on supporting resources (systems, sensors, data, etc.) are not being reflected in the contractor development plans, and testing plans. To some extent they can be found in a more general form as KPPs, or COIs. However, not all of these are critical to perform a given mission and the mission requirements may need to be more specific.

Research Question2. What are the common failures in the engineering process that result in missing mission critical elements? Where do these failures occur?

The authors conducted research on both the system engineering process and on systems that experienced difficulties during operational test and evaluation. This research indicates that significant emphasis is placed on the Defense Acquisition System measurable performance parameters. The result is an over emphasis of measurable parameters, which in some cases, results in a loss of the intent of the requirement, thus resulting in complications later in development. A lack of communication between the development community, the user community, and the operational test and evaluation community was noted. This may result in a duplication of effort with regard to testing the systems, but more importantly because of the lack of communication, the testing conducted varies between DT and OT, between different test agencies performing the same/similar testing and from one system to the next. This means that a system is evaluated according to one interpretation of the requirements during developmental testing (DT) and another during Operational Test and Evaluation (OT&E). These failures were observed in the form of problems with interoperability, reliability, training, suitability, and effectiveness. For the purposes of this report, the authors have chosen to address the issue of systems passing DT but failing OT&E as a result of a lack of interoperability. This is a mission critical area; however, when compared to standard performance goals it can be nebulous and difficult to test or simulate in a realistic way.

Research Question 3. How prevalent are mission critical failures of programs discovered during OT&E?

Mission critical failures are a serious problem. Systems are failing to meet their operational effectiveness or suitability requirements at a rate of approximately 50% [Defense Science Board Task Force, 2008]. The high rate of failures and the cost associated with reworking these systems necessitates that an approach to track and monitor mission critical elements be identified. While the failure rate included much more then interoperability, the authors did find that interoperability was the most prevalent. Additionally, a secondary effect of fixing interoperability issues earlier in the design and development process is that it will allow for resources to be re-allocated and cost savings to be applied to other critical areas of system.

Research Question 4. What kinds of Modeling and Simulation (M&S) can be leveraged to analyze DoN System Engineering processes?

There are many M&S techniques available. For this project we found two techniques useful; both a Table Top Exercise and statistical/mathematical analysis through software simulation. Table Top Exercises are a good method for evaluating single steps within the DODI 5000.02 process; these exercises allowed us to focus on deficiencies in both the current process as well as the recommended improved process. In addition to finding flaws in the systems, the Table Top Exercises allow for the intentional introduction of specific events, challenges, missing or incorrect data and allow the observers to see how the process proceeds when the human element is included. Unfortunately, running a table top exercise to simulate the whole of the DODI 5000.02 requirements process is too costly and time consuming. The cost and time issues significantly outweigh any benefit from conducting such a large exercise. For this reason, the entire process was simulated as a mathematical process. While numerous modeling and simulation software programs are capable, MATLAB was chosen based on the skill sets of the Research Project authors. MATLAB was used to simulate the higher level steps of the overall process, both current and proposed. The analysis included a comparison of estimated costs for both processes, as well as assessing the quality of the interoperability readiness of the simulated products for both processes. To achieve this, I/ORLs were assigned to the simulated products in accordance with the proposed process. For comparison the simulation evaluated the output of current process and assigned an I/ORL after the current process was complete. These two I/ORLs were used to compare the two processes.

<u>*Research Question 5*</u>*. Can process improvements be used to supplement the DoN System Engineering processes to improve handling of mission critical elements of programs?*

The authors developed a process to assess the interoperability maturity of a system. To accomplish this, the authors developed I/ORLs as a tool to assess the maturity of interoperability throughout the design process of a system. This improvement evaluates the developmental status of capabilities and interfaces that allow the system to interoperate with other legacy and new systems in support of mission critical threads. I/ORL values are assigned throughout the process and are used to predict the system's ability to pass operational test and evaluation with regard to interoperability. This report outlines the proposed process and provides a list of possible improvements.

<u>*Research Question 6*</u>*. What are the cost ramifications and possible benefits of implementing these enhanced processes?*

As demonstrated by the modeling, by identifying problems earlier, these enhanced processes have the potential to decrease developmental costs by 6.29%. The earlier problems are addressed, the less rework is required in both time and money. Equally importantly, the model shows an increased OT&E pass rate through an increase in systems engineering efficiency; leading to decreasing costs (both time and money).

B. RECOMMENDATION

It is the recommendation of the authors that DOD included the I/ORL proposed process as part of an improved SETR process. While introducing additional I/ORL requirements and simultaneously streamlining the process may seem contradictory, they are mutually beneficial. The streamlining suggested is a more concise, articulated set of rules and definitions for program managers, systems engineers, contractors, users, and financial personnel. This streamlining includes providing clear definitions and guidance on the use of mission criticality. The current process is improved upon by introducing I/ORL's. However, the integration of the human into the SE process still requires improvement, as is expected in any process where humans are involved. The additional information provided to programs in the form of I/ORL requirements and clarifying definitions will help to improved interoperability in system development.

C. AREAS FOR FURTHER STUDY

Throughout the process, the authors realized there were numerous areas that could not be studied by the authors do to a lack of resources and time. Early on in the project, it was realized that the scope of the project needed to be reduced to a more manageable size. The initial research pointed to three common causes of OT failure: interoperability, reliability, and training issues. The authors chose to study interoperability, as every system studied in the research failed OT with some interoperability issues, while only 75% failed with reliability and training issues. No further investigation was made into the cause of reliability or training failures after the down scoping of the project. These have the potential to become separate projects in and of themselves.

Another area that was briefly discussed during the down select is the cost of implementing the new process. The authors are aware there are costs associated with training, implementing, and maintaining process; no analysis was done to estimate the actual cost of implementing the new system or the administrative burden. Despite any possible increased costs during initial implementation it is assumed during the down selection that:

- All of the new processes considered have training and implementation costs.
- The long term savings of implementing a new process will far outweigh the cost of process implementation.
- The new process would result in better OT results than the current process.

It is suggested that an additional study be done to determine the actual cost of implementation and training on the new processes. It is likely that these costs can be mitigated to some degree by combining with other proposed changes to the SE process; however, the authors did not conduct research to determine the cost or timeline to implement such process improvements.

APPENDIX A: PROJECT MANAGEMENT PLAN

NAVAL POSTGRADUATE SCHOOL

CAPSTONE PROJECT

FOR

MASTERS OF SCIENCE

IN

SYSTEMS ENGINEERING

Identification, Management and Testing of Mission Critical Operationally-Focused Requirements in Support of the Systems Engineering Process for Naval Acquisition

PROJECT MANAGEMENT PLAN

NAVSEA COHORT #1

MSSE COHORT 311-092S

SUBMITTED BY	NPS CAPSTONE Team Representatives	FOLEY.KYLE.1367165355 — Digitally signed by FOLEY.KYLE.1367165355 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USN, cn=FOLEY.KYLE.1367165355 Date: 2010.06.03 16:20:15 -04'00' Digitally signed by THRIFT.MICHAEL.L [illegible]
REVIEWED BY	Project Advisors	SHEBALIN.PAUL.VALENTINE.1020238107 — [illegible] MILLER.GREGORY.A.1157388157 — Digitally signed by MILLER.GREGORY.A.1157388157 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USN, cn=MILLER.GREGORY.A.1157388157 Date: 2010.05.07 12:48:50 -07'00'
REVIEWED BY	311 Academic Associate	
APPROVED BY	SE Department Chair	

Revision History

Revision	Description of Changes	Date
-	Original Document	01 April 2010
1	Professor Miller's Comment Incorporated	25 April 2010
2	Professor Miller's Comment Incorporated	26 April 2010
3	Professor Miller's Comment Incorporated	27 April 2010
4	Final Draft update	28 April 2010
5	Incorporation of New Professor Comments	30 April 2010
6	Incorporation of Final Professor Comments	1 May 2010

I. Introduction

This is the Capstone Project Management Plan (PMP) for the Naval Sea Systems Command (NAVSEA) Cohort 311-092S, hereto after referred to as the Mission Critical Team. As part of the Naval Postgraduate School (NPS) Master of Science in System Engineering (MSSE) Capstone Project, the Mission Critical Team will investigate changes to the requirements identification and management processes that a system will utilize during the Department of the Navy System Engineering process.

1.1 Problem Statement

The current Department of the Navy (DoN) system engineering process has documented instances of programs failing to detect critical inter-operational failures prior to operational level testing. Programs are successfully passing developmental testing; however, these tests do not provide adequate assurances that the system will satisfy user needs or CONOPS-based interoperating requirements of the operational community. Furthermore, requirements that are critical to mission success are not being identified in the current SE process, and allocations or dependency on supporting resources (systems, sensors, data, etc.) are not being reflected in the system engineering, contractor development plans, and testing plans.

DoDI 5000.02 and related documents describe the Defense Acquisition System used for development of Department of the Navy programs. Despite extensive guidance and multiple decision gates, programs are still failing to ensure that all requirements critical to meeting the user need are identified and properly tested prior to the start of the Operational Test and Evaluation (OT&E) process. Improvements must also be made to the system engineering requirements process to ensure that these critical requirements are made visible at key technical reviews(s) such as Preliminary Design Review (PDR), Critical Design Review (CDR), Test Readiness Review (TRR), and Production Readiness Review (PRR).

1.2 Research Questions

The following research questions will be answered as the project progresses:

- How are mission critical elements identified and managed using the existing acquisition and SE processes?
- What are the common failures in the engineering process that result in missing mission critical elements? Where do these failures occur?
- How prevalent are mission critical failures of programs discovered during OT&E?

- What kinds of Modeling and Simulation (M&S) can be leveraged to analyze DoDI 5000.02 processes?
- Can process improvements be used to supplement the DoDI 5000.02 processes to improve handling of mission critical elements of programs?
- What are the cost ramifications and possible benefits of implementing these enhanced processes?

1.3 Stakeholders

- <u>Naval War Fighter</u>

  The key stakeholder for this project is the naval war fighter. Although the war fighter does not encounter the identified problem until a system becomes operational, the war fighter is left to deal with consequences of an ineffective system that is delivered with deficiencies. The Joint Capabilities Integration and Development System (JCIDS) process describes the Joint Forces Command (JFCOM) as the war fighter representative into the acquisition infrastructure. Commander, US Fleet Forces Command (CFFC) is the approval authority for the Capability Development Documents (CDDs) and Capability Production Documents (CPDs).

- <u>ASN (RDA) CHENG</u>

  The Assistant Secretary of the Navy for Research, Development and Acquisition Chief Engineer's Office is responsible for System Engineering Technical Reviews (SETR) for all ACAT programs, regardless of the ACAT designation ASN (RDA) CHENG will be interested in the outcome of this project as our sponsor. We will be engaged with their representative on a continuous basis to understand and receive guidance on the direction of the project. They will also be interested in the utilization of the possible process changes for incorporation into the SETR process.

- <u>Program Office/Program Managers</u>

  The Program Offices and Program Managers for specific development systems may be impacted by this project. The programs/systems may be able to utilize the output of this project to re-define their systems engineering process, requirements definition, test planning and conduct.

- System Design, Development and Validation Teams

  The design engineering teams may be affected by the outcome of this project. This could be the prime contractors or the SYSCOM field activities charged with the system development efforts. The criteria identified for "mission criticality" may have impacts on the design and development of a system, along with the testing requirements identified.

- U.S. Navy Operational Test and Evaluation Force (OPTEVFOR)

  OPTEVFOR assesses the operational effectiveness and suitability of new and improved war fighting systems and capabilities. The outcome of this project may provide additional information in order to evaluate systems under test.

1.4 Project Proposal

Based on the need to address this deficiency in the current system development process, the current DoDI 5000.02 process will be analyzed by investigating methods to improve capturing, monitoring, implementing and testing the requirements critical to ensuring mission success. Improvements to the DoDI 5000.02 processes will be developed to ensure that these requirements are identified and promulgated through key program documents and design reviews. The objective of this capstone project will be to develop enhanced processes supplementing DoDI 5000.02 to improve the handling of these requirements. These enhanced processes will be simulated on a DoD system in a tabletop exercise to provide an example of how this modified process should be performed. The enhanced process and the demonstration will be documented in the capstone final report.

System engineering principles and methodologies will be used to propose changes to the requirements processes in the DoN acquisition system to ensure that requirements that are critical to mission success are identified and ensure that these requirements are integrated into the system development plans and testing plans. These requirements must be aligned with the user needs and system requirements and must be testable at the system and interoperability levels. This process is initiated at the system needs analysis phase and continues through the operational testing phase. Development of these requirements requires the early involvement and support of the users and testers in order to ensure that operational testing accurately represents the needs of the users and to align the system development process with the user needs. In addition to ensuring that these requirements are included in the original requirements baseline, this process will ensure that these requirements are included in the appropriate development and testing plans and all applicable design reviews.

A DoN program will be selected to use as a demonstration of the enhanced process. This program will be selected based upon availability of critical information and the knowledge, interest, and experience of the capstone team. The critical information necessary will be system requirements as tested during operational testing and the history of how the requirements were determined from the user needs and how those requirements changed over the development cycle. This demonstration will entail performing the key steps of the requirements process as a tabletop exercise. The results from these steps will be documented in the final capstone report. In addition, the team will perform a cost/benefits analysis of the enhanced process, including an assessment of how the requirements and/or testing of the program would have changed if this modified requirements process had been performed.

1.5 Organization

The Mission Criticality team is made up of 15 members located in three different geographical locations: NSWC Indian Head MD, NSWC Dam Neck VA, and NSWC Port Hueneme CA. The cohort's project orientation is functionally organized between Project Management and Systems Engineering, as indicated in Figure 1. The roles and responsibilities of each team member may be re-assigned to meet the project needs and requirements.

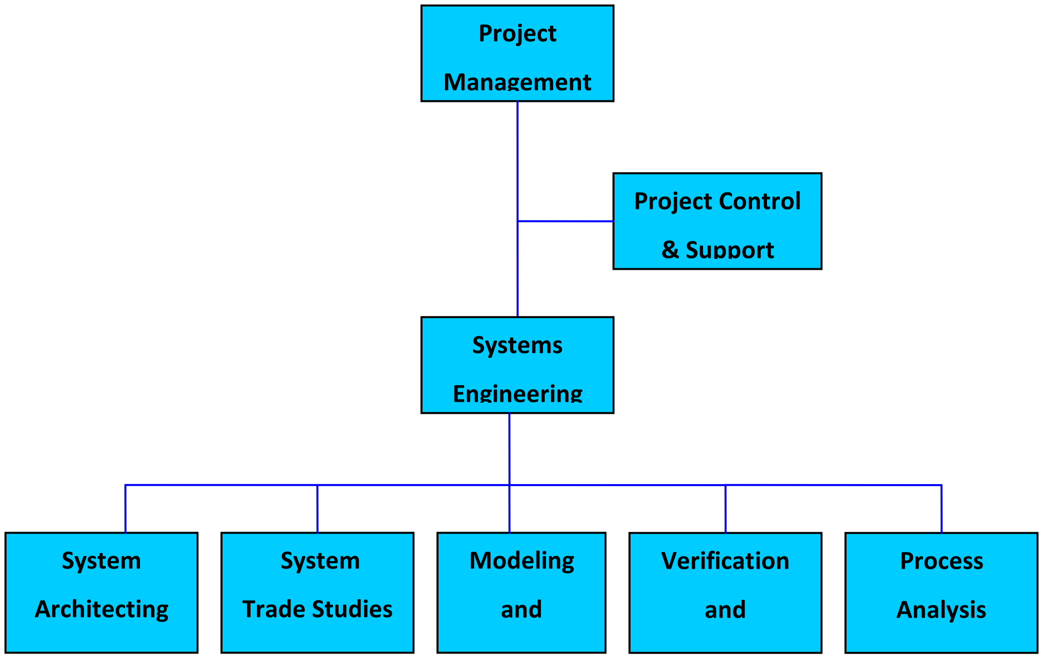


Figure 1 Organizational Chart

1.5.1 Roles and Responsibilities

Table 1. Roles and Responsibilities

Role	Responsibilities
Advisor(s) Instructors(s) Stakeholder(s)	♦ Provide guidance throughout the project
Program Manager	♦ Interface with the sponsor, stakeholders, instructor, and advisor ♦ To monitor project progress and ensure schedule and documentation requirements are met
Editor (Project Control)	♦ Edit and compile all documentation ♦ Ensure format structure is maintained throughout all documentation
Librarian/Webmaster(s)	♦ Maintains copies of all submitted drafts and final documentation submitted to the instructor and

(Project Control)	stakeholders (through SAKAI) ♦ Maintains organization of SAKAI group webpage ♦ Takes minutes for all meetings involving the entire Capstone Team ♦ Collects and maintains meeting minutes from the leads of each small group
Scheduler (Project Control)	♦ Responsible for developing and updating the schedule and tracking all due dates for the project
Systems Engineering Team	♦ All group members will participate in the System Engineering Process. ♦ Ensure the appropriate Systems Engineering approach is utilized throughout the project ♦ Perform all system engineering tasks as required ♦ Break into smaller teams to perform parallel system engineering tasks as appropriate

1.5.1 Team Member Assignments

The initial team member roles are listed in Table 2. As previously stated, most members are a part of the systems engineering team. Their specific assignments will change as the project progresses. Several systems engineering team members have additional aptitude in specific roles (e.g. modeling and simulation); these will be taken into account during task assignment

Table 2. Team Member Roles and Responsibilities

Name	Initial Roles & Responsibilities
Kyle Foley	Co-Program Manager
Michael Thrift	Co-Program Manager
Eric Hawley	Lead Editor
Janet Holt	Librarian/Webmaster
Alex Guerao	Scheduling Lead
Peggy Rogers	Systems Engineering (Backup Editor)
Chirana Pimsarn	Systems Engineering (Backup Librarian/Web)
Tien Phan	Systems Engineering (Backup Scheduler)

Steve Tegtmeyer	Systems Engineering
Steven Possehl	Systems Engineering
Jesus Garcia	Systems Engineering
Phong Trinh	Systems Engineering
John-Anthony Gorospe	Systems Engineering
Theodore Schindler	Systems Engineering
Mark Cavolowsky	Systems Engineering

1.6 Project Advisors

Dr. Paul Shebalin is Director of the Wayne E. Meyer Institute of Systems Engineering and a Senior Lecturer of Systems Engineering at the Naval Postgraduate School in Monterey, CA. Mr. Gregory Miller is a Lecturer of Systems Engineering at the Naval Postgraduate School in Monterey, CA. These two professors will be our project advisors for the duration of the capstone project.

1.7 Risk Management

Risks affecting the success of the development of an improved process will be identified throughout the project. In identifying the risks, the probability of occurrence and the potential consequence will be quantified by initiator of the risk, on a scale from 0 to 1. A risk rating will be given (probability of occurrence times potential consequence), which will be used to prioritize the risks. Once the risks are properly identified and prioritized, mitigation strategies and contingency plans can be developed in order to reduce the risk rating. These strategies and plans will be brought to the team as a whole for approval before taking action on the risks. Once these mitigation strategies and/or contingency plans are approved, the risk will be monitored as the mitigation steps occur, up until the risk will be at a point that the program is willing to assume. The risk matrix shown in Figure 2 will be used to visually display the risk.

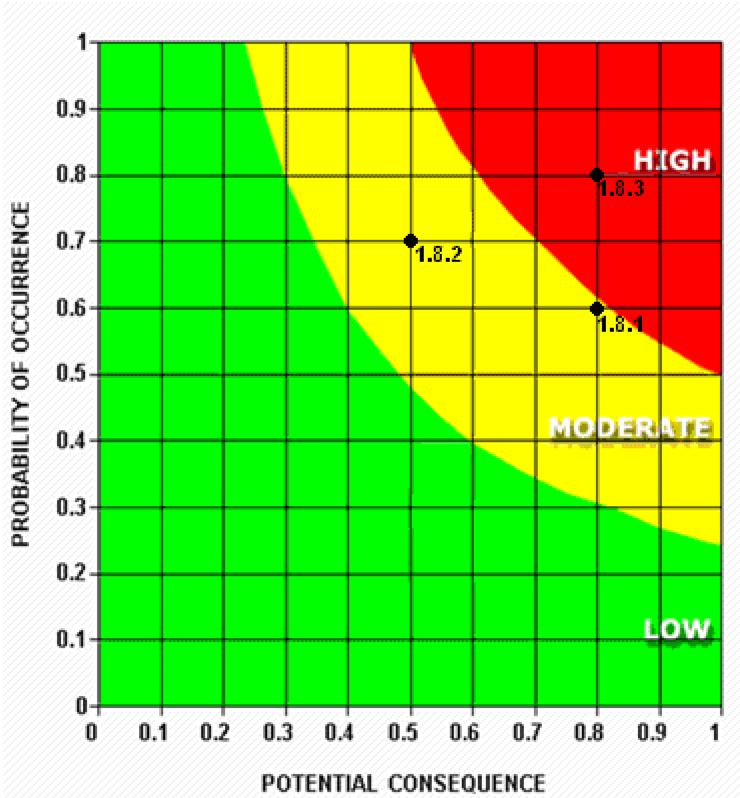


Figure 2. Risk Matrix

1.7 Risk Management

Below are the initial risks to this project as identified by the project team. As the project progresses, additional risks will be added as they are identified.

1.8.1 Personnel Risk

Description: If the project is not properly scoped to the amount of personnel on the team, then the project schedule may slip to the right, missing the due date.

- Risk Rating: 0.48
  - Probability of Occurrence: 0.6
    - The problem statement for the team has been established, and the project management plan contains an attainable schedule. The team must meet the deliverables and milestones in order to stay on schedule to meet the due date. The probability will reduce as the project progresses according to schedule.
  - Potential Consequence: 0.8

        - If the team over-estimates what can be accomplished, then it can affect the successful completion of this project on time. This can result in having an uncompleted project at the due date.
- Mitigation Steps:
    - Keep the team engaged by scheduling regular meetings.
    - Ensure scope of the project does not increase to the point where the team cannot realistically accomplish the goals.
    - Properly decide when to move onto the next phase of the project.

1.8.2 Resource Risk

Description: If the project lacks the resources to collect data from past and current systems, then the proposed process (deliverable) may be inadequate.

- Risk Rating: 0.35
    - Probability of Occurrence: 0.7
        - The lack of data for this project is potentially high due to the difficulty of obtaining historical information from past and current ACAT acquisition programs. As the project progresses and more data are received, this rating can be reduced.
    - Potential Consequence: 0.5
        - While this will unlikely prevent the completion of the project, the amount of data is directly related to the quality of the project. The more data that can be studied, the better the quality of the project.
- Mitigation Steps:
    - Talk to various points of contacts to obtain historical data on ACAT Acquisition programs.
    - Analyze data to ensure its quality.

.8.3 Changing Requirements/Scope

Description: If the requirements for the project continuously change/grow, then the project schedule may slip to the right, missing the due date.

- Risk Rating: 0.64
    - Probability of Occurrence: 0.8

        - The project is currently still being defined through the PMP. Requirements for the project have not been written down. Probability of occurrence can be reduced throughout as the project progresses.
    - Potential Consequence: 0.8
        - The consequence of allowing requirements to change while unmanaged can increase the scope of this project, affecting the successful completion of this project on time. While a product can still be turned in at the due date, the product would be incomplete.
- Mitigation Steps:
    - Ensure the scope/requirements of the task are within the team's capability.
    - Baseline the requirements to prevent requirements creep.
    - Manage requirements change.

