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SYSTEMS ENGINEERING CAPSTONE REPORT

ASSESSMENT FRAMEWORK FOR OPERATIONAL EFFECTIVENESS IN MULTI-DOMAIN OPERATIONS (MDO)

by

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September 2021

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The Research and Analysis Center–Monterey lacked a methodical process to assess if the innovative systems of systems technologies demonstrated at Project Convergence (PC) met the operational effectiveness required to provide the Joint Force with the necessary speed, range, and convergence to yield future decision dominance and overmatch for great power competition. To combat this, a conceptual assessment framework was developed using a proven systems engineering (SE) process. Throughout this SE process a stakeholder analysis, objectives hierarchy, functional analysis, and relevant and collectible measures of effectiveness were developed. Value modeling was accomplished using a modified Langford method to rank measures on a constructed scale and the Parnell method of swing weighting was leveraged to afford stakeholders the ability to place a level of importance on each measure. This produced an aggregate weighted value score that indicated the level of operational effectiveness. With this framework and ability to produce an operational effectiveness score, the stakeholders can make more informed decisions related to future PC activities and technology development. It is recommended that the stakeholders utilize the assessment framework on additional use cases to test flexibility and usability, as well as conduct further studies that investigate the influence that human-system interfaces and procedures/doctrine have on operational effectiveness.

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ABSTRACT

The Research and Analysis Center–Monterey lacked a methodical process to assess if the innovative systems of systems technologies demonstrated at Project Convergence (PC) met the operational effectiveness required to provide the Joint Force with the necessary speed, range, and convergence to yield future decision dominance and overmatch for great power competition. To combat this, a conceptual assessment framework was developed using a proven systems engineering (SE) process. Throughout this SE process a stakeholder analysis, objectives hierarchy, functional analysis, and relevant and collectible measures of effectiveness were developed. Value modeling was accomplished using a modified Langford method to rank measures on a constructed scale and the Parnell method of swing weighting was leveraged to afford stakeholders the ability to place a level of importance on each measure. This produced an aggregate weighted value score that indicated the level of operational effectiveness. With this framework and ability to produce an operational effectiveness score, the stakeholders can make more informed decisions related to future PC activities and technology development. It is recommended that the stakeholders utilize the assessment framework on additional use cases to test flexibility and usability, as well as conduct further studies that investigate the influence that human-system interfaces and procedures/doctrine have on operational effectiveness.

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LIST OF ACRONYMS AND ABBREVIATIONS

AASLT	Air Assault
AFC	Army Futures Command
AI	Artificial Intelligence
APC	Armored Personnel Carrier
ATEC	Army Test and Evaluation Command
ATGM	Air-to-Ground Missile
C2	Command and Control
CFT	Cross Functional Team
CIP	Common Intelligence Picture
COP	Common Operating Picture
CROP	Common Relevant Operational Picture
DAC	Data Analysis Center
ERCA	Extended Range Cannon Artillery
EW	Electronic Warfare
FLOT	Forward Line of Own Troops
FU	Firing Unit
HSI	Human-System Interface
HTK	Hit to Kill
IADS	Integrated Air Defense System
IFV	Infantry Fighting Vehicle
ISR	Intelligence, Surveillance, and Reconnaissance
IVAS	Integrated Visual Augmentation System
JMC	Joint Modernization Command
LIB	Less is Better
LOE	Line of Effort
LP/OP	Listening Posts/Observation Posts
MARFORRES	Marine Forces Reserve
MC	Mission Command

MDO	Multi-Domain Operations
MDTF	Multi-Domain Task Force
MIB	More is Better
MOE	Measure of Effectiveness
MRL	Multiple Rocket Launcher
MS	Microsoft
NPS	Naval Postgraduate School
OE	Operational Environment
OP	Operation
PC	Project Convergence
PNT	Positioning, Navigation, and Timing
POO	Point of Origin
S2S	Sensor-to-Shooter
SATCOM	Satellite Communications
SE	Systems Engineering
SMAT	Supply and Maintenance Team
SoS	System of Systems
SPARTY	Self-Propelled Artillery
ST	Strategic
TAC	Tactical Command Post
TRAC	The Research and Analysis Center
U.S.	The United States
WVS	Weighted Value Score

EXECUTIVE SUMMARY

Project Convergence (PC) is an Army learning campaign that is designed to integrate and advance their contribution to the Joint Force (Army, Navy, Air Force, and Marines). According to The Research and Analysis Center (TRAC)–Monterey, “PC ensures that the Army, as part of the joint fight, can rapidly and continuously integrate or ‘converge’ effects across all domains—air, land, sea, space, and cyberspace—to overmatch our adversaries in competition and conflict” (The Research and Analysis Center [TRAC] 2020). The goal is to assess if the new innovative systems of systems (SoS) technologies being demonstrated at PC21 meet the operational capabilities required to provide the Joint Force with the necessary speed, range, and convergence, to yield future decision dominance and overmatch for great-power competition. However, TRAC-Monterey currently lacks a methodical process to measure the operational effectiveness and whether convergence as an Army and as a Joint Force is being achieved, given the infusion of various modern technologies during PC. Therefore, the focus of this project is to develop a conceptual assessment framework that will determine the operational effectiveness of SoS in multi-domain operations (MDO) missions being tested at the PC21 exercise. This framework will concentrate on the operational effectiveness of those technologies demonstrated to reduce the sensor-to-shooter (S2S) timeline to neutralize a stationary target in joint MDO missions.

The team determined that a functional decomposition of a given capability, in conjunction with a modified version of Langford’s Integrated Framework, which is used to develop MOEs, would result in good measures that describe the operational effectiveness of that given capability. To transform the measures into value scores, the team used an ideal range method of constructed value scales which establishes a best to worst case for each measure, giving it the flexibility to be adapted to any capability. The Parnell method of swing weighting was leveraged to quantify the importance the stakeholder gave to each Langford derived MOE to determine a weighted value score (WVS) for each MOE of the capability. The WVS were summed to derive an aggregate value score, which provided the final assessment of operational effectiveness. The team

then generated an operational effectiveness scale to illustrate to the stakeholders where, within this scale, their capability scores.

The project concludes by applying a PC21 use case against the conceptual assessment framework to gauge its robustness in generating MOEs that are the most relevant for the capability in the use case as well as a single operational effectiveness score. Final validation of the model will be conducted during PC21 currently scheduled to start in October 2021.

In conclusion, the team used a systems engineering process to build a conceptual assessment framework system that will enable TRAC-Monterey the ability to evaluate the operational capabilities of the new innovative SoS technologies demonstrated during PC21. The team developed a stakeholder analysis, a stakeholder-derived objectives hierarchy, a functional decomposition, and a process that creates good measures, transforms those measures into value scores, quantifies the importance of the measures, and aggregates the resulting values into a single operational effectiveness score. The framework will provide information to stakeholders that allows them to make informed decisions on further technology development. TRAC-Monterey can also use the metrics developed in this study as a guide to collect relevant information throughout PC21 and in future PC activities.

It is recommended that TRAC validate the conceptual assessment framework against the S2S use case 1–1 during PC21. Additional use cases should also be applied to test the framework's flexibility and usability. Further research is also recommended for the cognitive aspects of operational effectiveness and how that information may be utilized to expand the scope of this assessment framework. TRAC and JMC indicated to the team the efforts of PC are going to help rewrite doctrine in how Joint Operations are conducted.

References:

The Research and Analysis Center. 2020. *Project Convergence 2020 (Evolution I) Integrated Analysis Report*. Unpublished analysis report, TRAC.

I. INTRODUCTION

A. BACKGROUND

Project Convergence (PC) is an Army learning campaign that is designed to integrate and advance their contribution to the Joint Force (Army, Navy, Air Force, and Marines). Through this, "it ensures that the Army, as part of the joint fight, can rapidly and continuously integrate or 'converge' effects across all domains—air, land, sea, space, and cyberspace—to overmatch our adversaries in competition and conflict" (The Research and Analysis Center [TRAC] 2020). The PC exercise events are intended to demonstrate innovative technologies that, over time, generate transformational change with how the Army fights by shaping how the Army is organized for combat in support of multi-domain operations (MDO) (Naval Postgraduate School [NPS] 2021).

PC20, or Evolution I, was the Army's effort to bring MDOs from a concept to reality. It featured a series of integration and field experimentation activities that occurred from 10 August 2020 - 23 September 2020 (TRAC 2020). PC20 highlighted some of the most promising emerging technologies from five of the Army Futures Command (AFC) Cross Functional Teams (CFT), centering on the integration of artificial intelligence (AI), cloud technologies, and autonomous systems at the tactical level (NPS 2021).

Building on the success of PC20, AFC has now made PC a recurring annual event. PC21, scheduled for October 2021, will incorporate the lessons learned from PC20 and expand beyond a platoon-size Army element to a Brigade or Division size element to include sister service assets. PC21 will continue to increase the breadth and depth of analysis by adding more modernization priority capabilities and operational units to evaluate joint interoperability (NPS 2021). PC21 is pursuing the following lines of effort (LOE):

- LOE 1: Technology Assessment (The United States [U.S.] Army Test and Evaluation Command [ATEC])—Assesses capability performance.
- LOE 2: Operational Effectiveness Assessment (U.S. Army Joint Modernization Command [JMC])—Assess capability level effects.

- LOE 3: Network Assessment (Data and Analysis Center [DAC])—Assess joint integrated networks.
- LOE 4: Joint Interoperability (TRAC)—Assess the status of joint mission command integration. (TRAC 2020)

> MDO describes how the U.S. Army, as part of the Joint Force, can counter and defeat a near-peer adversary capable of contesting the U.S. in all domains (air, land, maritime, space, and cyberspace) in both competition and armed conflict. The concept describes how U.S. ground forces, as part of the joint and multinational team, deter adversaries and defeat highly capable near-peer enemies in the 2025–2050 timeframe. PC21 is intended to inform and test MDO concepts, technologies, force structures, and procedures, not just within the Army, but as they also relate to the other Services, as well as Allies and Partner Nations. (Congressional Research Service 2020)

To accomplish this, PC21 will conduct the following scenarios (Data Analysis Center [DAC] 2020):

1. Joint Mission Thread: "Operations (OP) 3.1 Conduct Joint Targeting - Use Case 1–1A&B: Multi-Domain Task Force (MDTF) and Special Operation Forces Identification Targets and Develop a Common Intelligence Picture (CIP) / Common Operating Picture (COP)/ Joint All Domain Situational Awareness" Operational Environment (OE): An adversary deploys strategic air and missile defense systems onto an island in the first Island Chain. Integrated air and missile defense, long range fires, and adversary capabilities in the information environment deny U.S. Forces freedom of maneuver across multiple domains. U.S. forces in the contact layer are tasked to build and maintain a CIP.
2. Joint Mission Thread: "Strategic (ST) 6.1.5 Conduct Joint Missile Defense - Use Case 2–1B: Joint sensors identify cruise missile, assign appropriate Joint Fires element to interdict" OE: The adversary prepares a RK-55 Transport Erector Launcher vehicle. After missile launch, a F35 senses and identifies the incoming missile and disseminates information into joint network. Patriot Fire Unit acquires and intercepts missile and passes point of origin (POO) back to

F35 and Extended Range Cannon Artillery (ERCA) firing unit (FU) to conduct joint counter-fire mission.

3. Joint Mission Thread: "ST 3.1.2 Assign Joint Theater Fires to Targets - Use Case 2–2A: Conduct Joint Fires" OE: As Enemy intelligence, surveillance, and reconnaissance (ISR) identifies U.S. formations, they begin to target with long range fires (PHL-03 multiple rocket launcher (MRL) systems) and quickly reposition to avoid counterfire. U.S. Joint sensors (TPS-80) tracks incoming salvos and identifies POO. Relevant data is transferred along Joint Network to ERCA battery, who engage using hit-to-kill (HTK) systems.

4. Joint Mission Thread: "OP 4.4.1.1 Conduct Joint Sustainment Operations - Use Case 3–1A: Semi-Autonomous Resupply" OE: As the threat anti-access area denial capabilities are dis-integrated, the ERCA Battery will require a Class III and Class V resupply to maintain operations.

5. Mission Thread: "OP 3.1 Conduct Joint Targeting - Use Case 4–1A: AI / Autonomous Reconnaissance" OE: U.S. Forces are opposed by two Mechanized Companies positioned abreast and one Company in the rear to support and serve as a strike force. Company battle positions are reinforced by fires positioned near the forward line of own troops (FLOT) to maximize range and standoff. Battle positions will be supported by tactical electronic warfare (EW) jammers to provide positioning, navigation, and timing (PNT) disruption and Strategic Support Forces provide intermittent satellite communications (SATCOM) jamming to disrupt U.S. freedom of maneuver.