2 Systems Engineering Approach

The approach outlined below provides the overall systems engineering process that will be used during this project.

2.1 Overview

The goal of the project is to analyze the deficiencies of the current systems engineering process supporting Department of Navy (DoN) Acquisition in the area of requirements critical to ensuring mission success. This will likely include creating an addendum to the current systems engineering process.

2.2 Process Phases

The project will consist of five phases: Process Review and Problem Identification, Analysis of Alternatives, Detailed Process Design, Process Validation, and Present Recommendations (Figure 3). Each phase will be executed by taking the inputs and feedback from later phases. Once the given outputs are of suitable quality, then each phase can be considered complete. A detailed description of each phase is found in the subsequent sections.

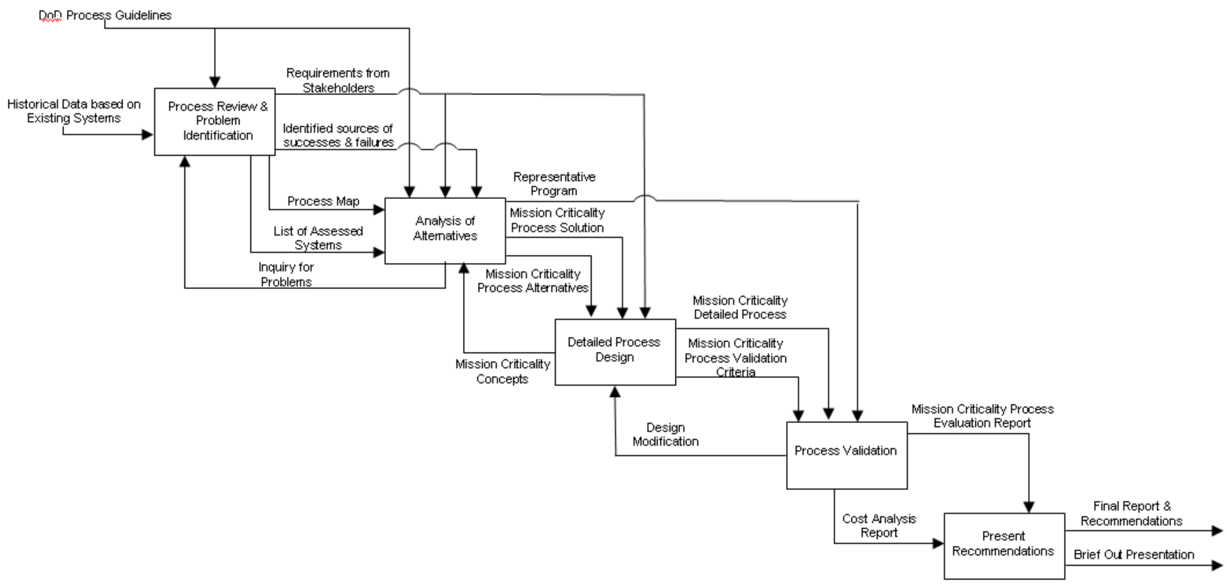


Figure 3. SE Process Diagram

2.1.1. Process Review and Problems Identification

Process Description:

All stakeholder needs and requirements will be collected and prioritized based on pertinence to the project objectives and stakeholder importance. Conflicting needs/requirements will be discussed with the required stakeholders to reach an agreement/compromise before the team baselines the requirements.

The team will review the current systems engineering process contained within the Department of Defense (DoD) acquisition process. The goal will be to examine the process's overall effectiveness at identifying the mission critical requirements and evaluating these requirements during developmental testing. The process will be evaluated to determine how system level requirements are developed from user needs. Further investigation will be conducted to examine how operational tests are developed based upon the system requirements and the underlying user needs.

Research will be done to identify recently developed systems that passed and failed operational testing. Each system will be examined to determine sources of success and causes of failure. This will be accomplished by addressing questions such as:

- How are a system's requirements captured in a Capability Development Document (CDD) supported by (or connected to) doctrinally-defined missions?
- Are appropriate user-centric, solution-neutral metrics identified?
- Are a system's external interfaces identified?
- Are realistic Concepts of Operation (Conops) used?
- Were testers and end users formally involved in the Systems Engineering Technical Review (SETR)?

The system's ability to meet their requirements and objectives that satisfy the stakeholders' needs will be analyzed to determine the mission critical beneficial concepts and shortfalls for a system's engineering process.

<u>Inputs:</u>

- DoD Process Guidelines: VCJCS Oversight (CJCSI 3170.01), USD(AT&L) Oversight (DoDI 5000.02), Navy SETR Handbook., WSARA, and the Navy NR-KPP Implementation.
- Historical Data based on Existing Systems (Both Passed and Failed OT)
- Inquiry for Problems (Feedback from Analysis of Alternative Phase)

<u>Outputs:</u>

- Agreed Upon Requirements from Stakeholders
- Identified mission critical beneficial concepts and shortfalls based on historical data
- Process Map of existing SE Process
- List of assessed systems

2.2.2. Analysis of Alternatives

<u>Process Description:</u>

The analysis of alternatives will be accomplished following the identification of the source of failures pertaining to requirements critical to mission success within the system engineering process. Key decisive criteria will be established at this phase to determine feasible alternatives. The application of decisive criteria will be employed to exclude undesirable solutions and highlight acceptable alternatives. Multiple process concepts will be developed based upon these decisive criteria. A cost analysis will be developed for each of the concepts, analyzing the cost of implementation and the cost of execution. These concepts will also be rated based on the quality of process improvement, looking at factors concerning thoroughness, traceability, and simplicity. The resulting concepts will then be evaluated and chosen to develop the best mission criticality process based on cost-effectiveness and process improvement in order to prevent the shortfalls identified in the previous phase.

The programs identified in the previous phase will be evaluated to determine what program will be used as the representative example. This evaluation will be done based on availability of critical information, team knowledge of the program, and the representative nature of the program. The representative nature is defined as being of sufficient complexity to adequately demonstrate the process and also the likelihood of the problems encountered on that program. Based on these evaluations, a single program will be selected as the representative example.

Inputs:

- Agreed Upon Requirements from Stakeholders
- DoD Process Guidelines: VCJCS Oversight (CJCSI 3170.01), USD(AT&L) Oversight (DoDI 5000.02), Navy SETR Handbook., WSARA, and the Navy NR-KPP Implementation.
- Identified mission critical beneficial concepts and shortfalls based on historical data
- List of assessed systems
- Process Map of existing System Engineering (SE) Process
- Mission Criticality Concepts (Feedback from the Detailed Process Design)

Outputs:

- Mission Criticality Process Solution
- Mission Criticality Process Alternatives
- Representative Program
- Inquiry for Problems (Feedback to Process Review and Problem Identification Phase)

2.2.3. Detailed Process Design

Process Description:

The selected process concept will be used to develop a mission criticality process that can be integrated into the DoD system engineering process. The new process could possibly include new deliverables such as: new exit/entrance criteria, modified documents, new/modified instructions, and organizational charts that describe roles and responsibility. Mission Criticality Process Alternatives will be used as reference material when encountering detail design issues. Concepts for improvement can be taken from the alternatives or generated during the detailed design. These concepts can be used as inputs in the Analysis of Alternative phase to create an improved process solution. While designing the new process, the mission criticality validation criteria must be developed. In the next phase, this process will be simulated on the representative program selected in the previous phase.

Inputs:

- Mission Criticality Process Solution
- Mission Criticality Process Alternatives
- Agreed Upon Requirements from Stakeholders
- Design Modifications (Feedback from the Process Validation Phase)

Outputs:

- Mission Criticality Detailed Process
- Mission Criticality Process Validation Criteria
- Mission Criticality Concepts (Feedback to the Analysis of Alternatives Phase)

2.2.4. Process Validation

Process Description:

The new mission criticality process will be evaluated on the representative system by performing table-top exercises. The exercises will use the validation criteria developed during the design/modeling phase to evaluate the process. Cost data concerning the execution of the process will be collected while the process is validated. The results from the evaluation will be analyzed and reported.

Inputs:

- Mission Criticality Detailed Process
- Mission Criticality Process Validation Criteria
- Representative Program

Outputs:

- Mission Criticality Process Evaluation Report

- Cost Analysis Report
- Design Modification (Feedback to the Detailed Process Design Phase)

2.2.5. Report Findings and Make Recommendation

Process Description:

Once the process is simulated and analyzed, a final report can be generated for the sponsors, stakeholders, and advisors. The report will include how successful the new process was at addressing the problems encountered on the representative system and how other systems examined could have benefited from this new process. The report will include a cost analysis for implementation of this process for future systems. A presentation will accompany the report in order to present the findings of the team.

Inputs:

- Mission Criticality Process Evaluation Report
- Cost Analysis Report

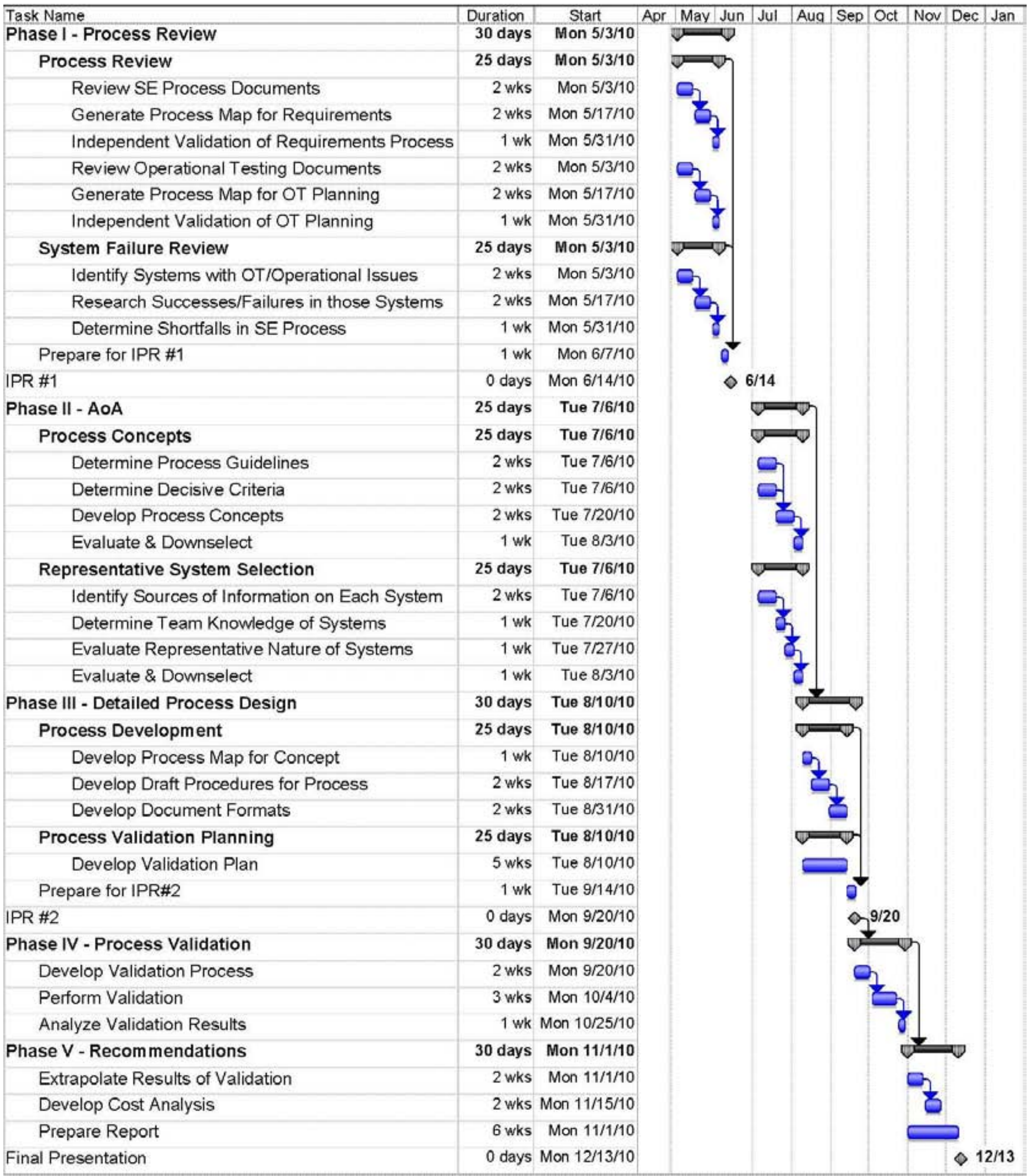
Outputs:

- Final Report and Recommendations
- Brief Out Presentation

3 Milestones & Deliverables

Figure 4 below provides the proposed schedule and milestones for this capstone project. The major milestones are IPR #1, IPR #2, and the Final Presentation.

3.1. Schedule



Task Name	Duration	Start
Phase I - Process Review	**30 days**	**Mon 5/3/10**
Process Review	**25 days**	**Mon 5/3/10**
Review SE Process Documents	2 wks	Mon 5/3/10
Generate Process Map for Requirements	2 wks	Mon 5/17/10
Independent Validation of Requirements Process	1 wk	Mon 5/31/10
Review Operational Testing Documents	2 wks	Mon 5/3/10
Generate Process Map for OT Planning	2 wks	Mon 5/17/10
Independent Validation of OT Planning	1 wk	Mon 5/31/10
System Failure Review	**25 days**	**Mon 5/3/10**
Identify Systems with OT/Operational Issues	2 wks	Mon 5/3/10
Research Successes/Failures in those Systems	2 wks	Mon 5/17/10
Determine Shortfalls in SE Process	1 wk	Mon 5/31/10
Prepare for IPR #1	1 wk	Mon 6/7/10
IPR #1	0 days	Mon 6/14/10
Phase II - AoA	**25 days**	**Tue 7/6/10**
Process Concepts	**25 days**	**Tue 7/6/10**
Determine Process Guidelines	2 wks	Tue 7/6/10
Determine Decisive Criteria	2 wks	Tue 7/6/10
Develop Process Concepts	2 wks	Tue 7/20/10
Evaluate & Downselect	1 wk	Tue 8/3/10
Representative System Selection	**25 days**	**Tue 7/6/10**
Identify Sources of Information on Each System	2 wks	Tue 7/6/10
Determine Team Knowledge of Systems	1 wk	Tue 7/20/10
Evaluate Representative Nature of Systems	1 wk	Tue 7/27/10
Evaluate & Downselect	1 wk	Tue 8/3/10
Phase III - Detailed Process Design	**30 days**	**Tue 8/10/10**
Process Development	**25 days**	**Tue 8/10/10**
Develop Process Map for Concept	1 wk	Tue 8/10/10
Develop Draft Procedures for Process	2 wks	Tue 8/17/10
Develop Document Formats	2 wks	Tue 8/31/10
Process Validation Planning	**25 days**	**Tue 8/10/10**
Develop Validation Plan	5 wks	Tue 8/10/10
Prepare for IPR#2	1 wk	Tue 9/14/10
IPR #2	0 days	Mon 9/20/10
Phase IV - Process Validation	**30 days**	**Mon 9/20/10**
Develop Validation Process	2 wks	Mon 9/20/10
Perform Validation	3 wks	Mon 10/4/10
Analyze Validation Results	1 wk	Mon 10/25/10
Phase V - Recommendations	**30 days**	**Mon 11/1/10**
Extrapolate Results of Validation	2 wks	Mon 11/1/10
Develop Cost Analysis	2 wks	Mon 11/15/10
Prepare Report	6 wks	Mon 11/1/10
Final Presentation	0 days	Mon 12/13/10

Figure 4. Schedule and Milestones

3.2. Deliverables

Based on the need to address this deficiency in the current system development process, the current DoDI 5000.02 process will be analyzed by investigating methods to improve capturing, monitoring, implementing and testing the requirements critical to ensuring mission success. There will be two primary deliverables of this capstone project. First, enhanced processes will be developed supplementing DoDI 5000.02 to improve the handling of these critical mission requirements. Second, these enhanced processes will be simulated on a DoD system in a tabletop exercise to provide an example of how this modified process should be performed. The results from these steps will be documented in the final capstone report. In addition, the team will perform a cost/benefits analysis of the enhanced process, including an assessment of how the requirements and/or testing of the program would have changed if this modified requirements process had been performed.

APPENDIX B: OPERATIONAL TEST PLANNING PROCESS

The Operational Test Director (OTD) uses several documents in preparation for testing. OTDs have an obligation to get involved early as possible in the development of a new weapon system including providing meaningful input to various foundation documents. The defense acquisition system has undergone significant changes since the introduction of the Joint Capabilities Integration Development System (JCIDS) in 2003. Since many programs continue to use legacy documents, the OTD references legacy and current foundation documents including:

- Mission Needs Statement (MNS)
- Operational Requirements Document (ORD)
- Analysis of Alternatives (AOA)
- Acquisition Program Baseline (APB)
- Acquisition Information Assurance (IA) Strategy
- Initial Capabilities Document (ICD)
- Capability Development Document (CDD)
- Capability Production Document (CPD)

1. Mission Need Statement (MNS)

DoD Regulation 5000.1R, a legacy document, required DoD components to document deficiencies in capabilities and opportunities to provide new capabilities in a MNS. These capabilities are expressed in broad operational terms in the MNS. System performance objectives and minimum acceptable requirements were developed from the MNS as part of the development of the ORD.

2. Operational Requirements Document (ORD)

DoD Regulation 5000.1R, a legacy document, required the use of the ORD to document system requirements. The JCIDS process uses capabilities documents for system definition, some programs may still use an ORD to define system requirements.

3. Analysis Of Alternatives (AOA)

DoD Instruction 5000.2 describes the use, format, and content of an AOA. The AOA is an analytical comparison of operational effectiveness, suitability, and life-cycle cost of alternatives that satisfy established mission capability requirements. The OTD may use the AOA as a source document supporting MBTB and TEMP development.

4. Acquisition Program Baseline (APB)

The PM initially develops the APB as a concept baseline prior to program initiation. A development baseline and a production baseline are prepared for MS-B and MS-C capturing the key parameters that define the system and listing the objectives and thresholds are listed. Key parameters are the Measures of Effectiveness (MOEs) and the Measures of Suitability (MOSs) identified in the requirements/capabilities document. The OTD reviews the APB to ensure consistency between the requirements/capabilities document, the baseline which establishes explicit performance and thresholds, and the TEMP.

5. Acquisition Information Assurance (IA) Strategy

IA is defined as measures that protect and defend information and information systems by ensuring their availability, integrity, authentication, confidentiality, and nonrepudiation. This includes providing for restoration of information systems by incorporating protection, detection, and reaction capabilities. IA must be addressed for all weapon systems; command, control, communications, computers, intelligence, surveillance, and reconnaissance systems; and information technology programs that depend on external information sources or provide information to other DoD systems.

6. Initial Capabilities Document (ICD)

The ICD is required before MS-A, as part of the JCIDS process. It is the equivalent of the legacy MNS, but is much more definitive in describing the program to be developed. An ICD documents the requirement for materiel or nonmateriel approach, or an approach that is a combination of material and nonmateriel, to satisfy specific capability gap(s). It defines the capability gap(s) in terms of the functional area, the relevant range of military operations, desired effects, time, and Doctrine, Organization, Training, Material, Leadership, Personnel, and facilities (DOTMLFP), education, and policy implications and constraints. The outcome of an ICD could be one or more joint DOTMLPF change Recommendations (DCRs) or CDDs. Programs that enter the acquisition process at MS-B shall have an ICD that provides the context in which the capability was determined and approved, and a CDD that describes specific program requirements. Pre-MS-A projects shall rely on the ICD as the basis for the evaluation strategy.

7. Capability Development Document (CDD)

The CDD is required at MS-B and serves the same purpose as the legacy ORD. The CDD outlines an affordable increment of militarily useful, logistically supportable, and technically mature capability. The CDD may define multiple increments if there is a sufficient definition of the performance attributes (key performance parameters, key system attributes, and other attributes) to allow approval of multiple increments. The CDD is required at Milestone B for new programs and for each increment of an evolutionary acquisition program.

8. Capability Production Document (CPD)

The CPD is required at MS-C as part of the JCIDS process. This is the capabilities document that supports IOT&E. The CPD reflects the operational requirements resulting from Engineering Manufacturing and Development and details the performance expected of the production system. Software shall have demonstrated the maturity level required in the CPD prior to deploying it to the operational environment. Once the maturity level has been demonstrated, the system or increment is base-lined, and a methodical and synchronized deployment plan is implemented for all applicable locations. OT&E shall determine the operational effectiveness and suitability of a system under realistic operational conditions, including combat: determine if thresholds in the approved CPD and COIs have been satisfied; and assess impacts to combat operations.

9. Reviewing Foundation Documents

When reviewing these documents the OTD considers from an operations viewpoint, why develop it? How will it be used? In what installations or platforms? In what environments (natural and mandate)? How well should it work? When should it work? What must DT&E and OT&E do to prove the system's operational effectiveness and suitability? When must DT&E and OT&E prove the system's operational effectiveness and suitability?

10. The Test and Evaluation Master Plan (TEMP)

The TEMP is the single most important T&E document associated with an acquisition program. It is the controlling T&E management document for all acquisition programs and, in general, must be approved by the Director of DT&E and the Director of OT&E at milestone B prior to beginning OT&E. The TEMP is directive in nature, and defines and integrates test objectives, critical issues, system characteristics, test responsibilities, resource requirements, and test schedules.

11. Purpose of the TEMP

The purpose of the TEMP is to combine the DA's DT&E plans and COMOPTEVFOR's OT&E plans into one integrated master plan approved by the CNO or higher authority. COMOPTEVFOR develops the Critical Operational Issues (COIs) for each program and publishes them in the TEMP. The COIs are linked to CNO requirements established in the ORD, ICD, CDD, or CPD.

Determining the essential elements of operational effectiveness and operational suitability, the COIs to be resolved in OT&E, and the questions which must be answered to resolve those issues is difficult; a contributing factor to the difficulty is the number of sources or agencies involved. MOEs and MOSs should be clearly established in the requirements documents COMOPTEVFOR reviews for testability and appropriateness prior to this process. When the DA provides a list of MOEs and MOSs on a first-draft TEMP, the OTD ensures that they are operational characteristics, not technical characteristics. From OPTEVFOR's viewpoint operational backgrounds overshadow technical backgrounds. The OTD should ask two basic questions when developing input to the TEMP:

- What should it do from an operational mission accomplishment viewpoint?
- What shouldn't it do from an operational mission accomplishment viewpoint?

Additionally the TEMP serves several secondary purposes. It allows all involved to see exactly what hurdles the system must clear and when, it allows the DA to project T&E costs which must be funded, and it allows Fleet, range, simulator, and target schedulers to plan, well in advance, for the required services. Specifics, including requirements of new or modified facilities, must also be identified in the TEMP.

12. TEMP Policies

The contents of the TEMP and the relationship of key portions to the successful completion of the overall OT&E program cannot be overstated. An approved TEMP or an approved TEMP revision, constitutes direction to conduct the specified T&E program, including the sponsor's committed support, and constitutes approval of the COIs. Test plans will be prepared directly from the TEMP and will carry out its provisions.