6. Joint Mission Thread: "OP 1.2 Conduct Operational Maneuver - Use Case 4–2A: Integrated Visual Augmentation System (IVAS) enabled Soldiers execute an air assault (AASLT) to seize key terrain" OE: As the ground maneuver develops, the enemy establishes an Integrated Air Defense System (IADS) command and control (C2) tactical command post (TAC) element in an urban village to avoid detection and targeting. The TAC security consists of a squad

of light infantry positioned throughout the village and one HQ-7 provides point air defense protection.

7. Joint Mission Thread: "OP 1.2 Conduct Operational Maneuver - Use Case 4–3A: Mounted AI Enabled Attack" OE: The enemy continues its mobile defense in depth. Friendly elements forced a mechanized infantry company to retrograde back to secondary battle positions. 4 x Type 90 Main Battle Tanks, 4 x ZBD-05 infantry fighting vehicle (IFV), and 2 x Type 08 Armored Personnel Carrier (APC), supported by dismounted soldiers with air-to-ground missile (ATGM) systems occupy multiple listening posts/observation posts (LP/OP). As U.S. units are identified and approach battle positions, the threat utilizes local point jammers to disrupt U.S. Forces C2 and simultaneously begins to mass fires employing PHL-03 MRL and PLZ-05 Self-Propelled Artillery (SPARTY) systems (DAC 2020).

B. PROBLEM STATEMENT

Currently, TRAC-Monterey lacks a methodical process to assess if the new innovative systems of systems (SoS) technologies being demonstrated at PC21 meet the operational capabilities required to provide the Joint Force with the necessary speed, range, and convergence, to yield future decision dominance and overmatch for great-power competition. The intent is to test MDO concepts, force structures, technologies, and procedures in simulated use cases; however, as seen in PC20, it currently does not have the structure to synthesize the data being collected and provide decision makers the knowledge they require to make informed decisions if further investment into the modern technologies is advantageous and warranted.

C. STAKEHOLDER NEEDS

To measure operational effectiveness and whether convergence as an Army and as a Joint Force is being achieved, given the infusion of various modern technologies, TRAC-Monterey has employed the assistance of NPS to develop a conceptual assessment framework that will determine the operational effectiveness of SoS in MDO missions being tested at PC21. To respond to the identified need, the framework will need to entail optimal measures of effectiveness (MOE) that will enable TRAC-Monterey to assess if convergence was successfully achieved during the demonstrations at PC21.

D. RESEARCH OBJECTIVE

Team RM4 Convergence will deliver TRAC-Monterey a conceptual assessment framework that will enable evaluation of the operational capabilities of the new innovative SoS technologies demonstrated during PC21. This framework will concentrate on the operational effectiveness of those technologies demonstrated to reduce the sensor-to-shooter (S2S) timeline to neutralize a stationary target in joint MDO missions. To accomplish this, the research objectives for this project are as follows:

- Develop a stakeholder-derived objectives hierarchy that will deconstruct and baseline the objectives to be accomplished.
- Create a functional hierarchy that decomposes the necessary functions the conceptual assessment framework must perform.
- Develop a conceptual assessment framework to create good measures, transform those measures into value scores, quantify the importance of the measures and aggregate the resulting values into a single operational effectiveness score.
- Apply a use case to the conceptual design to gauge the robustness of the conceptual assessment framework's ability to produce good relevant measures that aggregate into a single operational effectiveness score.
- Create and receive stakeholder concurrence on the conceptual assessment framework implementation plan for TRAC's use during PC21 in October 2021.

E. PROJECT LIMITATIONS AND ASSUMPTIONS

The conceptual assessment framework will be directed toward LOE 2, Operational Effectiveness Assessment, which includes aspects of all the other LOEs based on documentation and further clarification provided by TRAC-Monterey. Definitions provided in LOE 2 will be utilized to develop the models. LOE 2 defines operational effectiveness as the ability to achieve both mission completion and mission success, which were defined by TRAC-Monterey during stakeholder discussions on 21 May 2021. Per TRAC-Monterey, mission completion for the desired capability is determined by the ability of joint SoS to engage a hostile target with speed, accuracy, and interoperability through accurate communications and system functions. Mission success is determined by the destruction or incapacitation of a hostile target while experiencing minimal loss to friendly personnel and equipment, making it possible to quickly re-engage. Validation of the framework will be limited to a single PC21 scenario, Conduct Joint Targeting–Use Case 1–1, focusing on reduction of the S2S timeline.

F. PROJECT BENEFIT

The stakeholders can expect a conceptual assessment framework that can determine the operational effectiveness of the SoS technologies involved in PC21. The framework will elevate decision makers' ability in identifying the degree that the convergence of innovative SoS technologies can reduce S2S time, and thereby inform the performance requirements for the constituent's systems. It will also provide decision makers with the knowledge required to make informed decisions if further investment into the modern technologies is advantageous and warranted.

G. CAPSTONE OVERVIEW

This paper describes an effort conducted at the NPS to apply a SE approach to develop a conceptual assessment framework for the operational effectiveness (LOE 2) of those technologies demonstrated at PC21 to reduce the S2S timeline to neutralize a stationary target in joint MDO missions. This report provides the research conducted by the team, detailed in Chapter II; the methodology used to accomplish this task, detailed in Chapter III; the results of our analysis, detailed in Chapter IV; and the conclusion and recommendations, detailed in Chapter V.

II. LITERATURE REVIEW

This chapter examines the major areas the authors investigated through a literature review. This chapter begins with an overview of PC, then discusses thesis efforts that are relevant to assessing system interoperability and the development of MOEs and value models. This chapter concludes with a review of the key concepts of the SE process that will enable the successful design and development of an assessment system for PC21.

A. RELATED EFFORTS

To gain a better understanding of convergence as it relates to the common relevant operational picture (CROP) for the scenarios conducted during PC21, Johnson's thesis entitled "Common Relevant Operational Picture: An Analysis of Effects on The Prosecution of Time-Critical Target" was reviewed and determined to be relevant to this project due to a concept born out of the Joint Vision 2010, which "called for leveraging technological opportunities to achieve new and higher levels of effectiveness in a joint operating environment" (Johnson 2002). The U.S. Joint Forces Command, the stakeholder for Johnson's thesis, considers COP a significant indicator that the joint systems are achieving convergence.