TEMPS may be reviewed in their entirety twice: once when the DA submits a draft for comment, and again when the final version is received for the Commander's signature. Before the first review, the OTD should have provided the DA with OT&E schedule inputs for Part II, a complete Part IV, and OT&E resource requirements fro the Part V. At that time, OT-C and OT-D should be included in the schedule. The OTD's review of the complete TEMP should address all parts. The DA is responsible for ensuring the TEMP is updated at milestones, when the program baseline has been breached, or on other occasions when the program has changed significantly. The OTD works closely with the DA to ensure COMOPTEVFOR's input is provided in sufficient time to support the required update, ensuring that COMOPTEVFOR is not responsible for program delays while preparing TEMP updates.

The TEMP must be updated at all milestones, when significant program changes occur, or when the program baseline has been breached.

13. TEMP Basics

A TEMP is prepared jointly by the DA and COMOPTEVOR, with the involvement of both the OPNAV program sponsor and the N091 T&E coordinator in early draft reviews. During the TEMP review process, the OTD ensures the minimum acceptable operational performance requirements (older programs) or MOE/MOS (newer programs) from the approved ORD/ICD/CDD/CPD are incorporated. COMOPTEVFOR contributes to all parts of the TEMP and provides the OT&E portions throughout the document. The parts specifically provided by COMOPTEVFOR are drafted by the OTD.

The TEMP is required at MS-B for all programs. Since the TEMP is prepared jointly by the DA and COMPOPTEVFOR, the OTD is involved in all stages of TEMP preparation. This requires the OTD to be familiar with other program documentation (MNS, ORD, ICD/CDD/CPD, Information Assurance (IA) strategy, ONI Capstone TA, etc.) and close coordination with the DA, particularly during program changes.

14. Test Planning

Operational testing consists of exercising a system or equipment under conditions that are as close as possible to the expected natural, operational, and combat environment using operational scenarios. Forces, friendly and oppositional, apply realistic tactics against targets that fight back. Additionally, operational testing consists of ensuring that the test article is representative of the intended production equipment and is installed as it is expected to be installed in the Fleet. The test article is operated and usually maintained by Fleet personnel.

OT provides data on system performance in the operational environment. Performance includes all the elements of operational effectiveness and operational suitability. The environment includes many things such as people (operators, maintainers, etc.); other systems that will also be consuming power, radiating, etc., in the same ship or aircraft; ships or aircraft in the vicinity, employing their own systems; established constraints or rules of engagement; natural environmental factors (visibility, sea state, oceanographic, etc.); the simulated enemy, tactics, and countermeasures the operator employs; and so on.

15. Test Plan Preparation

Test plans are required for each identified phase of OT&E for all ACAT programs. Preparing the test plan focuses on several fundamental issues important to the overall OT&E process. These issues include the purpose of the test; capabilities/functions of the COIs to be examined; how the test will be conducted, whether operation-oriented or scenario-oriented testing will be used; evaluation criteria against which test results will be measured; resources required to support OT&E; data collection methods and requirements; and data analysis methods to be employed. Test plan writing begins upon resolution of these issues.

16. MBTD Planning Process

The OT&E methodology is moving from functional-based test design to Mission-Based Test Design. Regardless of the stage in the acquisition process a program resides, the initial steps in the MBTD process are alike once the decision has been made to use the MBTD methodology. The MTBD process is also applicable to FOT&E. The MBTD planning process is followed in its entirety for each increment or spiral of a program, although some portions of the process may be abbreviated.

Figure 32 from COMOPTEVFOR Instruction 3980.1 [2008] reflects an overview of the MBTD and OT Framework development process. This figure depicts the steps of a mission analysis for the system under test. It shows the steps required to develop the information needed to write the OT Framework. It also depicts how the OT Framework acts as input to the IT integration process (if applicable) and how the mission analysis provides the OTD/C the capability to trace the results of testing back to the mission offering bidirectional traceability.

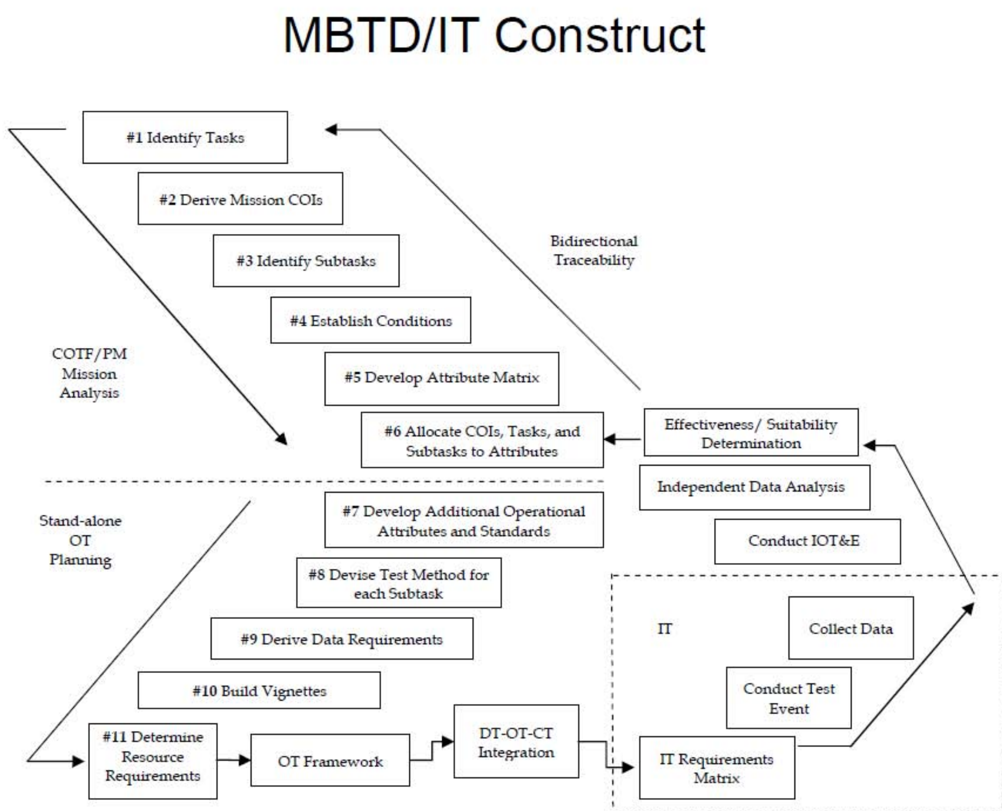


Figure 32. MBTD (and IT when applicable) Process Flow Chart "From COMOPTEVFOR Instruction 3980.1 [2008]."

The MBTD process begins with a meeting or series of meetings held between the program T&E stakeholders. The intent of these meetings is to [COMOPTEVFORINST 3980.1: 6-3]:

- Define and map the overarching T&E strategy to ensure all stakeholders start from the same philosophical foundation.
- Develop a list of acquisition and operational documents required to support the mission analysis effort.
- Determine who should participate in/support the mission analysis effort and where and when it will commence.
- Define the format and content of testing requirements inputs to an IT matrix database (if IT is applicable).
- Determine where the IT matrix database (if IT applicable) will be maintained and who will have access.

- Derive test data and information sharing rules (may be adjusted for the ITT charter).
- Establish separate analysis/reporting requirements.

The ground rules and definitions from the meetings are documented in the approved TEMP. The ground rules may be incorporated in a Memorandum of Agreement (MOA) approved at an appropriate level in the event that the TEMP or a TEMP update is too far in the future. The ground rules and definitions are later followed by approval in the TEMP.

17. Mission Analysis

The purpose of mission analysis is to identify the tasks the system will support, derive the mission-based COIs, partition the tasks into subtasks, and correlate the result with the required capabilities and their associated attributes from the ORD/Capabilities Document (CD). Upon completion of these tasks direct traceability of any system enhancement, risk area, or deficiency discovered during testing to a mission or missions is enabled.

Mission analysis is a combined effort among COMOPTEVFOR, the program representatives, and other participants such as the Fleet Forces Command (N8) representatives and operational users. Additional Subject Matter Experts (SME) may be included to ensure this evolution is completed thoroughly. Inclusion of key participants ensures DT, OT, and CT stakeholders (when included) are in full agreement concerning the missions, tasks, requirements, and defined capability attributes of the system. To ensure all T&E members are working from the same foundation, key participants must first complete and agree on the mission analysis for the system. The mission analysis is conducted by the participants to derive the tasks and missions applicable to the system to be tested using the following system documents:

- The CONOPS or concept of employment
- The current ORD/CD
- The Universal Navy Task List (UNTL) (OPNAVINST 3500.38B)
- The Universal Joint Task List (UJTL), (CJCSM 3500.04C) (for joint programs)
- The Navy or Marine Mission Essential Task List (METL)
- Other appropriate documents

18. Detailed Process Description

Mission analysis consists of 6 steps: identify tasks; derive mission COIs; identify subtasks; establish conditions; develop attribute matrix; and allocate COIs, tasks, and subtasks to attributes. Mission analysis is an iterative process where two or three of these steps will be conducted together and repeated several times to complete the breakdown of a given mission into tasks, subtasks, and conditions. When the mission analysis is complete, the results must be documented in the OT Framework and approved in the TEMP (or MOA if needed).

Step One: Identify Tasks. This step begins by conducting an analysis of available documents (ORD/CD, CONOPS, UNTL, and METL for units employing the system under test) to identify tasks that the system under test will support. There are 2 general cases to this task. The first case is when the Mission Essential Tasks (MET) that the system will support are known and well documented. The second is when the specific MEATs are not adequately documented.

Step One, Case 1: The METs that the system will support are known and well documented. This is usually documented in the CONOPS section of the CD or some other task lists. The known METs are collected and sorted into categories as either "mission tasks" or "supporting tasks." The definition of mission tasks is highly dependent upon the system and the unit employing it. Supporting tasks include those tasks that support a defined mission task or multiple mission tasks.

Some tasks may not be called out in available documentation. Upon completion of sorting the METs noted above, the UNTL is reviewed to determine if there are other tasks that would fit the system under test. If additional tasks are identified, agreement between all stakeholders is sought early in the process to ensure that all selected tasks are appropriate for test.

Step One, Case 2: In the case when specific METs are not adequately documented there may be no direct relationships established to the UNTL. Consequently, all available requirements documents must be analyzed to determine what missions the system might support. Once a notional mission list is compiled, the UNTL is then reviewed and appropriate UNTL tasks are "mapped" to the notional mission list.

Additionally, reviewing the UNTL may yield unique mission tasks not found in other documents and/or supporting tasks that could be considered for multiple missions. Once tasks have been selected, agreement between all stakeholders is sought early in the process to ensure that all selected tasks are appropriate for test.

Upon completion of step one the OTD should have a documented list of all mission and supporting tasks.

Step Two: Derive Mission COIs. The mission COIs are derived next based on the list of mission tasks identified in step one. COIs are created from individual mission tasks or from grouping similar mission tasks to form a single COI. It is important to ensure that tasks are combined such that the COI is specific enough to be relevant to the unit using the system, but not so specific that each COI is simply a variation of an overarching mission. Upon completing additional steps in the MBTD process, the similarities in task breakdowns, conditional variations, and capabilities correlation that exist between COIs may become more obvious and the COI list may need to be adjusted. The result of this step is a list of specific COIs written in a particular format. Additionally, a COI/task summary and a COI task breakdown hierarchy is developed.

Step Three: Identify Subtasks. Subtasks are separate actions to be performed to carry out each task. It is important to breakdown the subtasks to the correct level as the subtask breakdown will enable the identification of all conditions (in step four) that may potentially impact task performance. It will also allow for correlation of capability attributes to specific subtasks.

Temporal views, block diagrams that depict the steps of the task process in order of occurrence, are produced for each task to depict the breakdown of the task into its component subtasks. The numbering system established in step two is further expanded to include the subtasks in order to create a hierarchical numbering of each mission-task-subtask breakdown. At the completion of step three, the OTD should have a temporal view for each task, a mission-to-subtask hierarchical list, and a subtask cross-reference table.

Step Four: Establish Conditions. Conditions are variables of the operating environment that affect the performance of the subtask; they describe the physical (littoral, open ocean, calm seas, low visibility, etc.), military (single unit/task force/joint operations, aircraft division, etc.), and civil (population density, civil unrest, etc.) variations that impact subtask performance and form the operational context for selected subtasks. Conditions/descriptors should be derived or implied for the ORD/CD. If the more general UNTL conditions/descriptors need to be used, they should be modified to fit the system-specified capabilities.

Once the conditions are established and documented, the informational view, a temporal view block diagram with *conditions, inputs, and outputs* added to it, is produced using the temporal view (from step three). First applicable conditions for each subtask are added. Once conditions have been added, subtask inputs and outputs are added. At the completion of this step, the OTD should have produced a conditions directory listing applicable conditions for all subtasks and an informational view for each task.

Step Five: Develop Attribute Matrix. Document capability attributes from the ORD/CD in matrix format. An attribute, sometimes referred to in legacy documents as a "requirement," is as a quantitative or qualitative characteristic of an element or its actions, where element refers to the system. Qualitative attributes may be expressed in terms of an action or outcome required from the system. Quantitative attributes usually have numbers associated with them and may have quantifiable standards.

Once all attributes have been documented, standards are defined. Standards may be provided in the ORD/CD. In cases a standard has not been defined in the ORD/CD, one must be defined. If possibly a quantitative standard is applied to a qualitative attribute. If this is not possible the attribute matrix must somehow specify what is "good enough" with regard to the attribute, even if a survey is used as the data collection method.

At the completion of step five, the OTD should have a table or spreadsheet of all ORD/CD-defined attributes and their associated standards. This matrix will form the basis for subsequent steps as additional information is added, and will end up forming the basis for the OT-DT-CT input to the integration effort that occurs after framework development.

Step Six: Allocate COIs, Tasks, and Subtasks to Attributes. This step continues the population of the attribute matrix created in step five. It takes the documented ORD/CD attributes and their associated standards, and linking COIs, tasks, and subtasks to them. Many linkages are explicitly defined in the ORD/CD. For those that are not, linkages will have to be determined based on operational experience. Many attributes may be linked to multiple missions, tasks, and subtasks, further complicating the process. However, the linkages must be made as they are absolutely essential to the direct traceability between attributes/standards (including Key Performance Parameters (KPP) and thresholds) and mission COIs.

At the completion of this step, the attribute matrix developed in step five, and further populated with COI and subtask information, should form the basis of the attribute-to-subtask matrix. If, at the end of step six, it is determined that an attribute from the list cannot reasonably be associated to a COI, task, or subtask, consideration may be given to removing it from the list as either an orphan attribute or as a system attribute that has little or no relation to the operational effectiveness or suitability of the system. The program sponsor and other members of the ITT should be consulted prior to making a final decision with regard to removal of an attribute from the list since this database will be shared by T&E stakeholders within the ITT.

Once the above steps are complete the mission analysis section is complete. This provides the prerequisites for stand-alone OT planning. If consensus between all T&E stakeholders on the mission analysis for the system is not achieved the statutory requirement for OT independence dictates that further OT planning be based on the OT position regarding the specific disagreement. The product of this mission analysis effort, including the templates and the database, must be documented (to confirm agreement among the participants) in the evaluation strategy or TEMP. If the TEMP is still months away, an MOA can be used in the interim.

19. Completing the OT Framework/Stand-Alone OT Planning

Additional steps are performed by the OTD to complete the OT Framework. Note that once the mission analysis is complete and documented, OT and DT (and CT at some point) can begin *separate* test planning. Separate planning is conducted to produce the stand-alone test objectives for OT and DT (and CT, when appropriate).

OT and DT planners document their test objectives, prior to integrating, to ensure:

- The IT and independent OT will provide OPTEVFOR sufficient data and assurance in the results of testing to make an effectiveness and suitability determination, and Fleet release/Fleet introduction recommendation.
- A basis is established for calculating savings/cost avoidance attributable to the IT effort.
- Each entity (OT, DT, and CT) has an adequate and approved framework for their testing and the integration process; for oversight programs, this would include DOT&E approval of the OT Framework.

The separate OT planning begins with the products of the mission analysis effort.

Step Seven: Develop Additional Operational Attributes and Standards. The OTD expands on previous steps by developing operational attributes which were not included in the ORD/CD; developing associated standards for these attributes; and tying them to COIs, tasks, and subtasks. By developing a list of operational attributes to be used in conjunction with the ORD/CD documented attributes, the OTD helps to more clearly focus the testing toward answering the COI questions so as not to become a mere “spec checker.” At the completion of the process, the OTD should have a comprehensive attribute-to-subtask matrix that includes all necessary test attributes. This comprehensive matrix is not intended to ensure all requirements and operational expectations for the system are defined prior to the beginning of IT.

Step Eight: Devise Test Methods for Each Subtask. In steps eight and nine the OTD devises test methods for each subtask, keeping in mind the attributes/standards and data collection requirements associated with these subtasks. Although these tasks are listed as separate steps, they are completed simultaneously. Test methods describe the approach to be used to collect the data necessary to determine the satisfactory execution of the subtask, and to determine performance as compared to the derived and implied standards. Consequently, data collection requirements must be known before test methods can be finalized. When completed, the test methods will form one of the building blocks for the vignette descriptions built in step ten.

The OTD uses the subtask cross-reference matrix developed in step three to begin devising test methods for each subtask. This matrix ties all like subtasks together to enable the OTD to develop a common method for common subtasks. The OTD adds "Attribute," "Test Method," and "Data Requirements" columns to the matrix. Using the matrix from step seven, the attribute numbers corresponding to the subtasks should be added. The test method is added to the matrix for each subtask once it has been developed. In conjunction with step nine, data requirements are added to the final column. The goal of this step is to ensure the collection of the data necessary to determine the satisfactory execution of the subtask and to determine performance as compared to the attributes/standards.

Step Nine: Derive Data Requirements. Derive data requirements for all subtasks to determine whether the COI, task, and subtask have been satisfactorily accomplished, and whether all standards, quantitative and qualitative, have been met. Describe quantitative and qualitative data requirements in sufficient detail to support the integration process. For qualitative data, the OTD first defines what qualitative information is needed from the survey to support the resolution of COIs and standards before relevant, useful surveys can be constructed. At the completion of steps eight and nine, the OTD should have a test method/data requirements matrix that directly ties data elements back through test methods, standard, subtasks, tasks, and COIs.

Step Ten: Build Vignettes. The OTD's team (analyst, other operational testers) takes all of the information developed in steps one through nine and builds test "vignettes." Vignettes are designed to ensure the thorough testing of all attributes, standards, tasks/subtasks, and missions. Creating vignettes consists of parsing mission and task execution into manageable chunks which can be accomplished within a dedicated OT period or throughout the longer IT period. Vignette descriptions provide the test team with a detailed methodology and “game plan” for the execution of individual test events to ensure all OT objectives are met.

When involved in the IT process, the OTD uses the vignette development process to determine how much independent OT is required at the completion of IT. Executing the IT vignettes provides much of the information necessary to resolve COIs prior to the commencement of IOT&E at the end of the IT phase. IOT&E becomes a series of end-to-end mission confirmation events based around combined IT vignettes.

Vignettes are constructed from single subtasks in some cases and in others subtasks can be grouped together logically to be executed together. The OTD attempts to minimize the number of overall conditions, developed in step four, associated with the task and its component subtasks. In this step, the condition list should be reviewed and narrowed down to include only those conditions which impact the performance of the system under test in relation to the subtask.

The OTD decides on appropriate subtask parsing and develops basic vignette descriptions. The vignettes descriptions, their associated identifiers, subtasks, and conditions are then combined into a vignette-to-conditions matrix. Typically there will be many subtasks and associated conditions, multiple matrices may be needed. The end result this process should provides the OTD with a basic description of the vignettes, which will be used to create more detailed vignette procedures.

The OTD identifies each vignette as a candidate for integration or as an independent OAT or IOT&E when planning for IT. This facilitates the integration process and provides fidelity to the OT Framework.

The test method and data requirements, derived in steps eight and nine, supports the development of detailed vignette procedures by adding fidelity to the vignette description. The output of step ten is a vignette-to-conditions matrix, a vignette cross-reference matrix, and a vignette procedures matrix to which resource requirements will be added in step eleven.

Step Eleven: Determine Resource Requirements. Upon completing the previous steps the OT team has all the information required to determine test resource requirements for stand-alone OT of the system. In this step the OTD documents these requirements in sufficient detail to support either dedicated OT or the IT integration process, including:

- Number of test articles with any specific configuration requirements
- Specific aircraft, ship, submarine, unit, or exercise support requirements
- Specific range, test site, instrumentation, and threat requirements
- Flight hours, at-sea time, or system operating time
- Special support equipment requirements
- Any M&S requirements
- Specific operator or maintenance training requirements
- Pre-faulted modules or Maintenance Demonstrations (M-DEMO)
- Any special instrumentation or data collection requirements

These resources are identified by vignette and then rolled up to determine the overall stand-alone OT&E requirements. The OTD also identifies any potential limitations to test for inclusion in the OT Framework in this step. Examples include threat replication, inability to test the system in certain environments that were identified as significant conditions in step ten, or unavailability of key test resources or instrumentation.

Once the step is completed the OTD can now bi-directionally trace a data element all the way up to the mission COI based on the requirements/capabilities-to-subtask correlation already completed in the mission analysis effort. The OTD can now write an OT Framework, with the key component being the final vignette matrix developed through this process.

20. OT Framework

The OT Framework is the primary document that defines adequate OT and, when appropriate, for integrating the OT objectives with DT and CT objectives to form an IT matrix. The OT Framework also provides the basis for the OT input to the TEMP, and defines the OT objectives and the specific test requirements for resolution of each COI, and the OTD's minimum IOT&E test requirements. The OT Framework is reviewed and changed if necessary any time there are significant program or documentation changes/revisions since it is generated much earlier in the T&E process timeline. Changes include completion of CDR, the release of a CDD or CPD, or any major program perturbations. An update or change to the OT Framework is an appropriate place to document any limitations to test that may arise during the course of the IT effort.

The OT Framework must be approved by COMOPTEVFOR and DOT&E for oversight programs. Once approved, the OTD is ready to begin the integration process. Any future changes to the OT Framework would be handled in the same way changes to an approved test plan are handled.

21. Test Integration

IT combines CT, DT, and OT to form a cohesive testing continuum. Participants (CT, DT, and OT) must have determined their entering objectives for adequate testing of the system under evaluation before integration testing can occur. IT does not alleviate the requirement for independent OT reporting based on separate OPTEVFOR analysis of the shared test information produced by the IT effort.

The integration process begins with the OT Framework approved. The goal of the process is to identify any and all opportunities for synergy in planning, execution, and data collection during the IT period. However, from an OT perspective, an identified synergy may be lost if the system configuration changes at a later date or the data collected is deemed unusable for some other reason. Each entity should enter the process with a matrix of test objectives in a compatible format and based on an agreed mission analysis structure. The first accomplishment is preparing and obtaining approval of an Integrated Test Team (ITT) Charter. The charter specifies critical coordination factors such as [COMOPTEVFORINST 3980.1: 6-19]:

- IT matrix development and format for OT, DT, and CT inputs
- Detailed IT event planning and execution process
- Data/test information sharing criteria
- Separate analysis/reporting
- Data format and handling
- Data repository location
- Data fidelity requirements
- Scoring criteria and formula for calculated metrics
- Process for arbitration of disputes
- Process for inclusion of supplemental or regression testing requirements
- Process for prioritization of testing requirements
- Method for identification of comparative cost savings/schedule compression as a result of IT

The ITT should stand up soon after contract award, which ensures OT participation early in the development of the system under test. The product of the IT integration effort is an IT database, similar in structure and content to the OT Framework database, but merged with DT and CT objectives.