Xian and Yee provided a good guide of how they developed their stakeholder-derived objectives hierarchy, measurable system attributes, and a framework to evaluate value for the Marine Forces Reserve (MARFORRES) G-4 by "developing relevant measurable system attributes and corresponding value models to better articulate the contributions of the Supply and Maintenance Team (SMAT) inspection program to the MARFORRES mission" (Xian and Yee 2019).

The team leveraged Goh's thesis exploring the development of MOEs for network-centric environments since PC21 has many C2 elements in its missions. The thesis discusses the need for interoperability between C2 systems and the systems of other services in ad-hoc situations. PC21 is demonstrating the same interoperability, but instead of ad-hoc, the services are jointly entering the mission with AI enhancement. Another common aspect is the fusion of the different service's intelligences into a common situational picture, in other words, convergence. Also, in this literature, Goh references the characteristics of good MOEs by Roger Stevens, which the team adopted and will be discussed in Section B.4 of this chapter. Langford's integrative framework, depicted in Figure 1, utilizes a subjective-objective intersection that captures certain relationships between users and objects, as well as procedures and objects, to create areas of interest for MOE development. Table 1 provides further insight into these subjective-objective relationships by providing descriptions of the pairs of MOEs that should be developed within each intersection. This approach was used in Goh's project to determine MOEs for the effectiveness of C2 systems in the battlefield (Goh 2015).

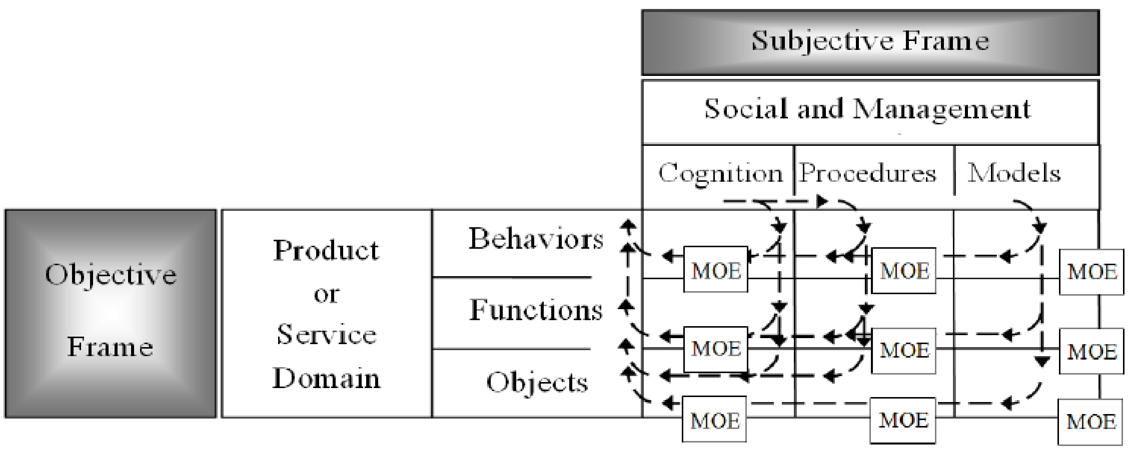

Figure 1. Integrative Framework. Source: Goh (2015).

Table 1. MOE Framework Intersection Descriptions. Source: Goh (2015).

Objects		Processes: Cognition	Processes: Procedures	Processes: Models & Representations
Objects	User Behaviors	Conceptualization of stakeholder behaviors **(MOE-a)** when the product*service is used; and when it not used (or available) **(MOE-p)**	Influence of procedures on processes and mechanisms describing user behaviors due to product*service **(MOE-i)**; Influence describing user behaviors due to lack of product*service **(MOE-f)**	Comparison of expectations of models or representations of stakeholder behaviors to actions **(MOE-t)**; Evaluation of behaviors to predicted actions **(MOE-v)**
Objects	Functions	Prognostication of consequences of interactions between objects through exchange of EMMI **(MOE-g)**; & Expectations of interactions **(MOE-c)**	Availability and Validity of processes and mechanisms that determine resource utilizations for functions **(MOE-u)**; Processes and mechanisms that define the boundary conditions for anticipated operations of all functions **(MOE-b)**	Models/representations showing all functional performances **(MOE-n)**; Models/representations showing all functional performance's quality **(MOE-q)**
Objects	Physical Entities - Object	Experience with posited objects **(MOE-e)** & anticipated responses of posited objects **(MOE-r)**	Availability and Validity of processes and mechanisms resulting in the selection and development of all physical elements **(MOE-s)**; Processes and mechanisms resulting in the development of all physical elements and operational contexts **(MOE-x)**	Models or representations of all physical elements, (structures, properties, traits, and attributes **(MOE-o)**; Models or representations of all social, political, economic elements **(MOE-j)**

Additional research was completed on Langford's integrated framework to confirm it was a good fit for this project. According to Langford, "A framework that is all inclusive of the subjective direction to accomplish a task is needed in conjunction with the objective results of those accomplishments" (Langford 2012). JMC has indicated to the team that cognitive factors play a crucial role in the effectiveness of systems and are not considered as much as they should be during operational testing.

B. SE CONCEPTS

1. Problem Definition and Problem Domain

In the fifth edition of the textbook *Systems Engineering and Analysis*, authors Blanchard and Fabrycky recognize that the systems engineering process begins with a want or desire from a stakeholder, generally derived from a problem or deficiency of existing capabilities (Blanchard and Fabrycky 2011). In Professor Brigitte Kwinn's NPS SE3100 course, she emphasized the importance of going beyond the notion of just defining the problem and exploring the problem domain to determine what type of problem needs solving. A needs analysis conducted early in the SE process will afford exploration of the problem domain. Kwinn also details that in exploring the domain, one should seek to identify the root cause of the problem instead of addressing the symptoms (Kwinn 2019).