22. OPTEVFOR Test Plans

COMOPTEVFOR test plans consist of E-tests and S-tests. E-tests are keyed to the COIs and are given the title of the COIs they are intended to address. There are 10 S-tests which are standardized in COMOPTEVFOR test plans. They are:

(1) Test S-1, Reliability

(2) Test S-2, Maintainability

(3) Test S-3, Availability

(4) Test S-4, Logistic Supportability

(5) Test S-5, Compatibility

(6) Test S-6, Interoperability

(7) Test S-7, Training

(8) Test S-8, Human Factors

(9) Test S-9, Safety

(10) Test S-10, Documentation

All of the 10 standard S-tests will usually be applicable to IOT&E. Some may not be appropriate to very early OT&E phases or to late FOT&E. The inappropriate tests are omitted in these cases. Additional tests are used as required.

23. COIs and Evaluation Criteria

Each phase of OT&E is an investigation of operational effectiveness and operational suitability of the system up to that point in time. Prior to IOT&E, in the early phases, COIs are assessed by evaluating risks associated with each COI. In IOT&E, COIs are resolved as either SAT or UNSAT, or are unresolved.

The essential elements of operational effectiveness, the things the system must and must not do for mission accomplishment, vary from one system to the next. For a given system, the essential measures of operational effectiveness and operational suitability form the framework for the capabilities and functions of the COIs; the COIs define operational effectiveness and operational suitability for a given program.

All COI capabilities and functions are examined in IOT&E. Not all COI capabilities and functions are examined during earlier OT&E. This is because, at this point, the equipment generally does not closely approximate the planned production configuration. The capabilities and functions of COIs for a phase of OT&E are documented in the TEMP.

24. Scenario-Oriented or Operation-Oriented Testing

Although the OT&E testing methodology is moving to MBTD, it is not always the way to perform OT testing. Two common methods in OT&E when not doing MBTD are scenario-oriented testing and operation-oriented testing.

Scenario-oriented testing is typically employed for systems whose modes of operation or functions change in response to a changing operational situation (e.g., a radar suite). The OTD develops scenarios based upon the threat as derived from the applicable threat documents to stress the system under test in a realistic threat-representative manner. Scenario-oriented testing typically allows the Fleet user the greatest flexibility in operating the system as the tactical situation changes. This affords the OTD greater opportunity to make informed decisions on the merits of the system and its capability to meet CNO-assigned thresholds.

When developing the scenarios, the OTD must:

- Be complete and state what results are expected from each scenario.
- Describe the tactical situation at the start of the exercise (e.g., single-ship littoral operations with a high probability of air attack).
- Describe the situation that develops (e.g., electronic surveillance detection of enemy aircraft) and what is expected to happen (e.g., detection, acquisition, and engagement of the enemy aircraft).
- Supplement this narrative with diagrams or tables specifying the movements of exercise participants (friendly and enemy) and their expected actions at specific times.
- Develop a sufficient number of scenarios to test the system, and be prepared for the unexpected. Commanding officer’s tactical decisions, loss of assets or services, or fouling of the firing ranges can all lead to unexpected results or non-completion of scenarios.

Several scenarios may be required for multipurpose systems to exercise their various capabilities. The data recorded during the scenarios are used for reconstruction and analysis of the various E-tests and S-tests. Often, scenario-oriented testing is dedicated testing (in terms of

Fleet RDT&E support), although it can be accomplished on a not-to-interfere basis during Fleet exercises.

Operation-oriented testing is typically employed for equipment whose mode of operation or function does not change with the tactical situation (e.g., torpedo tubes or waste disposal systems). These systems are either *in use* or *not in use*. They can be tested by simply operating them in the anticipated environment. The events and conditions necessary during system operation must be specified (e.g., the targets and operating environments) when operation-oriented testing is used. Test events and conditions must provide an operationally realistic test of the system.

In either scenario- or operation-oriented testing, the following are kept in mind:

Simulation of all possible enemy actions are included is included in testing. This includes countermeasures to tactics employed. All reasonable expected actions the target systems are expected to encounter must be adequately replicated in the test. The replication is representative of enemy capabilities. The range of environments and threats is covered.

The natural and electronic test environment should approximate the anticipated operating environment. This includes the anticipated background noise caused by other ships, aircraft, etc., to determine the effects of Electromagnetic Interference (EMI); the anticipated natural environmental conditions, such as sea state, temperature, cloud cover, etc., to enable a determination of their effect on system performance; operation of other equipment that may be used in conjunction with the tested equipment to allow evaluation of changes in electrical power loads, effects of gunfire-induced shock and vibration, EMI, etc.; and all relevant joint interfaces and other interfaced units/systems in the anticipated joint operating environment.

The number of resources required for testing should reflect what the weapon system would realistically be expected to encounter in actual operations.

25. Operational Test Director Responsibilities

The Operational Test Director has responsibilities prior to and during test operations. Many of these responsibilities include ensuring that various checks are performed.

26. OTD Responsibilities Prior to Test Operations

The OTD performs various checks as the date to begin test operations approaches. Checks include the following:

- Appropriately trained personnel will be available to operate and maintain the equipment
- The equipment to be evaluated will be installed and checked out
- Operator and maintenance manuals, the Integrated Logistic Support Plan/Acquisition Logistic Support Plan (ILSP/ALSP), NATP, and other necessary documentation will be available from the DA
- Instrumentation will be available and in working order
- Targets, simulators, electronic warfare services, etc., will be available
- Participants have received and understand test plans and LOIs
- RTD&E support services are on track
- Contingency plans are available for the unexpected
- Arrangements have been make for pretest briefings, including arrangements for additional briefers if needed
- Rehearsals of test operations are scheduled if appropriate
- Pre-faulted modules will be available for an M-DEMO if necessary

Immediately prior to the start of test operations the OTD ensures the following:

- All hands know what they are supposed to do
- The equipment to be evaluated is in working order
- Equipment necessary to the test scenario and instrumentation equipment is in working order
- Personnel to activate and deactivate data recorders, and backup data takers are in place
- Time synchronization and communications have been established as necessary
- Contingency plans have been discussed with appropriate personnel

27. OTD Responsibilities During Test Operations

During test operations the OTD ensures that:

- Tests are conducted per the test plan and the LOI; any deviations are noted, their impact assessed, and necessary corrective action taken; and contingency plans are implemented as necessary
- All hands are briefed on the test plan and understand their roles

- COMOPTEVFOR is advised of any potential issues that could result in a COI being unresolved unsatisfactorily

  Reports are generated as specified in the test plan

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APPENDIX C: FULL LIST OF BRAINSTORMING IDEAS

1. Incorporate backwards compatibility in standards for OT
2. DT exit criteria to include OT pass criteria
3. Move towards open architecture
4. Use actual shipboard hardware and software at the end of DT
5. Use a hull just for OT
6. Rotate active user representatives in the PM office
7. Specific SETR for interoperability
8. Pre-testing training for operators/users
9. Standardize test requirements
10. Interoperability simulation standards
11. Validate other systems meet interoperability requirement prior to OT
12. Include testing interoperability criteria into Mission Readiness Assessment (MRA) reviews
13. Use of mission threads for interoperability
14. Inform the OPTEVFOR about the system requirements early on
15. Create a new color of money for testing
16. Consider Interoperability at all milestone reviews
17. Improve the default requirements list
18. Involve interoperability Tech Warrant Holder early
19. Financial incentive for PM
20. Delete requirements before test that PM knows the system doesn't meet
21. Interoperability Readiness Levels
22. Ensure that all of the interfaces are synchronized
23. CONOPS and DRMs must be fed into test plans
24. Validate mission critical sequence with the user
25. Longer terms for PMs
26. Don't test Interoperability
27. * Salary penalties for PM
28. * Write tests that match requirements
29. * Allow PMs to self-certify OT passes
30. * Do not finalize test requirements procedures until system is ready to test
31. * No OT until PM says all requirements are met
32. * PM review of COI prior to OT
33. * Increase schedule allotted
34. * Combine all DoD into a single joint service
35. * Increase funding
36. * Increase test and requirements funding
37. * Write better requirements
38. * Develop simulation of your system for future systems
39. * Create a full test bed that does not require a ship
40. * Consider legacy systems
41. * Use better standards

42. * Write more complete MIL-STDs
43. * Stop improving technologies
44. * Involve users in DT test plans
45. * Better DT testing
46. * Have users involved in DT
47. * PM accountability over the lifecycle of the system
48. * Revise milestone C revision gate requirements to include interoperability
49. Regression testing after fixing a problem found in DT
50. Improve communication between interoperability personnel
51. Ensure the future programs have a minimal technology standard/ phase out legacy equipment
52. Need to work with stakeholder to ensure realistic requirements
53. Include industry or academia assessment of requirements
54. Harsher simulations (have a list of possible failures to test against)
55. Have higher fidelity simulators so more realistic tests can be run
56. Use real test data from previous systems to simulate events
57. Reevaluate the passing criteria for interoperability
58. Robot testers, incorporate automated test evaluations
59. Define in writing the grading criteria, trying to overcome that subject nature of Human evaluation
60. Compare evaluations from several different people, and provide an integrated score or assessment form those evaluators
61. Set Technical competence requirement for government representative who play the liaison role for the project
62. Use risk matrix to assess issues/problems
63. Force PMs to captain the ship

* Indicates ideas that were considered redundant or impractical and were not evaluated for effectiveness and cost

APPENDIX D: TABLE TOP EXERCISE DOCUMENTS

This appendix contains documents used in support for the ACIH TTX. The ACIH is a fictitious system created by the authors. All documents in this appendix were created by the authors. Note that several of these documents are excerpts from larger documents; therefore the formatting of table and figure numbers is not consistent throughout this appendix.

ACIH EXECUTIVE SUMMARY

Equipment for United States soldiers must offer advantages and capabilities far greater than that of the enemy in the battlefield. A fully-integrated battle suit, consisting of a combat helmet and body suit, provides the vital protection that is needed for the soldiers to successfully complete their mission. The combat helmet is the most complex piece of gear in the battle suit offering the protection required for any battlefield situation. The helmet also provides audible and visual communication between headquarters and ground troops and improves and enhances the solder’s visual awareness using night-vision and thermal imaging devices. The objective of the system architecture design is to create a helmet that can integrate audio and visual communications, intelligence information, display information, and provide head protection.

One of the most important aspects of the helmet is to convey communication between the squadron team and the command headquarters. The helmet will be connected to communication devices that transmit and receive audio, video, GPS, and navigation communication. It will have internal speakers and a microphone to relay audible signals for communication between the squads and command center. The helmet will also be equipped with an external video camera that allows the ground troops and headquarters to view the ongoing operation as it is in progress. The helmet will be a major part of the human interface that improves and enhances situational awareness along with providing head protection against blunt and ballistic impact for the warfighter.

DOCUMENTS USED FOR ASR TTX

Includes:

- **ACIH AoA**
- **ACIH OV-1**
- **ACIH Risk Assessment/Management Plan**
- **ACIH Requirements**
- **ACIH Notional Schedule**
- **ACIH Technology Development Acquisition Phase Plan**

1. ACIH AoA

The AoA was performed via a Concept Generation process. A morphological matrix was used as the tool used for concept generation for the ACIH components. The matrix includes several alternatives for each characteristic or property needed to perform functions of the ACIH. Characteristics for components arose from analyzing the leaf node functions. In general leaf nodes are functions that were simulated. Many variations and combinations of solutions can then be pursued.

Once emergent characteristics were identified, they were listed in the matrix. Next the team brainstormed to come up with possible alternatives. A wide array of alternatives was considered and listed in morphological matrix to obtain a broad range of possible solutions. The resultant morphological matrix is listed in Table 3.

Table 3 Morphological Matrix – ACIH Functional Allocation

Characteristic	Alternatives			
Navigation	GPS	Bathymetric		
Encryption/Decryption	KG-95	Software based	Element H/W based	
Transmission	Tin can	Video, audio	Audio, video, data	Audio
Receiver	Audio	Audio, video	Audio, video, data	Tin can
Image Capturing	Normal capture	Image snap shot	Capture with zoom capability	Draw on paper
Night Vision	Gen I	Gen II	Gen III	Gen IV
Thermal Vision	Infrared camera	Uncooled thermal imaging device	Cryogenically thermal imaging device	
Processor	Intel	AMD		
Video Display	CRT visor	Projection onto visor	OLED visor	Handheld monitor
Head Protection	Full face helmet	Open face helmet	Flip-up helmet	

Concept Selection

Concept selection continued from concept generation and was performed by using Pugh Matrices as a tool. The alternatives from the morphological matrix were considered and analyzed in a Pugh matrix. Specific components were selected and these components were created in CORE and mapped from functions. Table 5 shows the Pugh matrix for the Audio Video Transmission.

Table 5 Pugh Matrix Audio Video Transmission

Digital Light Weight Audio Video Transmitter				
Criteria	TX-MOD3	CVT-1400	DT-200	2.4 GHz Digital
Weight	DATUM	+	-	+
Size		-	-	+
Rugged		S	S	S
Consumption		-	+	-
Digital		-	S	S
Sum of Positives		2	1	2
Sum of Sames		1	2	2
Sum of Negatives		2	1	1

Encryption/Decryption

The communications between the soldiers is accomplished through wireless connection and therefore the security of the communication becomes an important concern for the soldiers. As such, all communications include audio and video must be encrypted for transmit and decrypted at the receiver end. Again, the weight, size, and power consumption of the component other than the component function are important factors when integrating it with the ACIH. While the secure communication devices offer compact, light weight, secure, user-friendly, portable voice and data communication, it is still an external component that adds a burden to the real estate of the ACIH. An alternative to the solution is to perform the functions of encryption and decryption with the encryption algorithm One-Time pads. Using this algorithm, the process of encrypting/decrypting data requires very little computation, and the generation of the random pads can be accomplished on the processor. The software encryption/decryption is ideal for this type of weight, size, and power consumption limitation. Table 6 shows the Pugh evaluation matrix for the encryption and decryption component.

Table 6 Pugh Matrix Data Encryption/Decryption

Digital Light Weight Audio Video Transmitter				
Criteria	TX-MOD3	CVT-1400	DT-200	2.4 GHz Digital
Weight	DATUM	+	-	+
Size		-	-	+
Rugged		S	S	S
Consumption		-	+	-
Digital		-	S	S
Sum of Positives		2	1	2
Sum of Sames		1	2	2
Sum of Negatives		2	1	1

Night Time Vision and Thermal Imaging

The Generation I, II, III, and IV Night Time Vision technology are the key alternatives for the Provide Night Time Vision function. The infrared camera, uncooled thermal imaging device, and cryogenically thermal imaging device are the key alternatives for the Provide Thermal Vision function. The top alternatives are determined using the Pugh matrix in the concept selection phase. The Pugh matrix provides the tool to evaluate and compare the physical architecture components that best suited to carry out the functions. The following Pugh matrices of alternative design concepts for the night time and thermal vision are evaluated and compared using vital criteria for the stakeholder, in Tables 7 and 8.

Table 7 Pugh Night Time Vision

Night Time Vision				
Criteria	GEN I	GEN II	GEN III	GEN IV
Image Resolution	-	-	D	+
Light Amplification	-	-	A	+
MTTF	-	-	T	-
Signal to Noise Ratio	-	-	U M	+
Sum of Positives	0	0		3
Sum of Sames	0	0		0
Sum of Negatives	4	4		1

Table 8 Thermal Vision

Thermal Vision			
Criteria	Infrared	Uncooled	Cryogenically
Operating Temperature	-	D	+
Sensitivity	-	A	+
Resolution	-	T U M	+
Sum of Positives	0		3
Sum of Sames	0		0
Sum of Negatives	3		0

The key criteria for the night time vision concepts are image resolution, light amplification, mean time to failure (MTTF), and signal to noise ratio. The key criteria for the thermal imaging concepts are operating temperature, sensitivity, and resolution. The design concepts are evaluated and ranked with respect to the design criteria to determine the preferred concepts.

The trade off analysis for the night time vision using the Pugh matrix shows the Generation III night time vision technology as preferred alternative with the best design concept. The Generation I and II do not ranked highly in the scoring matrix. The Generation IV technology is rejected due to its drawback in the mean time to failure (MTTF). In addition, the matrix for the thermal imaging depicts the cryogenically thermal imaging device as the preferred design concept. The device surpasses the datum concept of uncooled thermal imaging device when compared using the specified design criteria. The cryogenically thermal imaging device is the best design concept that meets the stakeholder requirements.

The selected design concepts are transferred into CORE as Component elements for the system architecture development. The Generation III night vision technology and the cryogenically thermal imaging device are the Component elements that perform the Provide Night Time Vision function and the Provide Thermal Vision function. The 2.4GHZ Digital Video and Audio transmitter performs video and audio transmission. The Encryption/decryption is based on software algorithm such as One-Time Pad. These elements are represented and related to the remaining the architecture model as shown below.

Navigation

For navigation we had 4 choices, Paper/Digital Maps & Compass, GPS, Bathymetric and Celestial Navigation.

Using Paper/Digital Maps & Compass consist of a sailor carrying a map of the area and using a compass to finds his/her location. The soldier would need to be contacting Head Quarters (HQ) or the rest of team to report his/her location. The size of the map would depend on the size of the area. The accuracy, the update rate and speed for the soldier to calculate the position and transmit the info would depend on the map, the compass, the surrounding area, the present situation (hostile and none hostile environment), and the experience of the soldier.

Using a GPS devise would require no soldier interface. The GPS would be part of the helmet. The size of the devise would be smaller than any map. The devise updates at about 1 record per second, and using a processor and a transmitter it would automatically sends its position to HQ or the rest of the team. The accuracy for a GPS Standard Positioning is <15 meters, 95% typical.

Bathymetry is use to measure the depths of large bodies of water, like oceans, seas, and lakes. It has more use for underwater assignments. It would not work on our dessert hostage scenario.

The last option we got is using celestial navigation. It uses the sun, moon, stars, or planets to find your way around. It would require a map, a Sextant and tables. This is a complex and involved process that involves a fair amount of calculating, correcting, referring to tables, knowledge of the heavens and the Earth, as well as a lot of common sense.

Using a Pugh evaluation matrix, we selected for criteria: weight, size, reliability, accuracy, update rate, portability, speed to process/ transmit data and require power. GPS score 7 (+), 1 (same) and 1 (-). Bathymetric and Celestial navigation didn't have a positive score. See Table 9.

Table 9 Pugh Matrix Navigation

Navigation				
Criteria	Maps/Compass	GPS	Bathymetric	Celestial Nav
Weight	DATUM	+	-	-
Size		+	S	S
Reliability		S	S	S
Accuracy		+	-	-
Update Rate		+	-	-
Portability		+	-	S
Speed to Process/Transmit data		+	-	-
Sum of Positives		6	0	0
Sum of Sames		1	4	4
Sum of Negatives		1	5	4

Receiver

Based on the Pugh selection matrix the Tin Can option is not a viable choice. Neither is the audio option, although it could be an improved audio. Both the audio/video combination and the audio/video/data combination should be pursued further. Considering stakeholder needs outlined in the Design Reference Mission, the best alternative to pursue at this time is the audio/video/data receiver. See Table 10 for the Pugh matrix.

Table 10 Pugh Matrix Receiver

Receiver				
Criteria	Audio	Audio/Video	Audio/Video/Data	Tin Can
Weight	DATUM	+	+	-
Size		S	-	-
Reliability		+	+	-
Accuracy		+	+	-
Sum of Positives		3	3	0
Sum of Sames		1	0	0
Sum of Negatives		0	1	4

Image Capturing, Processing, and Video Display

Table 11 Pugh Matrix Image Capturing

Image Capturing			
Criteria	Contour HD	GoPro Hero	Olympus D-595
Weight	-	DATUM	S
Size	S		-
Reliability	+		+
Accuracy	+		-
Update Rate	S		+
Portability	-		+
Sum of Positives	2		3
Sum of Sames	2		1
Sum of Negatives	2		2

Concerning image capturing: there were three options: normal capture (Contour HD), capture with zoom (GoPro Hero Wide), and image snap shot (Olympus CA Media D-595). We are comparing the cameras as a whole for parts, which will be later broken down into the helmet. Comparing the cost, Contour HD is the most expensive option as it provides HD video. The products' durability are all relatively equal, with the Olympus camera being less so. Concerning resolution, the Contour HD and the Olympus both can capture high resolution images. Concerning the frames per second, the Contour HD has the highest capability shooting either 60 fps at SD or 30 fps at HD, while the GoPro shoot only 30 fps SD. The Olympus is not a camcorder, and greatly losses in this area. The weight of the cameras is the same, while the Olympus is a bit lighter due to its ability. The GoPro and has a fixed zoom ability, while the Contour HD does not. The Contour does shoot higher resolution images which can be optically zoomed. The Olympus has the greatest zoom ability with a 3x optical zoom with high resolution. Based on the Pugh chart, the Olympus has the most benefits; however it comes at a great cost, it actually is not sending video, but slowly sending images. The Contour HD on the other hand seems to offer the best performance out of the three options. See Figure 11 for the Pugh matrix.

The image capturing is built in the video component system, and is implemented by the soldiers on the field. The image capture will stabilize the lens and capture the image to be used.

Processor

Table 12 Pugh Matrix Processing

Processor			
Criteria	Intel I7	Intel Core 2 Quad	AMD Phenom
Cost	-	DATUM	+
Clock frequency	+		S
Power Usage	+		S
L2 Cache	+		S
Performance	+		-
Sum of Positives	4		1
Sum of Sames	0		3
Sum of Negatives	1		1

Table 12 shows the Pugh matrix for the processor. There are two main producers of processor chips: Intel and AMD. The options chosen were high end processors, while also including the newest high-end processor (Intel i7). Even though these processors are our options, a more suitable processor may be decided later after processor requirements get further refined. The three options for processors are the Intel i7, Intel Core 2 Quad, and the AMD Phenom II X4. These were compared using five characteristics: cost, clock frequency, power usage, L2 Cache, and performance. The Intel i7 is the newest processor and because of that it is the most costly of the bunch. However, this gives the processor the best performance compared to the other two. Comparing the other two processors, they match with each other very closely. However, the AMD has been known for being somewhat cheaper than the Intel brand, making their Phenom processor slightly cheaper than the Intel Core 2 Quad. However, when comparing performance Intel Core 2 Quad has a slight edge compared to AMD's Phenom. Based on the Pugh Chart, the new Intel i7 provides the most positives between the options.

The processor is built from the custom SW to be run on the system and will be implemented by the soldiers in the field. The processor will perform a large array of tasks including: encryption of data, decryption of data, compiling the navigational map, displaying enhanced vision, and displaying video.

Table 13 Pugh Matrix Video Display

Display			
Criteria	OLED	Projection	LCD
Cost	-	D	S
Transparency	+	A	-
Brightness	+	T	+
Resolution	S	U	S
Size (Volume)	+	M	-
Sum of Positives	3		1
Sum of Sames	1		2
Sum of Negatives	1		2

There are three options for the video display (Table 13): an OLED screen that can be attached to a visor, a projector to place images onto the visor, and a removable LCD screen. These options were compared with five characteristics: cost, see through, brightness, resolution, and size. The most expensive option is the OLED since it is technology that is relatively new. The projection method and LCD method are more experienced technology with a similar price point. “Transparency” is a characteristic important for a visor display. The OLED can display a clear picture with a flexible screen as thin as paper, which is transparent. The projection method will project its image onto the visor; however, this may reduce the transparency of the visor. The LCD is not transparent at all and will need to be removable. The brightness of the LCD and OLED are equivalent, while the projection may suffer visibility issues during daylight. All three options have the same resolution. Volume wise, the OLED will take the least amount of space in the helmet compared to the other methods. The LCD will take up the most volume. Based on the Pugh Chart, the OLED provides the best performance.

The OLED display will be built in the helmet and implemented by the soldiers in the field. This component is the main interface for the soldier, displaying the navigational map, video, and enhanced vision.

Provide Head Protection

A Pugh matrix was put together to take a look at alternatives to the concept design of the helmet. Criteria were provided by the stake holders as to the needs the helmet is to meet during mission use. The criteria provided included strength, comfort, heat protection, impact cushioning, shrapnel protection and volume. Three helmet concepts were compared; full faced helmet, open faced helmet and flip face helmet. All three had positives and negatives. The best alternative to select is the full face helmet. Compared with the other helmets, the full face helmet meets 95% of the user's needs. See Table 14.

Table 14 Pugh Matrix Head Protection

Helmet			
Criteria	Full Face	Open Faced	Flip Face
Strength	S	DATUM	S
Comfort	-		-
Heat Protection	+		+
Impact Cushioning	+		+
Shrapnel Protection	+		S
Volume	+		S
Sum of Positives	4		2
Sum of Sames	1		3
Sum of Negatives	1		1

Selected Components

The trade off analysis for components was performed using the Pugh matrices of alternative design concepts. The selected design concepts are transferred into CORE as Component elements for the system architecture development. Figure 12 shows a hierarchical diagram with the allocated physical components based on the Pugh matrices evaluation.

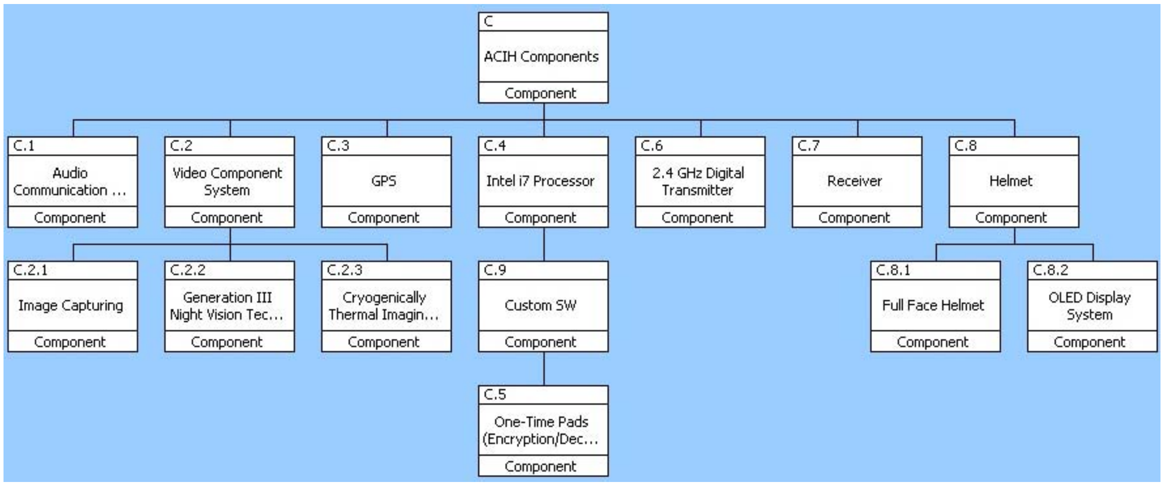
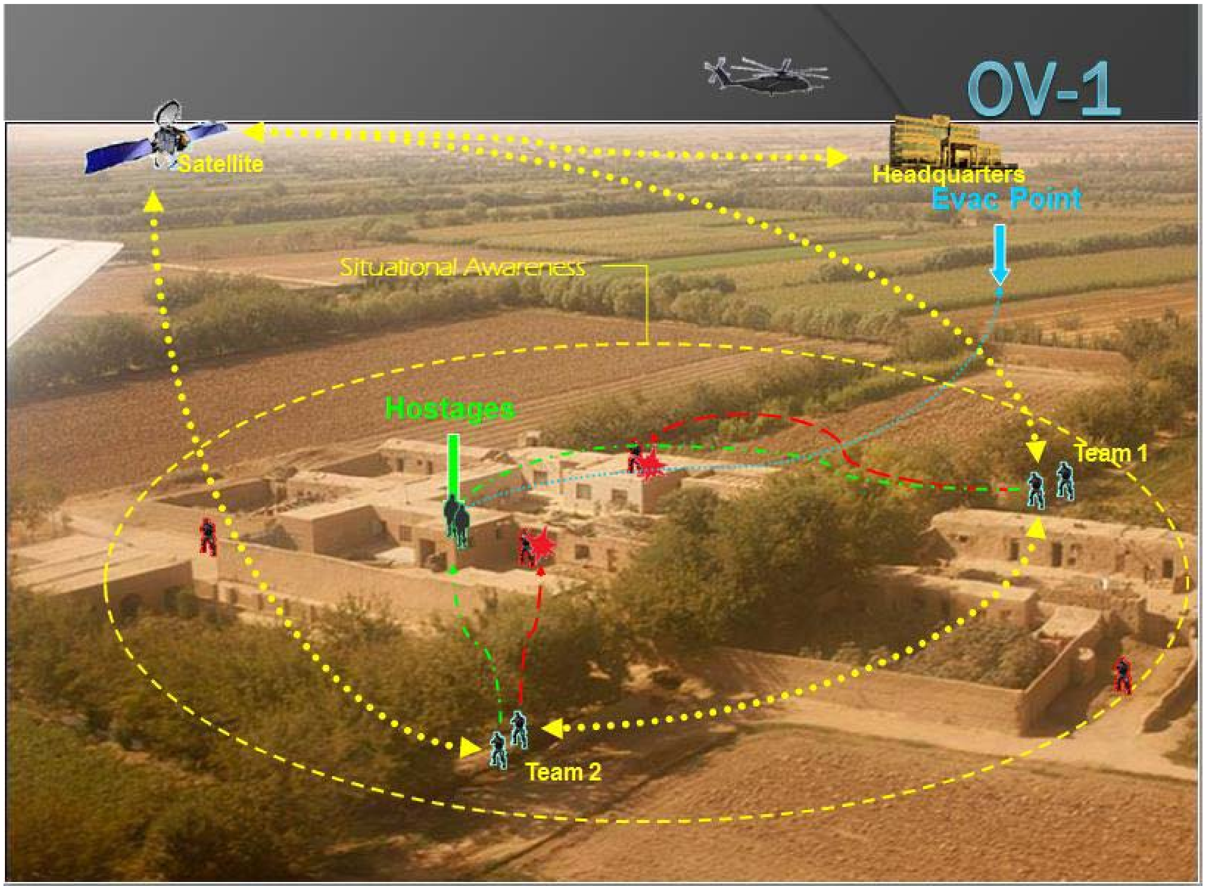


Figure 12 ACIH Component Selection and Allocation Hierarchy Diagram

2. ACIH OV-1



The OV-1 shows a hostage rescue scenario where the Advanced Combat Integrated Helmet provides the soldiers with increased situational awareness, showing them a navigational map and allowing them to know where their other team members and enemies are located. The helmet allows for constant encrypted video and audio communication between the soldiers and the headquarters.

3. ACIH RISK ASSESSMENT/MANAGEMENT PLAN

The risk assessment and associated risk management/mitigation plan includes the evolving external environment.

ASR review assesses the alternative systems that have been evaluated during Concept Refinement, primarily through the AoA, and ensures that the preferred system is cost effective, affordable, operationally effective and suitable, and can be developed to provide a timely solution to a need at an acceptable level of risk. Of critical importance to this review is the understanding of available system concepts to meet the requirements from the ICD or the CDD, as well as the affordability, operational effectiveness, technologies, and adaptability to the evolving external environment, risk inherent in each alternative concept.

One of the artifacts of this review is to provide a comprehensive assessment on the relative risks associated with including Commercial Off-The Shelf (COTS) or Non-Developmental Items (NDI) as opposed to a new design, with emphasis on host platform environmental design, diagnostic information integration, dependence on other government programs and maintenance concept compatibility.

All the components including hardware and software used in the ACIH shall be designed to provide encrypted and reliable communication serves as Operational Awareness to the special operation soldiers throughout the entire operation. The chosen components shall be capable of operate in a harsh environment. With fewer dollars available for research, test and evaluation, and procurement of new systems, an important advantage of many COTS and/or NDI acquisitions is the reduced acquisition cycle time. This reduction results primarily from decreased in design and engineering time due to the fact that the COTS components have already been tested and have gone through general acceptance of the product in the commercial marketplace or in a previous military application.

However, there are unique risks associated with COTS-based / NDI acquisitions. Most of the COTS components used commercially are not designed for used in the military operational environments. Failing to realize the impacts of using COTS components can add to system cost, schedule and performance risks. Therefore, this review must address some of the risk factors and the mitigations in order to keep the system development under cost and low risk.

COTS-based / NDI Component Risk Factors:

1. Rapid and asynchronous changes
2. Different obsolescence impacts
3. Proprietary data.
4. Higher life cycle costs
5. Multiple configurations
6. Commercial standards
7. Time-limited manufacturer support
8. Information security susceptibility

Mitigations:

1. Involve COTS - knowledgeable individuals in all analytical processes
   Benefit - Facilitates the application of COTS mitigation strategies and informed decision making
2. Involve users early and throughout the program life cycle to identify and resolve COTS-related constraints
   Benefit - Reduces chances of surfacing user acceptance issues late in system development and deployment
3. Perform continuous COTS product market research
   Benefit - Allows product team to project and plan for changes in technology, product configurations and obsolescence-related issues
4. Integrate market research results with field data and new requirements
   Benefit - Optimizes and prioritizes cost, schedule and performance factors between obsolescence-driven system changes and system upgrades
5. Develop and maintain flexible performance requirements suited to the use of COTS products
   Benefit - Allows for appropriate level of specified function description and the inclusion of COTS technical performance factors
6. Institute and maintain ongoing COTS product testing capability
   Benefit - Allows project to assess new COTS products/technologies for specification compliance, form/fit/ function compatibility and standards conformance
7. Integrate COTS-based technology evolution planning within the Integrated Program Plan
   Benefit - Provides centralized planning that captures system evolution strategy, obsolescence projections and risk mitigation decisions
8. Emphasize strong and COTS relevant configuration management practices
   Benefit - Reduces the possibility of untested COTS product changes affecting system performance and supports multiple system configurations
9. Use a COTS-experienced systems integration agent
   Benefit - Facilitates acquisition, development, deployment and support activities with proven COTS capable personnel and services
10. Leverage the commercial infrastructure wherever feasible

Benefit - Prevents costly duplication of already existing COTS product support infrastructure

11. Ensure the chosen hardware and software conform to IA compliance
    Benefit – Reduces the chances of unauthorized access to the system while increasing inter-operability among different products that meet commercial standards.

ACIH Operational Effectiveness Risk Factors:

The combat helmet is a vital piece of protective equipment hat is essential in the battlefield. The helmet should provide basic head protection as well as advance capabilities in a mission allowing an increase in situational awareness. Proper integration of audio and video components provides soldiers critical communication capability in such the team can strategically plan their operation to counteract the enemy and carry out their mission. Risk factors associate with operational effectiveness are as follow:

1. Communications (audio and video) intercept by enemy
2. Communications signal being jammed
3. Power consumption limitation
4. Transmit and receive distance
5. Helmet falls in enemy's hand

Mitigations:

1. All communications (audio and video) are encrypted. The communications are encrypted with one time secret key. The secret key is used to encrypt and decrypt audio and video signal. The strength of the secret key must exceed the life time of the mission
2. Anti-jamming algorithm prevent jamming signal interrupting communications
3. The battery shall have proper capacity to provide power to audio and video components throughout the entire operation.
4. The transmitter and receiver shall be capable of operate effectively within communications distance between soldiers.
5. The one time secret key shall be changed for each operation

4. ACIH REQUIREMENTS

NEEDS

In order to meet the needs outlined in the executive summary, the helmet must:

- Be well ventilated and comfortable to wear in lengthy operation.
- Properly seat on the head without obstructing the user's view.
- Absorb and reduce energy from blunt and ballistics impact to reduce the risk of head injury.
- Provide the capability enabling the soldiers to see and operate in an environment with or without visible illumination.
- Allow the soldiers to carry out their search, identification, and monitoring of enemy activities during all times of day as they prepare and organize their operation.
- Allow the soldiers to exchange situational information and video with one another as well as their command headquarter.

The Projected Operational Environment (POE) of the Advanced Combat Integrated Helmet (ACIH) is designed to be used in the desert area such as Iraq and Afghanistan. The ACIH is mostly used by Special Forces in the operation of a hostage rescue mission. Desert warfare is highly vulnerable to foreign armies that are not familiar or experienced with the area. Knowing how to navigate in the desert is the desert fighter's best advantage. The ACIH will have communication equipment (transmit and receive), and GPS and navigation, to provide better maneuvering and situational awareness during the rescue operation in the desert environment.

DRM Example

A group of armed hostiles take defensive positions in an urban city. Hostages are taken to deter engagements on their location. The objective is to retreat or eliminate soldiers. The mission is to infiltrate the building undetected, detect the enemy, capture or eliminate hostile enemies, and secure the hostages.

Mission Success Requirement

The ACIH provides advanced combat operation architecture to ensure special combat operation soldiers can effectively fight in a diverse range of operational environments to carry out their mission. Its ultimate goal is to accomplish Enhance User to Perform Rescue Mission.

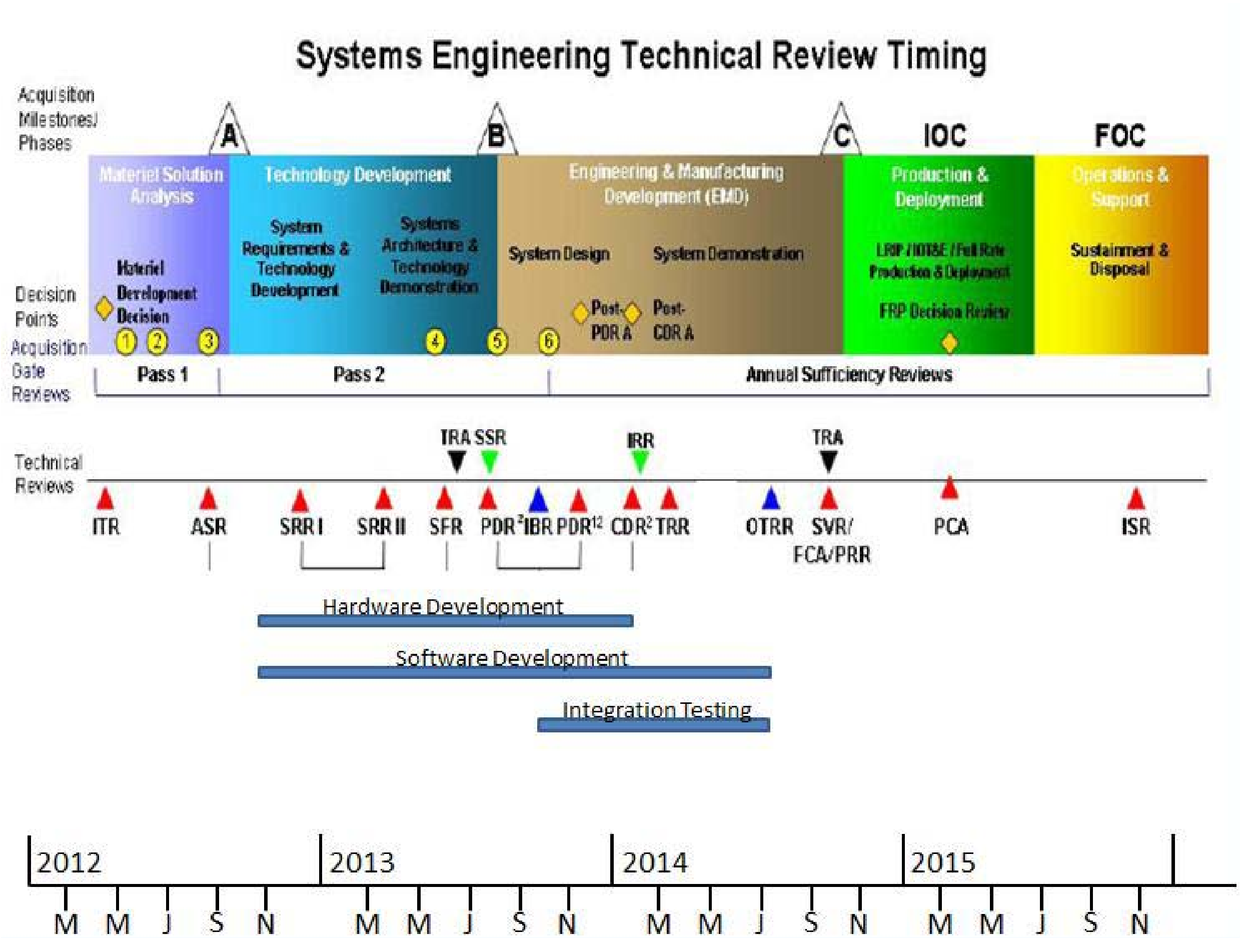
The mission is defined as a success if the following conditions are true:

- Enemy forces and hostages are identified
- Enemy and hostages activities are monitored
- Enemy and hostages activities are relayed to the squadron and command headquarter
- Operation is carried out at any time of day
- Enemies are captured
- Hostages are rescued
- Soldiers and hostages survive the rescue operation

ACIH Requirements:

- The Advanced Combat Integrated Helmet (ACIH) requirements shall provide and maintain audio and video communications throughout entire hostage rescue operational.
- The system shall provide Operational Awareness including the ability to transmit and receive user and team location, as well as receive intelligence from headquarters.
- The system shall enable to user to detect an enemy at a minimum distance of 400 meters in any environment, lighting, or condition.
- The ACIH shall protect the user from blunt force trauma, sharp objects, explosions, and bullet fragments. The ACIH will protect the user from injury, death, and illness.
- The ACIH helmet shall share encrypted data to protect users and the mission.
- The ACIH helmet shall process the data and output the required information to the user.
- The system shall have a MTBF of no less than 3900 hours.
- The system shall operate after impact from blunt forces.
- The system shall operate without hindering users' performance.

5. ACIH NOTIONAL SCHEDULE



6. ACIH TECHNOLOGY DEVELOPMENT ACQUISTION PHASE PLAN

The purpose of this phase is to reduce technology risk and to determine the appropriate set of technologies to be integrated into the full system. This will ensure that the proposed technology solution is affordable, militarily useful, and based on mature technology.

Entrance Criteria

A successful completion of AoA and proposed materiel solution is presumed at this stage of the acquisition process.

Phase Description:

1. The Technology Development Phase begins when the MDA has approved a material solution and the Technology Development Strategy (TDS).
2. The DoD component shall submit a cost estimate for the proposed solution(s) identified by the AoA.
3. Final Requests for Proposals (RFPs) for the Technology Development Phase shall not be released until the MDA has approved the TDS.

Technology and Development Plan for Advanced Combat Integrated Helmet (ACIH)

Description of Approach

The advanced combat helmet is a complex piece of gear that provides vital protection needed for the soldiers to successfully complete their rescue/hostage mission. The helmet provides audible and visual communication between headquarters and ground troops to enhance situational and operational awareness. The real-time audio and video data are processed and transferred using the current transmitter and receiver technology to facilitate instant communication. The latest and up-to-date situational and operational information is critical in a successful engagement planning and operational maneuver.

1. The selected approach is preferred due to the advanced transmitter and receiver technology that is widely available for immediate use. The use of transmitter and receiver to exchange audio and video data and information is advantageous as the maturity of the existing

technology has been previously studied and verified. It is more assuring that the transmitter and receiver will likely to perform as designed when earlier studied and documented data are examined and considered during the system design and development. An acceptable risk level can be determined from the use of commercial components to ensure that it is suitable for the overall system interoperability. The determination of suitable transmitter and receiver for the proposed system is successfully completed by using Pugh matrices. Refer to the AoA section for the Pugh Matrix for each component.

a. A 2.4 GHz audio transmitter is selected for the transmission of audio and video data. The transmitter offers the greatest capability with given criteria.
b. A Contour HD camera provides the required capability to capture image and process video. The camera offers HD video quality with high resolution. It is able to provide the highest image capturing capability at 30 frames per second. This feature is ideal for the diverse operating environment of the proposed advanced helmet system.
c. The audio/video/data receiver provides the needed capability for communication exchange. The selection fulfills the operational need of enhancing situational awareness in a combat operation.
d. OLED screen is the selected component that will provide clear picture or video display. The OLED is a thin transparent flexible screen that can be attached to a helmet visor to view video data.

2. A software interface will be used to integrate individual component into a full system. The software application will be used to manage, control, and maintain the interoperability of microphone, headphone, and video display. Equipment readiness is monitored to determine their operating condition. Data and information exchange between components is also processed and handled by the software program. The data is encrypted and decompressed prior to transmission then decrypted and uncompressed upon receipt. This ensures that the information is securely transferred to intended recipients. The One-Time pads is the selected component that provides a secure data transfer. .

The data encryption and decryption will be used in conjunction with a processor to process audio and video information. Intel 17 processor provides the best processing power and speed for such information exchange. Refer to the AoA section for the Pugh Matrix for encryption/decryption and the processor

3. A Technology Development Strategy will be prepared for additional reviews.
4. A preliminary acquisition strategy, including cost, schedule, and performance goals for the total research and development program will be provided during the review.
5. Final Requests for Proposals (RFPs) for the Technology Development Phase will be submitted.

DOCUMENTS USED FOR OTRR TTX

Includes:

- **ACIH Operational Requirements Document**
- **ACIH Operational Test Plan and Scenarios**
- **ACIH Training Plan**
- **ACIH DT&E Test Data**
- **ACIH DT&E Test Report**
- **ACIH Notional Integrated Logistics Support Plan**

1. ACIH OPERATIONAL REQUIREMENTS DOCUMENT

The ACIH Requirements artifact for the ASR was used as the Operational Requirements Document (ORD).