2. Stakeholder Analysis

In Dennis Buede's book *The Engineering Design of Systems: Models and Methods* he states there are many tools that can be used to conduct a needs analysis and one of which is a stakeholder analysis. "The primary purpose of the stakeholder analysis is to identify the people who are relevant to the problem and to determine their needs, wants and desires with respect to it" (Buede 2009). In identifying these relevant people, it is important to correctly identify their involvement and type, such as if they are active or passive. In Gary Langford's book *Engineering Systems Integration: Theory, Metrics, and Methods,* he expands upon the different types of stakeholders and categorizes them as internal or boundary. The boundary-type stakeholders interact with external entities across the system boundary and can be either first or second order. First order boundary stakeholders have direct contact with the system but not the internal stakeholders, whereas second order boundary stakeholders have indirect contact with the system through their interaction with a first order stakeholder (Langford 2012). Then, the stakeholder's needs, wants, and desires will translate into functional requirements and/or objectives for the system (Buede 2009). To assist with this, stakeholders describe the problem or their needs in terms of where they are now and where they want to be. By conducting a thorough stakeholder analysis, the team can ensure the client buys into the design process and the ultimate solution. From the stakeholder discussions, a hierarchy diagram is developed which describes and decomposes the stakeholder objectives in visual form, also known as an objectives hierarchy.

3. Functional Analysis

The functional analysis looks at "what" the system must do but not "how" the system will do it. The first step of the functional analysis is functional decomposition. As

Buede highlights, the primary purpose of functional decomposition is to identify and decompose the critical functions of the system. The result of a functional decomposition is a list of functions and sub-functions required of the proposed system (Buede 2009). Blanchard and Fabrycky states that functions are specific or discrete actions that are necessary for a specific objective of a system to be obtained. Top-level functions are defined and then decomposed into sub-level functions as many times as necessary to identify input criteria and constraints (Blanchard and Fabrycky 2011). When performing the functional decomposition, it is critical to avoid working your way into solutions. The outcome of the functional decomposition is a comprehensive list of the functions and sub-functions required of the system that stems directly from the problem statement or effective need. The second step of functional analysis is to organize this list of functions and sub-functions in a meaningful way. One method of organizing these functions and sub-functions is in a hierarchy of functions, typically at least two or three levels deep. Another method for organizing is a functional flow block diagram. A hierarchy must be created to support value system design (Buede 2009).

4. Determining Relevant Measures

Roger Stevens in his book, *Operational Test and Evaluation: Systems Engineering Process* defines MOEs as "any set of criteria established to determine the resolution of a critical issue" (Stevens 1979). The team has determined that the two stakeholder goals defined in Chapter I Section E are critical issues that need to be resolved to assess how operationally effective the SoS tested in PC21 are for a given capability. The list of characteristics of good MOEs provided by Stevens in Table 2 was utilized when the team developed the MOEs for this project.

Table 2. Characteristics of a Good Measure. Adapted from Stevens (1979).

Characteristics of Good Measures	
Relevance	The MOEs established should relate to the system's mission and identified critical issues
Completeness	Any input variable that causes a change to the value of an MOE should appear as an input to the MOE because it could impact the ability of a system to perform its mission.
Precise Definitions	Any possibility of misunderstanding an MOE needs to be avoided. The MOEs needs to be clearly and precisely defined in such a way that a researcher can duplicate a test and get the same value.
Mutually Exclusive	MOEs should not be dependent on any other MOE. Repeated instances of the same data will skew the results.
Meaningful	An MOE needs to be easily understood by testers, decision-makers, and new personnel as to what it represents.
Measurable	The inputs for an MOE need to be measurable. Quantifiable measures are preferred. Qualitative measure should be based on standard criteria.

Stevens (1979) has also defined rules for MOE development identified in Table 3, which was also be utilized.

Table 3. Development Rules for Measures of Effectiveness. Adapted from Stevens (1979).

Development Rules for MOEs
For each mission capability, there should be one MOE
Weights for each MOE will be assigned by the decision-makers
Missions/scenarios are to be fully defined before test data is collected
Collecting the data should not interfere with the system while it is operating
Quantitative data should be stated as probabilities
Qualitative data should use a standardized measurement scale
System and hardware failures are to be recorded as system failures

5. Parnell Method of Swing Weighting

Parnell developed a method to apply swing weights to value measures that utilizes a matrix to sort the measures based on the importance to the stakeholder and the range of the values for each measure. The sorted measures are then given a reasonable stakeholder determined value with the most important and impactful measure having the highest value and the least important/impactful having the lowest value. These values are then converted into a global weight based on the percentage they are of the sum of all the values (Parnell, Driscoll and Henderson 2011). Although typically the swing weighting is utilized for determining which candidate from multiple solutions is the best candidate, the team will leverage this method to quantify the importance the stakeholder gives to each measure.

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III. METHODOLOGY FOR DEVELOPING A DESIRED CAPABILITY ASSESSMENT FRAMEWORK

A. OVERVIEW OF APPROACH

The project team considered several systems engineering (SE) approaches and tailored an SE process to develop a solution to TRAC-Monterey's effective need. The resultant process consisted of five main phases: 1) information gathering and problem definition; 2) concept development; 3) framework development; 4) verification and validation; and 5) recommendations and conclusions. It was chosen for its ability to address each phase and its iterative nature and continuous stakeholder feedback loops. Figure 2 is a visual representation of the main phases, sub-phases, inputs and outputs, and continuous feedback required to accomplish the feat of providing the Joint Force decision makers the knowledge they require to make informed decisions if further investment into the modern technologies demonstrated at PC21 is advantageous and warranted.