Operational Requirements Document

Advance Combat Integrated Helmet

October 27, 2010

OPERATIONAL REQUIREMENTS DOCUMENT

1. General Description of Operational Capability.

Special operation soldiers in combat typically operate in a diverse range of operational environments and are vulnerable to injury threats placing demands on the soldiers' protective system to provide consistent performance throughout a range of situations and threats. The combat helmet is a vital piece of protective equipment that is essential in the battlefield. Stakeholders seek a comfortable helmet that provides basic head protection as well as advanced capabilities in a mission allowing an increase in situational awareness as such that the team can strategically plan their operation to counteract the enemy and carry out their mission of hostage liberation.

1.1. Mission Need.

The equipment for United States soldiers must offer advantages and capabilities far greater than that of the enemy in the battlefield. A fully-integrated battle suit, consisting of a combat helmet and body suit, provides the vital protection that is needed for the soldiers to successfully complete their mission. The combat helmet is the most complex piece of gear in the battle suit offering the protection required for any battlefield situation. In addition of providing audible and visual communication between headquarters and ground troops, the helmet also improves and enhances the solder's visual awareness using night-vision and thermal imaging devices. The objective of the system architecture design is to create a helmet that can integrate audio and visual communications, intelligence information, display information, and provide head protection.

1.2. Overall Mission Area Description.

The ACIH is designed to be used during the day or night in the desert area such as Iraq and Afghanistan. The ACIH is mostly used by Special Forces in the operation of a hostage rescue mission. Desert warfare is highly vulnerable to foreign armies that are not familiar or experienced with the area. Knowing how to navigate in the desert is the soldier's best advantage. The ACIH will have communication equipment (transmit and receive), and GPS and navigation, to provide better maneuvering and situational awareness during the rescue operation in the desert environment.

1.3. Descriptions of the Proposed System.

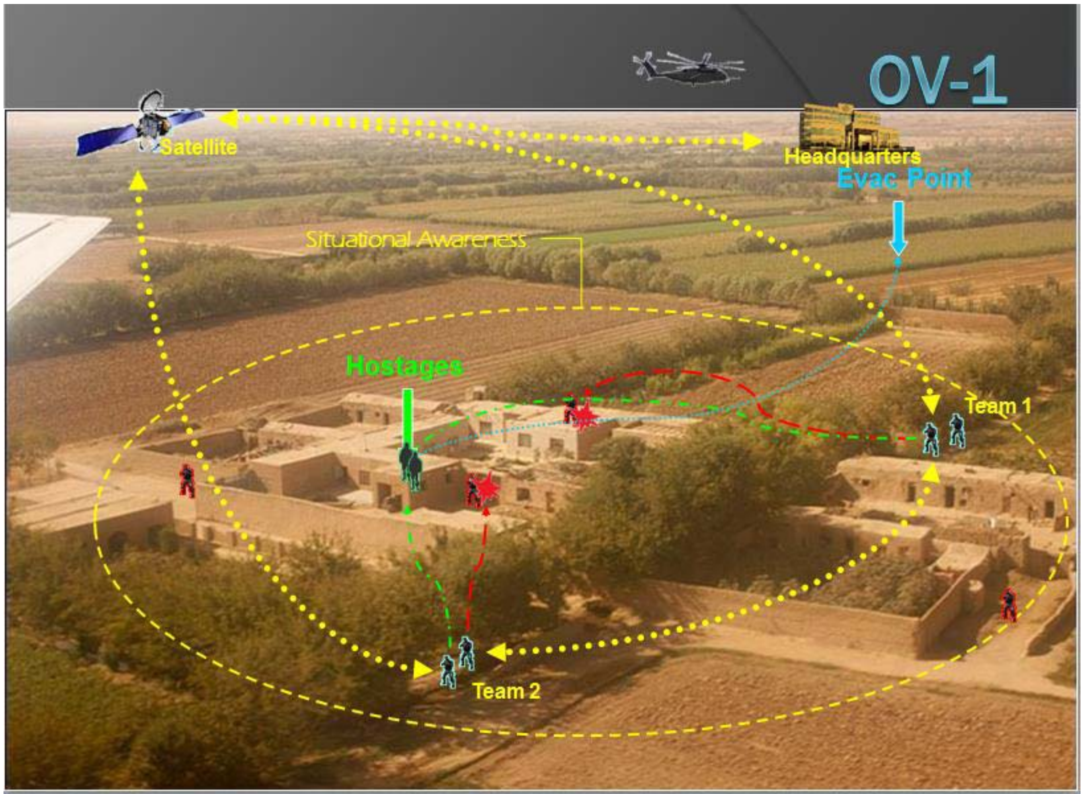
One of the most important aspects of the helmet is to provide reliable and encrypted communications between the squadron team and the command headquarters. The helmet shall be capable of transmit and receive audio, video, GPS, and navigation communication Audio communication between the squads and command center shall be accomplished without interruption causes by harsh operational environment. The helmet shall also be providing real-time video stream on the battle ground in such that allows the ground troops and headquarters to view the ongoing operation as it is in progress. The helmet will be a major part of the human interface that improves and enhances situational awareness along with providing head protection against blunt and ballistic impact for the warfighter. It is the most Advanced Combat Integrated Helmet (ACIH) that gives special operation soldiers ability to strategically plan their operation and carry out their mission with minimum casualty.

1.4. Supporting Analysis.

1.5. Mission the Proposed System Will Accomplish.

1.6. Operational and Support Concept.

1.6.1. Concept of Operations.



The OV-1 shows a hostage rescue scenario where the Advanced Combat Integrated Helmet (ACIH) provides the soldiers with increased situational awareness, showing them a navigational map and allowing them to know where their other team members and enemies are located. The helmet allows for constant encrypted video and audio communication between the soldiers and the headquarters.

1.6.2. Support Concept.

1.7. Acquisition Approach.

2. Threat.

The threat is an armed hostile group considered to be trained in firearms and explosives. The hostiles are operating in a desert urban environment. Threat is assumed to have no surveillance equipment installed.

Threat Properties:

Average Size: 8 hostiles
Weapons: Kalashnikov AK-47, Unknown Explosive Devices
Potential Hostages: 2-3

The threat's courses of action (COA) are defined as follows:

Most Likely COA: A disorganized armed group of hostiles retreat to a civilian location, taking a defensive position within a building. The hostiles will silently wait till the situation has died down before retreating to an enemy encampment. The hostiles will shoot at soldiers on sight if they suspect their location is compromised.

Most Dangerous COA: An armed team infiltrates a civilian location and reinforces the area with small scale explosives. The hostiles take civilian hostages to deter possible engagements. The hostile's goal is to eliminate as many soldiers as possible, shooting any soldier on sight. They have no regard for their own lives.

3. Existing System Shortfalls.

Operational Shortfalls. The ACIH is designed to combine advance combat technology to meet current and projected requirements. It is designed to provide comfortable head protection against blunt and ballistics impact and allow the soldiers to operate in low to no illumination environment. The helmet is designed to increase situational awareness by providing real time communication between the ground troops and headquarters. The immediate communication can provide valuable command and control and decision support in the search, identification, and monitoring of enemy.

4. Capabilities Required.

4.1. Operational Performance Parameters.

Conditions:

	Environment		
	Requirement	**Developed System**	**Projected Operation**
Temperature	-30 F to 110 F	-50 F to 130 F	60 F to 110 F
Time of Day	Night and Day	Night and Day	Night
Environment	Desert, Urban, Snow	Desert, Urban, Snow	Desert

4.2. ORD Key Performance Parameters (KPPs).

- Operator shall receive continuous geographical/navigational satellite data with a lag of less than 3 seconds.
- The encrypted video data shall be transmitted and received no greater than 1 second.
- The encrypted audio data shall be transmitted no greater than 1second and received no greater than 0.25 seconds.
- The navigational data shall be transmitted in less than 0.5 second.

- The ACIH high grade absorbent padded lining shall absorb blunt force within 6 milliseconds.
- The ACIH Kevlar shall protect the user from shrapnel traveling at 340 meters/second.
- The ACIH shall protect the user from heat and fire generated from a grenade explosion at 4 seconds.

4.3. System Performance.

4.3.1. Mission Scenarios.

A group of armed hostiles take defensive positions in an urban city. Hostages are taken to deter engagements on their location. The objective is to retreat or eliminate soldiers. The mission is to infiltrate the building undetected, detect the enemy, capture or eliminate hostile enemies, and secure the hostages.

4.3.2. System Performance Parameters.

4.3.2.1. The audio communication equipment such as headsets shall reduce noise exposure while delivering clearer audio and comfortable fit. High noise levels in surrounding environment can affect situational awareness. Misunderstood commands and repeated instructions can increase operational risk and reduce mission effectiveness. The headsets offer active and passive technologies which together provide full-spectrum noise reduction with comfortable, lightweight designs that can be worn continuously during long missions.

4.3.2.2. With the capability of the secure video communication, the soldiers during the hostage rescue operation can gain insight of the hostile environment via real-time video communications. The video communication should leverage satellite communication that provides a secure wireless video communications infrastructure between command center and the ground soldiers. The video communication provides the soldiers visibility and intelligence by feeding the soldiers imagery resulted of reconnaissance and coordinated mission planning. It also provides real-time streaming video of the operation to command center to assess the operation developments.

4.3.2.3. The ACIH shall use GPS to coordinate, record soldier and team location during a hostage rescue operation. This includes determining distance, direction, location, elevation/altitude, route, and data for navigation aids, orientation and rate of movement.

4.3.2.4. The ACIH shall enable the soldier to detect enemies at a minimum distance of 400 meters in any environment, lighting, or condition.

4.3.2.5. The system shall amplifies light to allow the soldier to see at dark. This allows the soldier to see in levels of light that approach total darkness. The device shall use a system no older than Generation 3 (GEN III).

4.3.2.6. The systems shall enable soldier to see enemy heat signatures.

4.3.2.7. The ACIH will protect the soldier's head from injury, illness, and death as a result of blunt force trauma, sharp objects (knives), and explosions.

4.3.3. Information Exchange Requirements.

4.3.4. Interoperability.

System interoperability involved the ability for the systems of system to provide and accept services from each other to enable them to operate effectively together. For ACIH system, audio, video, and navigational data must be exchanged via the transmitter and receiver to achieve the desired services. The data from the microphone and speaker is processed with software and delivered to the user after completion.

4.3.5. Logistics and Readiness.

4.3.6. Other System Characteristics.

5. System Support.

5.1. Maintenance.

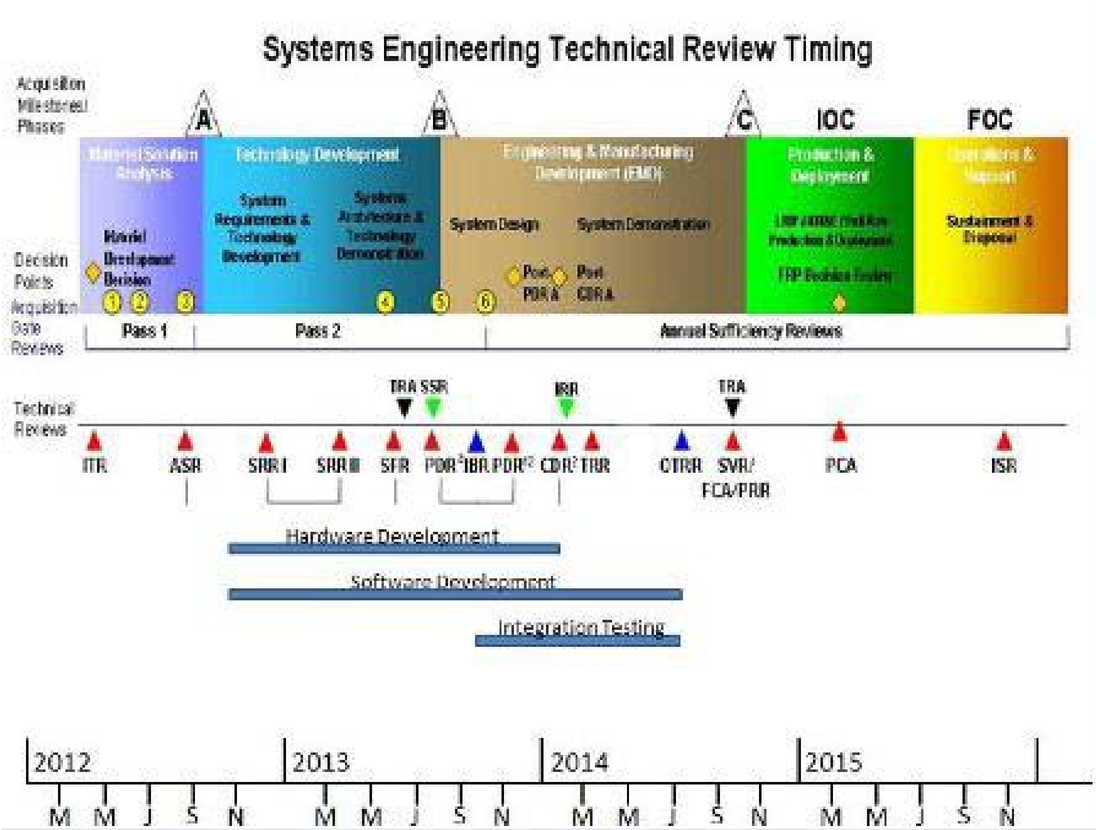
5.2. Supply.

5.3. Training.

5.4. Transportation and Facilities.

6. Force Structure.

7. Schedule.



8. System Affordability.

2. ACIH OPERATIONAL TEST PLAN AND SCENARIOS

ADVANCE COMBAT INTEGRATED HELMET (ACIH)

OPERATIONAL TEST & EVALUATION (OT&E) TEST PLAN

27 October 2010

PREPARED BY

COMMANDER, OPERATIONAL TEST and EVALUATION FORCE (COMOPTEVFOR)

Table of Contents

Contents	Page

Section 1
Introduction to the Project

1.0 Introduction

The purpose of this Operational Test (OT) event is to assess the Advanced Combat Integrated Helmet (ACIH) by identifying system enhancements and significant areas of risk to the programs successful completion of OT&E. OT ACIH will be conducted from 15 – 19 November 2010 at the U.S. Army Yuma Proving Ground Test Center, Yuma, AZ.

The level of risk is associated with the successful resolution of Critical Operational Issues (COI) during OT ACIH. This risk is based upon assessment of thresholds, program documentation, program plans, and Subject Matter Expert (SME) analysis.

1.1 System Description

The ACIH is intended to integrate audio and visual communications, intelligence information, display information, and provide head protection. The ACIH will convey communications between a squadron and command headquarters. It will be connected to communication devices that transmit and receive audio, video, Global Positioning System (GPS), and navigation communication. It will have internal speakers and a microphone to relay audible signals for communication between the squadrons and command centers. The helmet is also equipped with an external video camera that allows the ground troops and headquarters to view the ongoing operation as it is in progress.

The ACIH consists of a 2.4 GHz Digital Light Weight Audio Video Transmitter, One-Time Pads Data Encryption / Decryption, GEN III Night Vision, Cryogenically Thermal Vision, GPS Navigation, Audio/Video/Data Receiver, Contour HD (Image Capturing, Processing, and Video Display), Intel 17 Processor, OLED Display, and a full face helmet.

Section 2
Administrative Information

2.0 General

General responsibilities of activities involved in the testing are provided in this section, as well as appropriate points of contact. Continuing close liaison is essential to timely and successful prosecution of this event.

2.1 Responsibilities

COMPTEVFOR

1. Provide changes to this test plan.
2. Conduct briefings for all participating units, including Operations Security (OPSEC) requirements and procedures.
3. Supervise data collection, participate in test analysis, and publish final report.

Program Executive Office Integrated Warfare System (PEO IWS)

1. Furnish required material and technical support.
2. Provide for installation and maintenance of project equipment.
3. Provide funding for data collection, reduction, and analysis support.
4. Provide for and coordinate targets and range support.
5. Provide for appropriate safety certifications.
6. Certify system readiness for OT ACIH per SECNAVINST 5000.2C.

2.2 Points of Contact

Points of contact are provided in table 2-1.

Table 2-1 Points of Contact

Name/Rank	Title (Code)	Address	Commercial
CDR John Doe	Operational Test Coordinator (Code 72)	Commander, Operational Test and Evaluation Force 7970 Diven St Norfolk, VA 23505	757-222-2222

2.3 Visitor Control

SECNAV'S policy regarding visitor observance of Operational Testing (OT) is strict. This is to preclude any perception of a lack of objectivity in the T&E process or any perception of outside influence on the OT unit and/or OTD. Therefore, observers will not normally be permitted in the test area during OT. During testing, visit authorization will be controlled by Program Executive Office Integrated Warfare Systems (PEO IWS) and granted only for valid requirements or for technical assistance.

2.4 Disclosure Policy

Test Data. Factual OT data will, as expeditiously as possible, be released/shared with the program office. The logistics of release/sharing of data will not interfere with the conduct or evaluation of any OT. Factual data does not include information based on consensus or opinion, such as operator or maintainer surveys. Such information is subjective and part of the evaluation process, and will not be made available prior to the release of the final report. DOT&E access to test data will be per applicable sections of Title 10.

Proprietary Information. Requests for access to proprietary information will be referred to the proprietor agency for disposition. Proprietary information will not e disclosed by COMOPTEVFOR. Information collected by the OTD in the form of survey sheets (user and test team feedback, comments, opinions, and conjecture of system performance) during OT constitutes proprietary information of COMOPTEVFOR. This includes information gathered from questionnaires and interviews. Such information will be labeled: "FOR OFFICIAL USE ONLY – NOT RELEASABLE OUTSIDE OF COMOPTEVFOR.

Deviations from the test plan. The OTD is authorized to deviate from this test plan as the operational situation and good judgment dictates, keeping COMOPTEVFOR advised. COMOPTEVFOR will advise DOT&E of deviations from this test plan.

Release of information to the press or other agencies. Prior to formal issue of the final report, no test data will be released. Once the report is issued by COMOPTEVFOR, the CNO will release data per existing policy. Media requests to observe OT will be referred to Chief of Information (CHINFO) in Washington, DC. Requests for other than OT&E information will be referred to CHINFO for coordination with CNO and COMNAVSEASYSCOM.

Section 3

Scope of the Evaluation

3.1 Critical Operational Issue (COIs): COIs for OT ACIH:

COIs	Tests
Maintain Communications	E-1
Provide Operational Awareness	E-2
Enable User Vision	E-3
Reliability	S-1
Maintainability	S-2
Availability	S-3
Interoperability	S-4
Training	S-5

3.2 Evaluation Criteria

CNO provided the required Measures of Effectiveness (MOE), Measures of Suitability, and Critical Technical Parameters (CTP). Table 3-1 is the Operational Activities for the ACIH and MOEs. Table 3-2 is the Critical Technical Parameters. Table 3-3 is the Operational Activities that the components of the ACIH must meet. COMOPTEVFOR will consider all of these in the assessment of the ACIH. Data will be collected and analyzed to obtain a characterization of the ACIH and to determine improvement trends throughout the testing cycle.

Table 3-1: Operational Activities for the ACIH

Operational Activity	**Description**	**MOE**
Identify Target of Operation	Friend/Foe Identification	• User shall receive a constantly updated map with a lag no greater than 3 seconds.
Transmit Operational Information	Provide situational and operational information in planning for engagement	• The video data shall transmit encrypted data in no greater than 1 second • The audio data shall transmit encrypted data in no greater than 1 second • The navigational data shall transmit encrypted data in no greater than 0.5 seconds

Receive Operational Information	Obtain situational and mission information to facilitate operational maneuver	• The audio shall reach the user with a lag no greater than 0.25 seconds. • The video shall reach the user with a lag no greater than 1 second. • The user shall receive a constantly updated map with a lag no greater than 3 seconds.
Request Command & Decision Support	Request for support from command center for operation planning or decision making for tactical maneuver and engagement	• The video data shall transmit encrypted data in no greater than 1 second • The audio data shall transmit encrypted data in no greater than 1 second
Carry Out Rescue Operation	Operational maneuver and engagement to detain enemy and rescue hostages	• The ACIH high grade absorbent padded lining shall absorb blunt force within 6 milliseconds • The ACIH Kevlar shall protect the user from shrapnel traveling at 340 meters/second • The ACIH shall protect the user from heat and fire generated from a grenade explosion at 4 seconds • The user shall receive a constantly updated map with a lag no greater than 3 seconds

Table 3-2: ACIH Critical Technical Parameters

The Advanced Combat Integrated Helmet (ACIH) requirements shall provide and maintain audio and video communications throughout entire hostage rescue operational.
The system shall provide Operational Awareness including the ability to transmit and receive user and team location, as well as receive intelligence from headquarters.
The ACIH helmet shall share encrypted data to protect users and the mission.
The ACIH helmet shall process the data and output the required information to the user.
The system shall have a MTBF of no less than 3900 hours.

Table 3-3: Operational Activities that the components of the ACIH must meet

Component	**Function**	**Operational Activity**				
		Carry Out Rescue Operation	Identify Target of Operation	Receive Operational Information	Request For Command and Decision Support	Transmit Operational Information
2.4 GHz Digital Transmitter	Transmit Encrypted Audio Data				**X**	**X**
	Transmit Encrypted Navigational Data				**X**	**X**
	Transmit Encrypted Video Data				**X**	**X**
Audio Communication System	Output Audio Communication	**X**	**X**		**X**	
	Receive Audio Communication	**X**		**X**	**X**	
	Transmit Audio Communication	**X**				**X**
GPS	Display Marked Imagery/Map		**X**	**X**		
	Transmit User Location	**X**		**X**		**X**
Helmet	Provide Head Protection	**X**				
Intel i7 Processor	Continuously Mark Team Location	**X**		**X**		
	Decrypt Incoming Audio	**X**		**X**	**X**	

Component	Function	Operational Activity				
		Carry Out Rescue Operation	Identify Target of Operation	Receive Operational Information	Request For Command and Decision Support	Transmit Operational Information
	Decrypt Incoming Video			**X**	**X**	
	Decrypt Intelligence Information		**X**	**X**		
	Decrypt Navigational Data	**X**		**X**		
	Digitize and compress video					
	Display Enhanced Vision	**X**	**X**		**X**	
	Display Incoming Video		**X**		**X**	
	Display Marked Imagery/Map		**X**	**X**		
	Encrypt Outgoing Audio	**X**				**X**
	Encrypt Outgoing Video Feed					**X**
	Encrypt User Navigational Data	**X**				**X**

Component	Function	Operational Activity				
		Carry Out Rescue Operation	Identify Target of Operation	Receive Operational Information	Request For Command and Decision Support	Transmit Operational Information
	Mark Possible Enemy Location		**X**	**X**		
	Mark Possible Hostage Location		**X**	**X**		
	Output Audio Communication	**X**	**X**		**X**	
Receiver	Accept Incoming Audio			**X**		
	Accept Incoming Video			**X**		
	Receive Intelligence Information			**X**		
	Receive Team Location			**X**		
Video Component System	Display Enhanced Vision	**X**	**X**		**X**	
	Display Incoming Video		**X**		**X**	
	Provide Night Time Vision (NTV)	**X**	**X**	**X**		
	Provide Standard Video					**X**

Component	Function	Operational Activity				
		Carry Out Rescue Operation	Identify Target of Operation	Receive Operational Information	Request For Command and Decision Support	Transmit Operational Information
	Provide Thermal Vision (TV)	**X**	**X**	**X**		
	Receive Video Feed		**X**	**X**	**X**	
	Transmit Video Feed	**X**	**X**		**X**	**X**

3.3 Testing

Test operations will exercise the ACIH at the Yuma Proving Ground. System testing will provide data for operational effectiveness (E-tests) and operational suitability (S-tests) COIs. These are discussed further in sections 4 and 5.