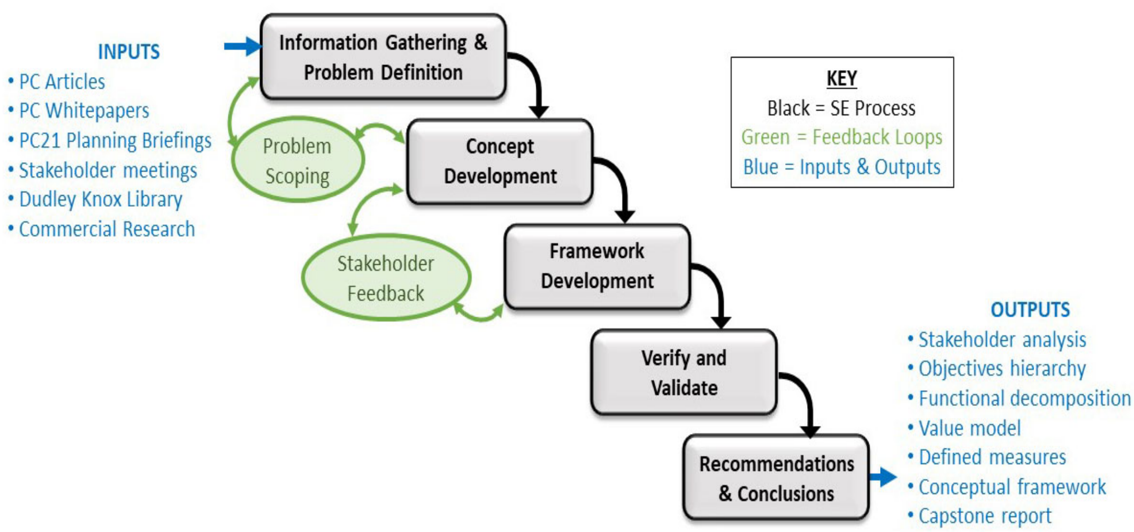

Figure 2. Tailored SE Process

B. INFORMATION GATHERING AND PROBLEM DEFINITION

At the inception of this capstone, the team began fact-finding and information gathering on TRAC-Monterey's perceived and expressed problem. This was done through elicitation of active stakeholders, such as TRAC-Monterey, and secondary and/or passive stakeholders our stakeholder analysis uncovered. The team gathered available and relevant literature as discussed in Chapter II to provide a full perspective and understanding of the problem domain.

It was important in this phase to identify and distinguish TRAC-Monterey's primitive need, and iteratively transform it into an effective or capability needs statement. This problem statement was the starting point for developing a solution and was defined in Chapter I:

> Currently, TRAC-Monterey lacks a methodical process to assess if the new innovative SoS technologies being demonstrated at PC21 meet the operational capabilities required to provide the Joint Force with the necessary speed, range, and convergence, to yield future decision dominance and overmatch for great-power competition.

C. CONCEPT DEVELOPMENT

Within the concept development phase of the SE process shown in Figure 2, there were three cyclical steps, defined in the sub-sections below, that were utilized to establish needs, functions, and objectives for the conceptual assessment framework (Blanchard and Fabrycky 2011). These steps were not purely sequential and had aspects, such as stakeholder discussions and requirements identification that were conducted concurrently.

1. Stakeholder Analysis

To gain a clear understanding of the problem, a stakeholder analysis was completed to document all known stakeholders, what type of stakeholder they were, their priority level, involvement type, relation or interest to the project, and any needs, objectives and goals as exemplified in Table 4. This was conducted through conversations with the stakeholders and review of PC21 data files.

Table 4. Stakeholder Analysis Table Example

Stakeholder	Type of Stakeholder		Priority Level	Involvement Type	Relationship with / Interest in project	Need/Objective/Goal
Name	Active / Passive	Internal / Boundary	Ranked	Direct / Indirect	Sponsor, Client, User, Analyst, etc.	Need(s) / Objective(s) / Goal(s)

The team completed the stakeholder analysis table and discussed it with the stakeholders to ensure the information captured was correct and properly categorized. From this table, system objectives were developed to address as many of these stakeholder's needs as practicable and placed into a hierarchy format.

2. Requirements and Constraints

The team initially began with research and a review of the literature shown in Chapter II. Documentation related to the activities of PC21 brought understanding of what data is to be collected. Several research papers were found that described similar framework development activities. This information influenced the team's approach to developing the requirements and constraints of this framework.

Through analysis and discussion, the needs gleaned from the stakeholder analysis were converted into the requirements of the conceptual assessment framework. Then the concerns captured during the stakeholder discussions were reviewed and utilized to develop assumptions and constraints (Parnell, Driscoll and Henderson 2011). The requirements and constraints contributed to the development of the functional analysis by focusing the team to the functions that were relevant to this specific project.

3. Functional Analysis

During the functional analysis, the team employed the analysis technique discussed in Chapter II Section B.3 to convert requirements from the stakeholder analysis and objectives hierarchy into the overarching functions of the operational assessment system. The stakeholder objectives hierarchy identified and clarified the objectives the key stakeholders needed to be addressed which led to a better understanding of the requirements for the conceptual assessment framework. First, the team identified the top-level function of the system, which informed what the assessment system must accomplish. The top-level function was then decomposed into sub-level functions to identify input criteria and constraints. These functions and subfunctions were used to create a functional hierarchy in the model-based SE tool, Innoslate. An example of this output is illustrated in Figure 3.

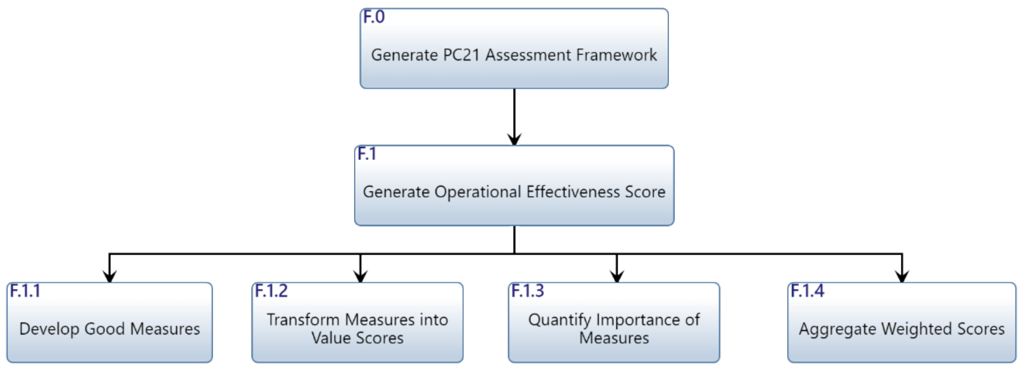

Figure 3. Innoslate Functional Decomposition Example

The lowest level functions of the functional hierarchy directed the team to determine what components would be needed to perform the required functions. This is discussed in detail in section D of this Chapter.

D. DEVELOPMENT OF A CONCEPTUAL ASSESSMENT FRAMEWORK FOR A DESIRED CAPABILITY

In the framework development phase, the team looked at literature used during the SE course of study as well as case studies from other researchers, as discussed in Chapter II, to determine what components would be needed to perform the functions identified in the conceptual assessment framework functional decomposition. After the literature review, the team decided to utilize a functional decomposition of the capability of interest along with a modified version of Langford's Integrated Framework for MOE development as the components to determine good measures (Langford 2012). The integrated framework considers more than just the measures of the capability itself; it also considers user interactions with the components of the capability and the procedures involved when the capability is in use. The team will also ensure the measures conform to the characteristics of good measures as detailed in Chapter II.