Section 4
Operational Effectiveness

4.1 Scenarios

Test scenarios are based on a squadron of 10 Special Forces soldiers using the ACIH. Their mission is to rescue a group of three hostages who are being held captive by a group of 8 hostiles. The hostiles are considered to be trained in firearms and explosives, and are armed with Kalashnikov Ak-47s and unknown explosive devices. The hostages are being held in a desert urban environment. The Special Forces are to be dropped via helicopter and once on the ground they are to communicate with each other and Headquarters via the ACIH. They will download satellite imagery of the terrain and building where the hostages are being held. The team will then locate the building using the GPS component of the ACIH. Once the building has been located, they will then transmit voice and video imagery of the situation to Headquarters awaiting further orders. All data will be encrypted and decrypted per OPSEC. Once the order is given, the team will engage the hostiles and take the hostages to a safe location using the ACIH communication devices that transmit and receive audio, video, Global Positioning System (GPS), and navigation communication. This mission will be executed twice, once during the day and once during the night. During the evening mission, the Special Forces will locate the hostiles using night vision and infrared components of the ACIH. All weapons engagements will be simulated. The ACIH will be operated continuously throughout the test period. A detailed schedule of events will be used during OT ACIH and will be promulgated by the test conductor prior to the test period.

4.2 Test E-1, Maintain Communications

Objective: The ACIH, operating with its integrated supporting components will maintain audio and visual communications throughout entire hostage rescue mission.

1. Receive Audio Communication and Transmit Audio Communication.

2. Receive Video Feed and Transmit Video Feed.

Procedure: ACIH will be assessed at each test event during the test period. Data will be recorded via observer notes, OT test team comment sheets and DX.

Data Analysis: Maintaining of Communications will be assessed qualitatively and quantitatively based on OT test team comment sheets, DX analysis, and operational experience. The ACIH will be evaluated on whether or not it can reduce noise exposure while delivering clearer audio providing full spectrum noise reduction with comfortable, lightweight design that can be worn continuously during long missions. ACIH will also be evaluated on being able to transmit and receive audio/video between team and headquarters. The video communication should leverage satellite communication that provides a secure wireless video communications infrastructure between command center and the ground soldiers. The video communication provides the soldiers visibility and intelligence by feeding the soldiers imagery resulted of reconnaissance and coordinated mission planning.

4.3 Test E-2, Provide Operational Awareness

Objective: The ACIH, operating with its integrated supporting components will maintain operational awareness throughout entire hostage rescue mission.

1. Receive Team Location

2. Transmit User Location

3. Receive Intelligence Information

Procedure: ACIH will be assessed at each test event during the test period. Data will be recorded via observer notes, OT test team comment sheets and DX.

Data Analysis: Providing Operational Awareness will be assessed qualitatively and quantitatively based on OT test team comment sheets, DX analysis, and operational experience. The ACIH will be evaluated on whether or not it can use GPS to coordinate, record user and team location during a hostage rescue operation. This includes determining distance, direction, location, elevation/altitude, route, and data for navigation aids, orientation and rate of movement.

4.4 Test E-3, Enable User Vision

Objective: The ACIH, operating with its integrated supporting components will enable user vision to detect enemies at a minimum distance of 400 meters in any environment, lighting, or condition.

1. Provide Night Time Vision (NTV)

2. Provide Thermal Vision (TV)

Procedure: ACIH will be assessed at each test event during the test period. Data will be recorded via observer notes, OT test team comment sheets and DX.

Data Analysis: Enabling User Vision will be assessed qualitatively and quantitatively based on OT test team comment sheets, DX analysis, and operational experience. While operating in levels of light approaching total darkness, the ACIH shall amplify light to allow the user to see. When operating in total darkness or at night, the ACIH shall allow the user to see heat signatures of the enemies.

Section 5

Operational Suitability

5.1 General

The suitability testing will use data generated by continuous operation of the ACIH throughout test operations, including effectiveness tests described in Section 4. A maintainability demonstration will also be conducted. Tests specifically designed to generate maintainability data are described in the following Suitability Tests (S-Tests).

5.2 Test S-1, Reliability

Objective: Will the ACIH reliability support completion of the mission?

Procedure: Reliability will be assessed continuously during the test period. Maintenance action forms will be completed for each failure or issue noted during operations, and for each preventive maintenance action that finds a failed part. Data will be recorded via observer notes/OT test team comment sheets, maintenance logs, and DX.

Data Analysis: Reliability will be assessed qualitatively and quantitatively based on observer notes/OT test team comment sheets, maintenance logs, and operational experience. Reliability quantitative assessment is based on calculations for $MTBOMF_{HW}$ and $MTBOWF_{SW}$:

$MTBOMF_{HW}$ is the mean time between operational mission hardware failures occurring during system operation and is calculated by:

$MTBOMF_{HW}$ = Total System Operating Time / # of Operational Mission Hardware Failures

Where an operational mission hardware failure is one which causes the ACIH to fail its mission. System operating time includes only the time the system is operating. It does not include standby time.

$MTBOMF_{SW}$ is an operational mission software fault. An operational mission software fault is an interruption of ACIH operation not directly attributable to hardware, which causes the ACIH to fail its mission.

$MTBOMF_{SW}$ = Total System Operating Time / # of Operational Mission Software Faults

5.3 Test S-2, Maintainability

Objective: Is the ACIH maintainable by Special Forces?

Procedure: Maintainability will be assessed continuously during the test period. Trouble and/or maintenance action reports will be completed and reviewed as appropriate. Data will be recorded via observer notes/OT team comment sheets, and maintenance logs.

Data Analysis: Maintainability will be assessed qualitatively and quantitatively based on observer notes/OT test team comment sheets, maintenance logs, and operational experience. Maintainability quantitative assessment is based on calculations for $MCMTOMF_{HW}$ and $MCMTOMF_{SW}$.

$MCMTOMF_{HW}$ is the average elapsed corrective maintenance time needed to repair all operational mission hardware failures.

$MCMTOMF_{HW}$ = Total Elapsed Time to Correct Operational Mission Failures / Total # of Operational Mission Failures.

5.4 Test S-3, Availability

Objective: Will the ACIH be available to support completion of the mission?

Procedure: All OT test team comment sheets, maintenance forms, and time meter recordings from tests S-1 and S-2 will be reviewed.

Data Analysis: A_O is computed using the formula: A_O = Uptime / Uptime + Downtime

5.5 Test S-4, I/O

Objective: Will the ACIH be interoperable with the systems with which it must interface?

Procedure: This test will be conducted throughout the OT ACIH. Test S-4 will examine the I/O between ACIH and interfacing systems.

Data Analysis: I/O will be assessed qualitatively based on observer notes/OT test team comment sheets, maintenance logs, and operational experience. The impact of any I/O issues on overall mission accomplishment identified during testing will be assessed.

5.6 Test S-5, Training

Objective: Will the ACIH training support system operation and maintenance by Special Forces?

Procedure: At this point, only adequacy of the ACIH Navy Training System Plan (NTSP) training programs will be assessed. Selected ACIH training courses may be audited by the OTD to determine adherence to NTSP requirements and potential effectiveness for training Special Forces.

Data Analysis: The ACIH training program will be qualitatively assessed based on operational experience and judgment. Training issues observed during the assessment will be evaluated on the basis of its impact on overall mission accomplishment.

Section 6

Reports

6.1 General

Reports required in connection with this project are described in the following paragraphs. Distribution should be limited where indicated.

6.2 Readiness Reports

PEO IWS Certification. PEO IWS shall certify the ACIH readiness for OT ACIH per SECNAVINST 5000.2C

Unit Readiness. Prior to commencement of testing, PEO IWS will submit a message report to COMOPTEVFOR if the Yuma Proving Ground test site is not ready to commence operations. This report will include the reason project operations cannot commence and any expectations or reservations on the part of PEO IWS.

6.3 OT Commencement Report

Upon commencement of OT ACIH, the ACIH OTD will notify COMOPTEVFOR indicating actual start time (Date-Time-Group (DTG) Zulu) of testing. Comments, particularly anticipated limitations, may be included in this communication.

6.4 Status Reports

Deficiency Reports

A deficiency recommendation will be submitted by quickest available means directly to COMOPTEVFOR by the ACIH OTD when the project is delayed because the equipment cannot be operated properly, the required support is lacking, or there has been prolonged delay in equipment delivery. The deficiency recommendation will contain a summary of the deficiency, action taken, and recommended corrective action.

Anomaly Reports

An initial anomaly report will be submitted by quickest available means directly to COMOPTEVFOR by the ACIH OTD when failures or anomalies occur that impact OT and require correction, but are not so severe that a deficiency report is required. The anomaly report will identify the failure or anomaly, its impact on OT and overall system performance, and recommend corrective action.

Completion of Test Operations Report

Upon completion of the OT ACIH data analysis process, the ACIH OTD will notify COMOPTEVFOR indicating the completion time (DTG Zulu) of OT ACIH.

6.5 Evaluation Reports

Analysis Report

Data Analysis Team (DAT) analysis reporting will be per reference x.

COMOPTEVFOR Report

COMOPTEVFOR will submit a final evaluation report to CNO within 90 days of completion of project operations.

3. ACIH TRAINING PLAN

NAVY TRAINING PLAN FOR THE

ADVANCED COMBAT INTERGRATED HELMET

(ACIH)

OCTOBER 2010

EXECUTIVE SUMMARY

Advanced Combat Integrated Helmet (ACIH) is a modern day device that helps enhance military capabilities in vital combat operation. The helmet helps improve situational awareness and operational readiness by providing real-time audio and video communication between the operating forces and headquarter. The exchange of up-to-date operational situations helps enhance tactical strategy development in offensive and defensive combat.

PART I – TECHNICAL PROGRAM DATA

A. Title-Nomenclature-Program
   a. Title Nomenclature Acronym: Advanced Combat Integrated Helmet – ACIH
   b. Program Element: XXXX

B. Security Classification: Security documents are developed in accordance with OPNAINST C5513.6C – Communication and Satellite security Guidance dated 7 DEC 2005
   a. Audio communication transmit/receive – Secret
   b. Video Communication transmit/Receive – Secret

C. NTP Principals

a. Director of Naval Training	CNO
b. Bureau of Naval Personnel	BUPERS
c. Commandant of the Marine Corps	CMC (ASM)
d. Principal Development Activity	NAVSEASYSCOM
e. Assistant Chief of Naval Operation	CNO
f. Manpower and Personnel Mission Sponsor	CNO

D. Operational Uses
   a. Purpose: The ACIH consists of audio and video assembly that provides real-time communication between operational forces and headquarter.
   b. Foreign Military sales and Other Source Procurement

E. Technical and/or Operational Evaluation (TECHEVAL/OPEVAL): The training plan developmental will be verified during OTRR. The plan will be revised based on inputs/comments from the review. The plan will be testing during OT.

F. Equipment/System/Subsystem replaced
   a. Audio Communication System:
      i. Receive/Transmit devices – I level maintenance
   b. Video Communication System:
      i. Transmit/Receive devices – I level Maintenance
      ii. Display component
      iii. Night time vision
   c. Processor – I level maintenance

G. Description

a. Functional Description: The ACIH consists of audio and video assembly that provides real-time communication between operational forces and headquarter. The audio assembly facilitates point-to-point verbal communication as the video assembly provides visual information that is displayed on the OLED screen on the face visor. The communication exchange is achieved with the use of digital transmitter and receiver to transfer encrypted information. The encrypted data is securely processed via a software interface called One-Time Pads. The One-Time Pads is a software program that is used to encrypt and decompress information prior to transmission. It is also used to decrypt and uncompressing data upon reception by the receiver. The secured audio information is sent to the user's earpiece and the video data is displayed onto the screen on the helmet.

b. Physical description: The physical and electrical characteristics of the ACIH are as follows:

    i. Weight
    ii. Diameter
    iii. Power requirement for Audio/Video
    iv. Power requirement for display

H. Training Concepts

a. Operational: The training is to provide the users with the best practice for ACIH operation. The user will gain in depth knowledge of the operation and maintenance of the helmet to ensure that it is properly used and function during the mission. The training curriculum provides operational concept so the operator will be able to operate and execute the ACIH function components

    i. Transmit/Receive audio communication
    ii. Transmit/Receive video communication
    iii. Display video information

b. Maintenance: The ACIH maintenance objective is to provide the means to restore the unserviceable unit back to serviceable condition with minimum down time. The training curriculum provides the end user information and tool to diagnose problem and determine what level support the unserviceable unit be sent to. Follow the initial diagnose results, the unserviceable unit will be sent to one of the three level maintenance which designed by the Naval maintenance principle

i. Organization level maintenance
ii. Intermediate level maintenance
iii. Depot level maintenance

I. Logistics
J. Schedules
K. Manpower Requirements
L. On-Board Training
M. List of Related Navy Training Plans and Applicable

PART II – BILLET AND PERSONNEL REQUIREMENTS

A. Billets Required for Operational and field Support
   a. Field Logistic Support
   b. Training refresh support

B. Billets Required for Maintenance
   a. I-Level Maintenance
   b. Depot Maintenance level

PART III - Training Requirement

A. <u>Length of the training program</u>
   a. Operator : 1.5 week course
      i. ACIH components familiar
      ii. Video communication Hardware operational
      iii. Audio communication Hardware operational
      iv. Basic Networking
      v. Basic Satellite communication
   b. Maintenance: 3 weeks course
      i. ACIH Hardware familiar
      ii. Basic electronics theory
      iii. Basic Networking theory
      iv. Troubleshooting Video communication system
      v. Troubleshooting Audio communication system
      vi. Troubleshooting ACIH main computer

B. Logistic Support

   a. Special Test equipment

      i. Network analyzer

      ii. Signal generator – audio/video

   b. Tool

PART IV - Points of Contact

A. NSWC-PHD Code XXX

B. FTCLANT Code XXX

C. FTCPACT Code XXX

4. ACIH DT&E TEST DATA

Six DT&E Test Data Sheets for the ACIH were utilized:

- Test Scenario Name: COMPONENTS
- Test Scenario Name: USER INTERFACE
- Test Scenario Name: HEADQUARTERS CONNECTION TO SATELLITE
- Test Scenario Name: CONNECTION BETWEEN HEADQUARTERS – SATELLITE - ACIH
- Test Scenario Name: ACIH CONNECTION TO ANOTHER ACIH
- Test Scenario Name: CONNECTION BETWEEN 10 ACIH UNITS

TEST SCENARIO NAME: COMPONENTS

Description: This test would desmonstrate the basic functionality of the ACIH component

Objective:
Verify microphone
Verify speaker
Verify camera
Verify Display
Verify helmet
Verify transmistter
Verify receiver
verify encryptor

Pass/Fail: PASS

Step	Requirments	Description	P/F	Comment
1	microphone Sensitivity	Sensitivity to be 54db	P	
2	microphone Impedance	Impedance to be 1000 Ohm	P	
3	Speakers Impedance	Impedance to be 80 Ohm at 1KHz	P	
4	Speakers Frequency	Frequency response 20Hz- 22KHz	F	The max freequency response was 19KHz
5	Speakers Sensitivity	Sensitivity to be 108db @ 1KHz	P	
6	OLED Display transparent		P	
7	OLED Display thinnes		P	
8	OLED Display ambient temperature	Ambient temperature to be 10f to 120f	F	The max temperature before it started to malfuntion was
9	Helmet protection	protects against 9mm FMJ and 44 Magnum	P	
10	Helmet weight	4 lb	P	
11	Processor clock speed	Mim 2.5 GHz	P	
12	Processor Frequency	Min 3.0 GHz	P	
13	Processor Bus/Core Ratio	21	P	
14	Processor Cache	Min 6	P	
15	Processor Memory	24 GB	P	
16	Processor VID	Require .70V - 1.34V	P	
17	Transmitter Test A- Audio	Transmit Audio	P	
18	Transmitter Test B- Video	Transmit Video	P	
19	Transmitter Test C- Navigation	Transmit Navigation data	P	
20	Encryptor Test A- Audio	Software encrypt and decrypt Audio data	P	
21	Encryptor Test B- Video	Software encrypt and decrypt Video data	P	
22	Encryptor Test C- Navigation	Software encrypt and decrpt Navigation data	P	
23	Camera Test A- Zoom	Camera zoom mim 400 meters	P	
24	Camera Test B- Night Vision	Spectral Response Visible to 0.90 µm (IR)	P	
25	Camera Test C- Thermal Vision	Resolution 320 x 240, Detection range minimum 400m,	P	
26	Camera Test D - Weight	Max weight 700 grams		
27	Camera Test F - Temperature	Max temp 120f		
28	Camera Test F - Voltage	Max Vdc 3.5		

TEST SCENARIO NAME: USER INTERFACE

Description: This test demonstrates the basic functionality of turning on and off the ACIH interfaces: microphone, speakers, transmitter, receiver, night vision, thermal vision and display.

Objective: Verify connectivity between the ACIH and headquarters
Verify video capability
Verify text data is received and sent
Verify vision and display capability

Pass/Fail: PASS

Step	Requirements	Description	P/F	Comment
1	User can turn on the audio.	The user turns on the Audio (speaker).	P	
2	User can turn on the microphone	The user turns on the microphone.	P	
3	Establish audio communication with headquarters.	Headquarters sends a communication check. The user replies and confirms communication is established.	P	Communication had a 2-3 seconds delay
4	User can stop sending voice communication while still able to receive communications from headquarters.	User uses the interface mute application, while still able to receive instructions from headquarters.	F	The user push the mute button. The user was getting voice information from headquarters. User started a conversation with the Tester, headquarters did not heard the user conversation. BUT after 45 seconds headquarters started hearing the conversation. Contractor would investigate this issue.
6	Verify video capability (part A - ON)	Headquarters requests video. User turns "on" video and requests a video verification check from headquarters.	P	
7	Verify video capability (part B - OFF)	Headquarters requests to turn "off "video. The user turns "off" the video and requests a verification check from headquarters.	P	
8	Verify Display Capability (part A ON/OFF)	User turns on and off Display capability and at the same time gets verification checks from headquarters.	P	
9	Verify Display Capability (part B - zoom)	User zooms in/out onto an object at 400 meters distance.	P	
10	Verify Display Capability (part C - Night Vision)	User turns on/off Night Vision capability and gets verification from headquarters .	P	
11	Verify Display Capability (part D - Thermal Vision)	User turns on/off Thermal Vision capability and gets verification from headquarters .	F	It turned on, but after about 5 seconds it turned off by itself. Test was repeated and the second time it turn off by it self after 10 seconds. Contractor would investigate this issue.
12	Verify Display Capability (part E - Location map layout)	User receives map layout from headquarters. User turns on/off the map layout display option.	P	

TEST SCENARIO NAME: Headquarters connection to Satellite

Description: This test demonstrates the basic functionality of sending and receiving information between the satellite and headquarters.

Objective:
Verify connectivity between the Satellite and headquarters
Verify there is constant information going back and forward
Verify video data is received and sent
Verify text data is received and sent
Verify voice data is received and sent

Requirement Coverage: ACIH - R1, ACIH - R2, ACIH - R3, ACIH - R5, ACIH - R7

Pass/Fail: PASS
Comment:

Step	Requirements	Description	P/F	Comment
1	Headquarters establishes a connection with satellite	Headquarters sends PING to the Satellite	P	It took 3 attempts
2	Head quarters sends text data to the Satellite	Headquarters sends a "text" word to the satellite	P	The word that was choose was "MISSION"
3	Satellite receives text data and sends it back to headquarters	Satellite receives the "text" word "MISSION" and sends it back to headquarters.	P	
4	Obtain .gif files from Satellite	Headquarters requests a picture (.gif file) from the satellite	F	
6	Obtain .jpg files from Satellite	Headquarters requests a picture (.jpg file) from the satellite	P	
7	Satellite receives and sends video	Headquarters sends a 10 minute video clip and receives it back	P	The receiving clip had a 3 second delay
8	Satellite receives and sends voice	Headquarters sends a 5 minute voice clip and receives it back	P	This clip was sent twice. First time the clip was cutout. The second time headquarters got the full clip with about a 1 second delay
9	Satellite receives/sends voice and data at the same time	Headquarters sends/receives a 5 minute video and voice	P	
10	Headquarters sends/receives encrypted data to the satellite for 24 consecutive hours.	Headquarters sends/receives voice, text, video data on encryption mode. The test run for 24 consecutive hours.	P	The video clip still has a 3 seconds delay. Connection was lost for 2 times for a period of 1 minute the first time and 45 seconds the second time; during 24hrs of testing

TEST SCENARIO NAME: Connection between Headquarters - Satellite - ACIH

Description: This test demonstrates the basic functionality of sending and receiving information between the satellite and the ACIH

Objective:
Verify connectivity between the Headquarters and ACIH
Verify there is constant information going back and forward
Verify video data is received and sent
Verify text data is received and sent
Verify voice data is received and sent

Requirement Coverage: ACIH - R1, ACIH - R2, ACIH - R3, ACIH - R5, ACIH-6, ACIH - R7

Pass/Fail: PASS
Comment: (artifact = object, person or target)

Step	Requirements	Description	P/F	Comment
1	Headquarters establishes connection with ACIH via Satellite.	Headquarters sends PING to ACIH via Satellite	P	
2	Headquarters requests ACIH position	Headquarters request GPS data from ACIH	P	
3	Headquarters obtains video data from ACIH	Headquarters requests video data from ACIH	P	On the first three attempts it didn't pass. Contractor re-calibrate the ACIH camera, try it the 4th time and it didn't work. Contractor change the camera and it work on the
4	ACIH receives GPS data from other artifacts around his position	Headquarters sends GPS information from one artifact around the ACIH unit.	P	
6	ACIH receives GPS data from multiple artifacts around his position	Headquarters sends GPS information from 5 artifacts around the ACIH unit.	F	The ACIH was only able to receive GPS data from 4 artifacts. Contractor would keep working on this issue
7	ACIH sends/receives voice data to and from headquarters	Headquarters receives/sends voice data to and from the ACIH unit	P	
8	ACIH receives map data from headquarters	Headquarters sends map layout of the ACIH position	P	It took 4 tries for the map layout to display on the ACIH OLED screen.
9	Headquarters receives Thermal Vision Video from the ACIH	The ACIH switches the regular view to Thermal Vision. Headquarters receives the new video format.	P	It took a minute for the user to find the switch to change the display into this mode. The user didn't know how
10	Headquarters receives Night Vision Video from the ACIH	The ACIH switches the regular view to Night Vision. Headquarters receives the new video format.	P	It took a minute for the user to find the switch to change the display into this mode. The user didn't know how
11	ACIH is able to detect detect a person at 400 meters	The ACIH detects a person using zoom options, thermal and night vision at a distance of 400 meters	F	The ACIH was able to detect a person under normal vision using the zoom options at 400 meters. But using the thermal and night vision was able to detect a person at a max of 375 meters

TEST SCENARIO NAME: ACIH connection with another ACIH unit.

Description: The ACIH (1) sends/receives information to and from ACIH(2). Both units are monitored by headquarters.