To transform the measures into value scores, the team reviewed case studies and methods of generating values scores from SE textbooks. The team decided to use an "ideal range" method of constructed value scores which establishes a best to worst case range of values for each measure with criteria that can be defined by the stakeholder giving them the flexibility to adapt the scale to any capability (Parnell, Driscoll and Henderson 2011). The Parnell method of swing weighting discussed in Chapter II was selected as the method to generate swing weights that quantify the importance of the measures (Parnell, Driscoll and Henderson 2011). This method utilizes a matrix which makes sorting the measure by importance and variation in range of the collected data intuitive. Finally, the team will use the additive value model to aggregate all the weighted scores into the total effectiveness score. The additive value mathematical function is:

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i)$$

where, $v(x)$ is the total effectiveness score of the capability, i=1 to n represent the number of MOE value scores, $v_i(x_i)$ is the aggregated value measure for each MOE, w_i is the normalized swing weight, or measure weight (Parnell, Driscoll and Henderson 2011).

E. VERIFICATION AND VALIDATION

To verify the conceptual assessment framework, the team traced all the components selected in the framework development phase back to the functional decomposition in Figure 3 and verifying that these components can produce the traced function. An example of a function trace is shown in Table 5.

Table 5. Tracing of System Functions to Conceptual Assessment Framework Components

Function	Conceptual Assessment Framework Component
Develop Good Measures	Function decomposition of desired capability
	Value Hierarchy of Capability
	Stakeholder objectives hierarchy of desired capability
	Modified Langford Integrated Framework
Transform Measures into Value Scores	Constructed value scales for MOE Measures
	Mathematical function for measure
	Measure weights for MOE Measures
Quantify Importance of Measures	Parnell Swing Weight Matrix
	Table of normalized swing weights
Aggregate Weighted Scores	Additive value model

TRAC-Monterey and JMC concurred with the methodology presented in this chapter.

IV. RESULTS

A. STAKEHOLDER ANALYSIS

As discussed in Chapter III, the team completed a stakeholder analysis by conducting research and elicitation of the known stakeholders. Initially, research was carried out through review of the documentation provided by TRAC-Monterey on PC, the previous exercise (PC20), and its next iteration (PC21), as well as publicly available information discovered through Internet searches. The team then used this information to create questions and held interviews to ascertain more about the active and passive stakeholders' goals, objectives, constraints, perceived needs, and any potential biases. The result of this analysis is presented in Table 6. The team then met with the sponsor stakeholder, TRAC-Monterey, and discussed our results. While the discussion touched upon all stakeholders, the focus was on the primary/active stakeholders, as they are the ones who have influence on or are influenced by the conceptual assessment framework. Priority level assignments shown in Table 6 are representative of the entity's relation to the expressed problem of the sponsor, specifically the ability to assess operational effectiveness (LOE 2).

Table 6. Stakeholder Analysis Table

Stakeholder	Type of Stakeholder		Priority Level	Involvement Type	Relationship with / Interest in project	Need/Objective/Goal
TRAC-Monterey (a)	Active	Internal	1	Direct	Sponsor	• To assess if the systems of systems technologies being demonstrated at PC21 provide the Joint Force with the necessary speed, range, and convergence, yielding future decision dominance and overmatch for great-power competition. • To accomplish LOE 4: Joint Interoperability.
JMC (b)	Active	Internal	2	Direct	End User	• To accomplish LOE 2: Operational Effectiveness Assessment. • Method to determine operational effectiveness of SoS in MDO missions being tested. • To determine relevant measures of effectiveness.
NPS (c)	Active	Internal	3	Indirect	Collaborator	• To advise and provide continuous feedback to the team. • Student(s) successful completion of Capstone Project.
ATEC (d)	Passive	Boundary/ Second Order	4	Indirect	Test & Evaluation	• To accomplish LOE 1: Technology Assessment. • Create/establish testing procedures, scenarios, use cases, and criteria. • Document testing results and outcomes.
DAC (e)	Passive	Boundary/ Second Order	5	Indirect	Test & Evaluation	• To accomplish LOE 3: Network Assessment. • Assess the joint integrated networks during PC21.

Logo sources:

(a) https://www.trac.army.mil/

(b) https://th.bing.com/th/id/OIF.iw7QmdSVRfxWKNji6bbtZQ?pid=ImgDet&rs=1

(c) https://nps.edu/

(d) https://en.wikipedia.org/wiki/United_States_Army_Test_and_Evaluation_Command

(e) https://armyfuturescommand.com/dac/

As a result of stakeholder discussions, a hierarchy diagram was developed to describe and decompose stakeholder objectives in visual form. The overarching objective of the sponsor and end user stakeholders, TRAC-Monterey and JMC, is to have the ability to measure the operational effectiveness of the technologies being tested and demonstrated at PC21, and whether convergence as an Army and as a Joint Force is being achieved, given the infusion of various modern technologies. The method for determining operational effectiveness must be tailorable (flexible) to meet the evolving needs of PC. The overarching objective was further decomposed into two sub-objectives, and they are: 1) Assess Mission Completion and 2) Assess Mission Success. The third level decomposes Mission Completion and Mission Success and identifies key capabilities that describe the degree to which these objectives are achieved. Figure 4 illustrates the stakeholder's objectives hierarchy.