Objective:
Verify connectivity between headquarters and 2 ACIHs
Verify connectivity between the two ACIHs
Verify there is constant information going back and forward
Verify video data is received and sent
Verify text data is received and sent
Verify voice data is received and sent

Requirement Coverage: ACIH - R1, ACIH - R2, ACIH - R3, ACIH - R6, ACIH-7, ACIH - R8

Pass/Fail: PASS

Comment:

Step	Requirements	Description	P/F	Comment
1	Headquarters establishes a connection with both ACIH units	Headquarters sends PING to ACIH (1) and ACIH(2)	P	ACIH (2) took 2 minutes longer, the user didn't know how to turn on the transmitter.
2	Headquarters receives/sends voice data from both ACIH units	ACIH (1) and (2) sends voice verification check to headquarters	P	
3	Headquarters gets video from both ACIH units	ACIH(1) and (2) sends video to headquarters	P	
4	Headquarters gets GPS data from both ACIH units	ACIH(1) and (2) sends GPS data to headquarters	P	
5	ACIH(1) establishes voice communication with AICH (2)	ACIH(1) sends/receive voice verification check with ACIH(2)	P	
6	Headquarters sends map layout to the ACIH units	ACIHs receives location map layout from headquarters	F	ACIH(1) did received the map layout, but ACIH(2) did not.

TEST SCENARIO NAME: Connection between 10 ACIH units.

Description: 10 ACIHs units are part of the test and are monitored and maintain communications with headquarters.

Objective:
Verify connectivity between headquarters and the 10 ACIHs
Verify connectivity between the 10 ACIHs
Verify there is constant information going back and forward
Verify video data is received and sent
Verify text data is received and sent
Verify voice data is received and sent

Requirement ACIH - R1, ACIH - R2, ACIH - R3, ACIH - R6, ACIH-7, ACIH - R8
Pass/Fail: PASS
Comment:

Step	Requirements	Description	P/F	Comment
1	Headquarters establishes a connection with 10 ACIH units.	Headquarters sends PING to each ACIH	P	3 user didn't know how to turn on the transmitter.
2	Headquarters receives/sends voice data from both ACIHs	Each ACIH sends voice verification check to headquarters	P	
3	Headquarters gets video from all ACIH units	Each ACIH sends video to headquarters	P	
4	Headquarters gets GPS data from each ACIH unit	Each ACIH sends GPS data to headquarters	P	
5	All ACIH units establish voice communication with each other	Each ACIH sends/receive voice verification check with each other	P	
6	Headquarters sends map layout to the ACIH units	ACIHs receives location map layout from headquarters	F	5 units did not received the map layout. Contractor would investigate this particular ACIHs units

5. ACIH DT&E TEST REPORT

DT&E TEST REPORT
For the
Advanced Combat Integrated Helmet

1. Executive Summary

The following paragraphs summarize the results of the Advanced Combat Integrated Helmet (ACIH) Developmental Test and Evaluation (DT&E). The purpose of this test was to assess the ability of the Advanced Combat Integrated Helmet (ACIH) to meet the Mission Critical Thread: *ACIH communications (audio/visual) shall not be interrupted and compromised throughout the operation.*

2. Scope

Testing was conducted at the Contractor's facility. The ACIH system accumulated 72 operating hours over a 7 day period.

3. Background

The developmental test was performed in preparation for the Operational Test Readiness Review (OTRR). The testing included the integration of the hardware, software, and interoperability. This evaluation included an assessment of the ACIH critical technical parameters in support of the mission critical thread.

4. Resources

Test resources include simulators (satellite, desert environment, etc.), GFE ACIH equipment, bandwidth limiter, noise signal generator, wireless network sniffer, wireless network throughput and latency measurement equipment.

5. Test Results

The overall finding is that the maturity of the ACIH during DT&E was found to be satisfactory. The assessment is based on the following:

Critical Technical Parameters

- The Advanced Combat Integrated Helmet (ACIH) requirements shall provide and maintain audio and video communications throughout entire hostage rescue operational.
- The system shall provide Operational Awareness including the ability to transmit and receive user and team location, as well as receive intelligence from headquarters.
- The ACIH helmet shall share encrypted data to protect users and the mission.
- The ACIH helmet shall process the data and output the required information to the user.
- The system shall have a MTBF of no less than 3900 hours.

All tests were performed according to the Test and Evaluation Master Plan (TEMP). Some issues arose in preparation for the test; contractors corrected the issues prior to system testing. For system testing four scenarios were tested: satellite connection to headquarters, connection between endpoints (headquarters to/from satellite to/from ACIH), ACIH connection to other ACIH units, and connection between 10 ACIH units.

Some issues arose during the test. Contractors corrected issues before proceeding. See DT&E DATA RESULTS.xls file for DT&E test data and results.

6. System Assessment

The ACIH was found to meet all system level requirements in support of the mission critical thread. This system level assessment is based on extensive testing in the laboratory. Testing included end-to-end performance in a desert environment and exercised audio and visual communications.

7. Findings

The overall finding is that the maturity of the ACIH was found to be satisfactory. Specifics of these findings include:

a. Finding #1: Successful communication paths tested: the ACIH successfully provided uninterrupted audio/visual communication throughout.

b. Finding #2: The ACIH met or exceeded all test objectives.

c. Finding #3: Although communications were demonstrated to meet the test objectives, some components lost communication for brief periods or did not receive all data.

Issues:

a. Issue #1: The ACIH was only able to receive 4 of 5 GPS information artifacts from headquarters.

b. Issue #2: Only the first ACIH received map layouts from headquarters, the second ACIH did not during ACIH to ACIH testing.

c. Issue #3: Only five ACIH units received map layouts, the other five did not during the ACIH test with 10 units.

8. Recommendations

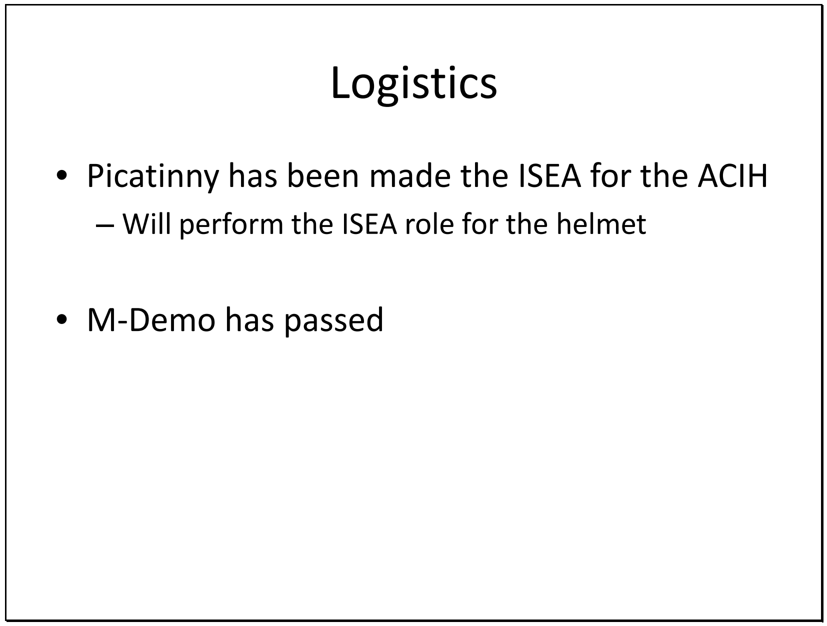
Issue #1 - #3: All issues pertained to loss of data. Although uninterrupted communication was achieved, the loss of data in some components may result in interrupted communication in operational use. Improve reliability of transportation and receipt of data.

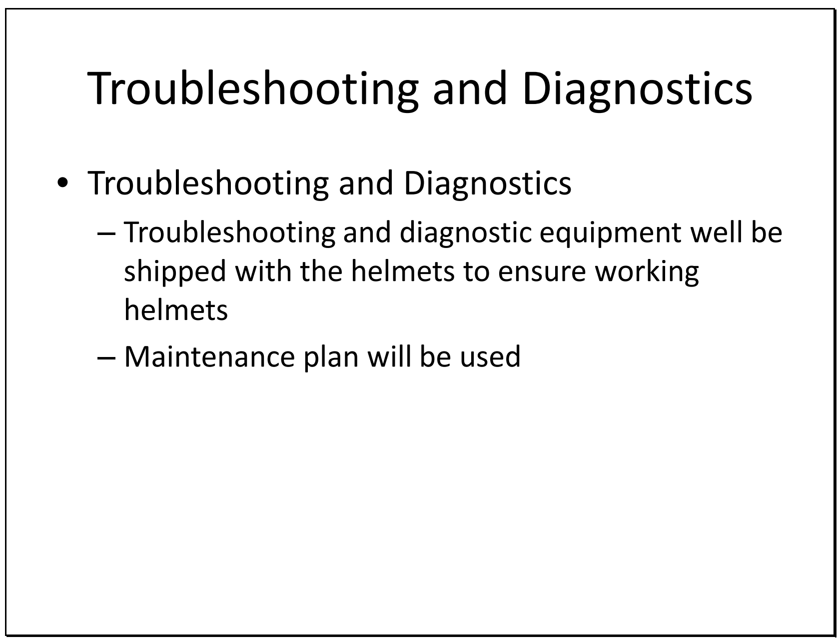
Other recommendations: Address Integrated Logistics Support.

9. Conclusion

ACIH DT&E was successful in meeting its test objectives demonstrating hardware, software, and interoperability maturity. We recommend that the ACIH proceed to OTRR.

6. ACIH NOTIOAL INTEGRATED LOGISTICS SUPPORT PLAN





Supply

- Lowest Replaceable Unit
  - Camera
  - Microphone
  - Speakers
  - Display
  - Transmitter/Receiver
  - User Interface
- Spare Helmets located at HQ
- Faulty helmets will be sent to Picitanny

APPENDIX E: MODEL DETAIL

main.m

```
%% Initialize variables
tic

nSys = 1000; % number of systems run
CTI_min = 5; % minimum number of Critical Technology Interfaces
(CTIs) a system can have
CTI_max = 20; % maximum number of CTIs a system can have

t = 1; % normalized program time

% define the I/ORL requirement for each review
MS_pass = {};
MS_pass.ASR = 1;
MS_pass.SRR = 2;
MS_pass.SFR = 3;
MS_pass.PDR = 3;
MS_pass.CDR = 5;
MS_pass.IRR = 6;
MS_pass.FRR = 7;
MS_pass.OTRR = 7;
MS_pass.OT = 7;

rework_time = {}; % amount of additional time it takes to fix a
I/ORL problem
rework_time.ASR = .1; % note this data was not validated, so it
is not used in the output
rework_time.SRR = .1; % if actual data is found, these values can
be adjusted
rework_time.SFR = .1;
rework_time.PDR = .1;
rework_time.CDR = .1;
rework_time.IRR = .1;
rework_time.FRR = .1;
rework_time.OTRR = .1;
rework_time.OT = .1;

a = 2.25; % scaling factor to match the relative costs to actual
SE data
rework_cost = {}; % amount of additional cost it takes to fix a
I/ORL problem
rework_cost.ASR = a*.001;
rework_cost.SRR = a*.002;
rework_cost.SFR = a*.005;
rework_cost.PDR = a*.0075;
rework_cost.CDR = a*.010;
```

```
    rework_cost.IRR = a*.015;
    rework_cost.FRR = a*.025;
    rework_cost.OTRR = a*.125;
    rework_cost.OT = a*.25;

    init = ones(1,nSys); % define an initial array of ones with one
element for each of the number of systems

    old = struct('pass',init,'sched',init,'cost',init,...
        'IORL_avg',init,'IORL_min',init); % data structure for
holding run info for the old SE process

    new = old; % data structure for holding run data for the new SE
process


    %% Run simulation

    for i=1:nSys
        %% initialize system

        t = 1; % reinitialize schedule variable
        new.cost(i) = 0; % initialize cost variable
        old.cost(i) = 0;

        nCTI = round(rand*(CTI_max-CTI_min)+CTI_min); % define number
of CTIs for system

        IORL_act_new = zeros(1,nCTI); % establish initial I/ORLs for
new SE process
        IORL_meas_new = zeros(1,nCTI); % establish array for
perceived I/ORL values

        IORL_act_old = IORL_act_new; % establish initial IORLs for
old SE process

        %% ASR
        'ASR';
        delta = work_IORL(IORL_act_new,'ASR')-IORL_act_new; %
calculate actual I/ORL improvement over the phase.  this ensures that
the improvement is only due to the rework and not random variation.

        IORL_act_old = delta + IORL_act_old; % add I/ORL improvement
to old
        IORL_act_new = delta + IORL_act_new; % add the same
improvement to new

        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new); %
measure the I/ORL levels
```

```
            t = t + rework_time.ASR*sum(IORL_meas_new<MS_pass.ASR);  % if
the system doesn't meet the I/ORL threshold, add schedule based on the
current review and number of failured interfaces
                                                                   %
this code may need to be adjusted based on the SE process data
discovered
            new.cost(i) = new.cost(i) +
rework_cost.ASR*sum(IORL_meas_new<MS_pass.ASR); % if the system misses
the threshold, also add cost based on the current review and number of
failed interfaces

            IORL_act_new(IORL_meas_new<MS_pass.ASR) =
rework_IORL(IORL_act_new(IORL_meas_new<MS_pass.ASR),'ASR',MS_pass); %
rework the I/ORL value until it passes
            IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new); %
convert actual interoperability values to measured I/ORL values

            %% SRR
            'SRR';
            % rinse and repeat for the SRR, etc.
            delta = work_IORL(IORL_act_new,'SRR')-IORL_act_new;
            IORL_act_old = delta + IORL_act_old;
            IORL_act_new = delta + IORL_act_new;
            IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

            t = t + rework_time.SRR*sum(IORL_meas_new<MS_pass.SRR);
            new.cost(i) = new.cost(i) +
rework_cost.SRR*sum(IORL_meas_new<MS_pass.SRR);

            IORL_act_new(IORL_meas_new<MS_pass.SRR) =
rework_IORL(IORL_act_new(IORL_meas_new<MS_pass.SRR),'SRR',MS_pass);
            IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

            %% SFR
            'SFR';
            delta = work_IORL(IORL_act_new,'SFR')-IORL_act_new;
            IORL_act_old = delta + IORL_act_old;
            IORL_act_new = delta + IORL_act_new;
            IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

            t = t + rework_time.SFR*sum(IORL_meas_new<MS_pass.SFR);
            new.cost(i) = new.cost(i) +
rework_cost.SFR*sum(IORL_meas_new<MS_pass.SFR);

            IORL_act_new(IORL_meas_new<MS_pass.SFR) =
rework_IORL(IORL_act_new(IORL_meas_new<MS_pass.SFR),'SFR',MS_pass);
            IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

            %% PDR
            'PDR';
            delta = work_IORL(IORL_act_new,'PDR')-IORL_act_new;
```

```
        IORL_act_old = delta + IORL_act_old;
        IORL_act_new = delta + IORL_act_new;

        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

        t = t + rework_time.PDR*sum(IORL_meas_new<MS_pass.PDR);
        new.cost(i) = new.cost(i) +
rework_cost.PDR*sum(IORL_meas_new<MS_pass.PDR);

        IORL_act_new(IORL_meas_new<MS_pass.PDR) =
rework_IORL(IORL_act_new(IORL_meas_new<MS_pass.PDR),'PDR',MS_pass);
        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

        %% CDR
        'CDR';
        delta = work_IORL(IORL_act_new,'CDR')-IORL_act_new;
        IORL_act_old = delta + IORL_act_old;
        IORL_act_new = delta + IORL_act_new;
        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

        t = t + rework_time.CDR*sum(IORL_meas_new<MS_pass.CDR);
        new.cost(i) = new.cost(i) +
rework_cost.CDR*sum(IORL_meas_new<MS_pass.CDR);

        IORL_act_new(IORL_meas_new<MS_pass.CDR) =
rework_IORL(IORL_act_new(IORL_meas_new<MS_pass.CDR),'CDR',MS_pass);
        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

        %% IRR
        'IRR';
        delta = work_IORL(IORL_act_new,'IRR')-IORL_act_new;
        IORL_act_old = delta + IORL_act_old;
        IORL_act_new = delta + IORL_act_new;

        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

        t = t + rework_time.IRR*sum(IORL_meas_new<MS_pass.IRR);
        new.cost(i) = new.cost(i) +
rework_cost.IRR*sum(IORL_meas_new<MS_pass.IRR);

        IORL_act_new(IORL_meas_new<MS_pass.IRR) =
rework_IORL(IORL_act_new(IORL_meas_new<MS_pass.IRR),'IRR',MS_pass);
        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

        %% FRR
        'FRR';
        delta = work_IORL(IORL_act_new,'FRR')-IORL_act_new;
        IORL_act_old = delta + IORL_act_old;
        IORL_act_new = delta + IORL_act_new;
        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);
```

```
        t = t + rework_time.FRR*sum(IORL_meas_new<MS_pass.FRR);
        new.cost(i) = new.cost(i) +
rework_cost.FRR*sum(IORL_meas_new<MS_pass.FRR);

        IORL_act_new(IORL_meas_new<MS_pass.FRR) =
rework_IORL(IORL_act_new(IORL_meas_new<MS_pass.FRR),'FRR',MS_pass);
        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

        %% OTRR
        'OTRR';
        delta = work_IORL(IORL_act_new,'OTRR')-IORL_act_new;
        IORL_act_old = delta + IORL_act_old;
        IORL_act_new = delta + IORL_act_new;
        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);

        t = t + rework_time.OTRR*sum(IORL_meas_new<MS_pass.OTRR);
        new.cost(i) = new.cost(i) +
rework_cost.OTRR*sum(IORL_meas_new<MS_pass.OTRR);

        IORL_act_new(IORL_meas_new<MS_pass.OTRR) =
rework_IORL(IORL_act_new(IORL_meas_new<MS_pass.OTRR),'OTRR',MS_pass);
        IORL_meas_new = measure_IORL(IORL_act_new,IORL_meas_new);


        %% Operational Test

        % compare the I/ORL values to the OT threshold and tally
        % the number of failures
        new.pass(i) = sum(IORL_act_new<MS_pass.OT);
        % for each failure, apply the OT rework costs for each
        % failed interface
        new.cost(i) = new.cost(i) +
rework_cost.OT*sum(IORL_act_new<MS_pass.OT);
        % repeat for the current SE process
        old.pass(i) = sum(IORL_act_old<MS_pass.OT);
        old.cost(i) = old.cost(i) +
rework_cost.OT*sum(IORL_act_old<MS_pass.OT);;

        %% Data Logging

        % store average I/ORL values
        new.IORL_avg(i) = mean(IORL_act_new);
        old.IORL_avg(i) = mean(IORL_act_old);
        % store minimum I/ORL values
        new.IORL_min(i) = min(IORL_act_new);
        old.IORL_min(i) = min(IORL_act_old);
        % store schedule slippage
        new.sched(i) = t;
        old.sched(i) = 1;
    end
```

```
    % calculate the percentage of passing systems
    perc_old = sum(old.pass==0)/nSys;
    perc_new = sum(new.pass==0)/nSys;

    % print data to matlab command window
    {['(', int2str(nSys), ' Samples)'],'Old','New';'Min
I/ORL',mean(old.IORL_min),mean(new.IORL_min);'% OT
Pass',perc_old,perc_new;'Cost Overrun',mean(old.cost),mean(new.cost)}

    % create the histogram
    figure(1);clf
    subplot(2,1,1)
    hist([old.IORL_min],[0:.5:9.5]+.25)
    hold on
    plot([MS_pass.OT,MS_pass.OT], [0 1*nSys], 'r-.')
    axis([0 10 0 1*nSys])
    title('Comparison of I/ORL process to Current SE Process')
    xlabel('Minimum System I/ORL Value - Current')
    subplot(2,1,2)
    hist([new.IORL_min],[0:.5:9.5]+.25)
    hold on
    plot([MS_pass.OT,MS_pass.OT], [0 1*nSys], 'r-.')
    axis([0 10 0 1*nSys])
    xlabel('Minimum System I/ORL Value - New')

    toc
```

work_IORL.m

```
function CTI_out = work_IRL(CTI_in,MS)

 % define mean and standard deviation of I/ORL work
mean = 1.115;
std = .215;

% determine the review that the system is being evaluated
% and apply the appropriate amount of I/ORL work
switch MS;
    case{'ASR'}
        CTI_out = CTI_in+max(0,mean+randn(size(CTI_in))*std);
    case{'SRR'}
        CTI_out = CTI_in+max(0,mean+randn(size(CTI_in))*std);
    case{'SFR'}
        CTI_out = CTI_in+max(0,mean+randn(size(CTI_in))*std);
    case{'PDR'}
        CTI_out = CTI_in+max(0,mean+randn(size(CTI_in))*std);
   case{'CDR'}
        CTI_out = CTI_in+max(0,mean+randn(size(CTI_in))*std);
    case{'IRR'}
        CTI_out = CTI_in+max(0,mean+randn(size(CTI_in))*std);
    case{'FRR'}
        CTI_out = CTI_in+max(0,0+randn(size(CTI_in))*std);
    case{'OTRR'}
        CTI_out = CTI_in+max(0,mean+randn(size(CTI_in))*std);

    otherwise
        debug = 'broken'
        CTI_out = CTI_in;
end

CTI_out = min(9,CTI_out);
```

rework_IORL.m

```
function CTI_out = rework_IRL(CTI_in,MS,MS_pass)

 % rework the system until it matches the requirement for the
review
 % if the interface is close to the requirement, increase it by a
small amount (.1 units)

switch MS;
    case{'ASR'}
        CTI_out = max(CTI_in+.1,MS_pass.ASR);
    case{'SRR'}
        CTI_out = max(CTI_in+.1,MS_pass.SRR);
    case{'SFR'}
        CTI_out = max(CTI_in+.1,MS_pass.SFR);
    case{'PDR'}
        CTI_out = max(CTI_in+.1,MS_pass.PDR);
   case{'CDR'}
        CTI_out = max(CTI_in+.1,MS_pass.CDR);
    case{'IRR'}
        CTI_out = max(CTI_in+.1,MS_pass.IRR);
    case{'FRR'}
        CTI_out = max(CTI_in+.1,MS_pass.FRR);
    case{'OTRR'}
        CTI_out = max(CTI_in+.1,MS_pass.OTRR);
    case{'SVR'}
        CTI_out = max(CTI_in+.1,MS_pass.SVR);
    otherwise
        debug = 'broken'
        CTI_out = CTI_in;
end

CTI_out = min(9,CTI_out);
```

measure_IORL.m

```
function CTI_out = measure_IRL(CTI_in,last)

% define probabilities
p_c = .8; % probability of getting the value correct
p_fp = .15; % probability of a false positive
p_fn = .05; % probability of a false negative

p = rand(size(CTI_in)); % create an array of random numbers

% create array to modify the I/ORL values
delta = zeros(size(p));
delta(p<=p_c) = 0; % if correct, leave alone
delta((p>p_c) & (p<=(p_c+p_fp))) = 1; % if false positive, add
one
delta((p>(p_c+p_fp)) & (p<=(p_c+p_fp+p_fn))) = -1; % if false
negative, subtract one

CTI_out = min(9,floor(max(last,CTI_in+delta))); % modify I/ORL
values and output the results
```

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