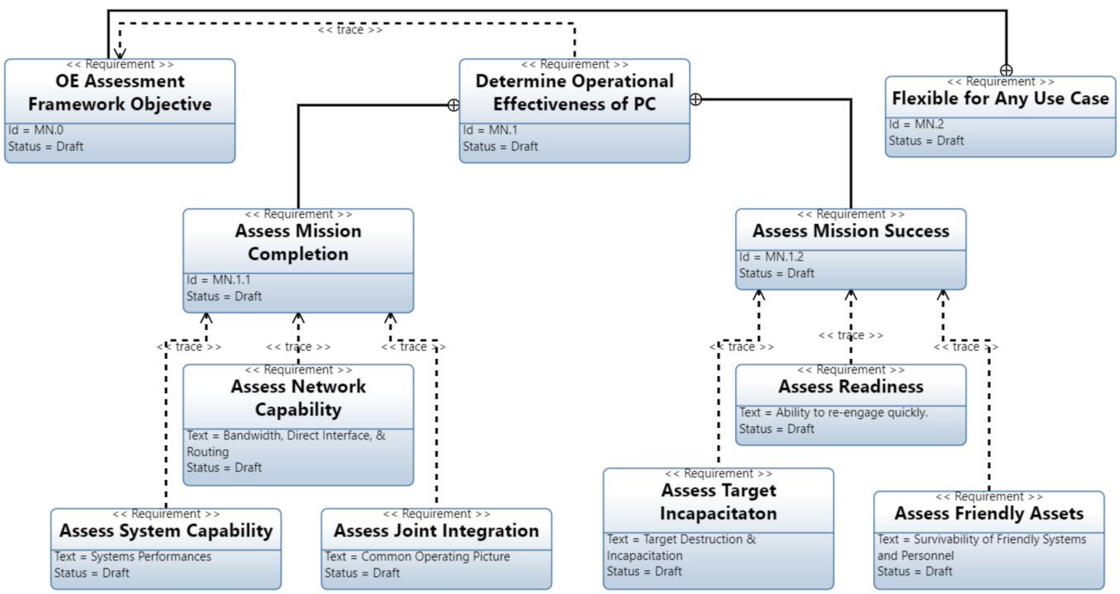

Figure 4. Stakeholder Objectives Hierarchy

B. FUNCTIONAL ANALYSIS

The functional analysis shown in Figure 5 resulted from converting the requirements from the stakeholder analysis into the overarching functions of the conceptual assessment framework. The identified top-level function of the system is to generate an operational effectiveness score. The top-level function was then decomposed into four sub-level functions which are 1) Develop Good Measures, 2) Transform Measures into Value Scores, 3) Quantify Importance of Measures, and 4) Aggregate Weighted Scores. The functional decomposition completed during the functional analysis phase informed the team that two of the functions of the framework are to provide good measures and to provide a total operational effectiveness score. Sections C through E of this chapter describes the actions that the team took to develop the major components of the assessment system that would achieve that stated function and meet the stakeholder's objectives.

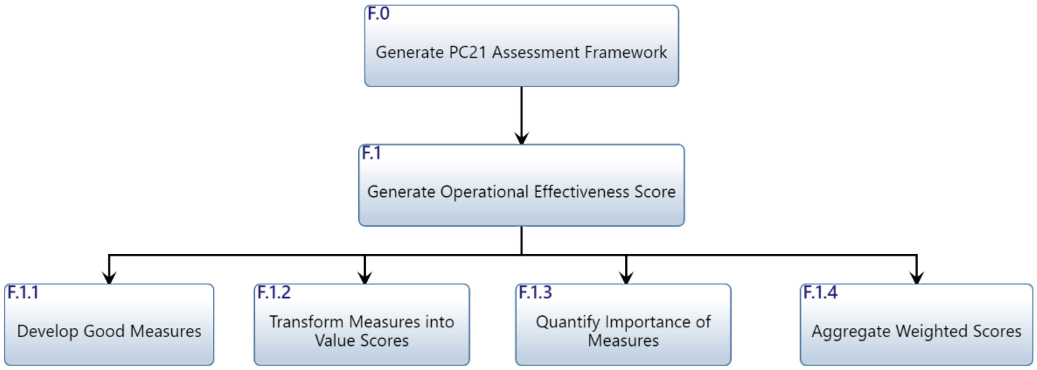

Figure 5. Conceptual Assessment Framework Functional Decomposition

C. DEVELOPING THE PROCESS FOR CREATING GOOD MEASURES

When developing the process for creating good measures, the team took into consideration TRAC-Monterey's use of observational data about users and processes as well as the need for a complete functional decomposition of a capability being assessed. The team also adopted a modified version of Langford's Integrated Framework, as was used in the case study by Goh (2015), for the development of MOEs and is shown in Table 7. This version removed the "Models and Representations" domain because it focused on the requirements gathering, documenting, and modeling of systems, which the team did not feel was relevant to this project's objective. The team made this assessment because the systems that will be assessed in PC21 in operational testing and this project is focused on providing a method to score a capability's operational effectiveness. The use of this modified integrated framework results in the development of six pairs of MOEs that address the joint integration of processes and objects, as well as the stakeholder objectives of having the flexibility to determine an operational effectiveness for any capability in question.

Table 7. Modified Integrated Framework Intersection Descriptions. Source: Goh (2015).

		Processes	
		Cognition	Procedures
Objects	User Behaviors	Conceptualization of stakeholder behaviors **(MOE-a)** when the product*service is used; and when it is not used (or available) **(MOE-p)**	Influence of procedures on processes and mechanisms describing user behaviors due to product*service **(MOE-i)**; Influence describing user behaviors due to lack of product*service **(MOE-f)**
	Functions	Prognostication of consequences of interactions between objects through exchange of EMMI **(MOE-g)** & Expectations of interaction **(MOE-c)**	Availability and Validity of processes and mechanisms that determine resource utiliziation for functions **(MOE-u)**; Processes and mechanisms that define the boundary conditions for anticipated operations of all functions **(MOE-b)**
	Physical Entities - Object	Experience with posited objected **(MOE-e)** & anticipated responses of posited objects **(MOE-r)**	Availability and Validity of processes and mechanisms resulting in the selection and development of all physical elements **(MOE-s)**; Processes and mechanisms resulting in the development of all physical elements and operational contexts **(MOE-x)**

To use the conceptual assessment framework, a functional decomposition of the capability being assessed is required. To assist with determining where the decomposition measures belong within the modified integrated framework, each intersection description could be restated as a question that relates to both the description of the MOE and the specific capability. For example, MOE-r is described in Table 7 as the "anticipated responses of posited objects." If the capability being assessed involves autonomous vehicles being used in off-road conditions, the description could be substituted with the question, "How effectively are the selected autonomous vehicles responding to changes in terrain?" Measures within the autonomous vehicle functional decomposition, that relate to off-road performance of the vehicles would be selected and aggregated if there were more than one relevant measure related to the question. Table 8 shows an example of singular measures for MOE-r and an aggregated normalized MOE score. The determination of the MOE Score will be discussed in Section D of this chapter.

Table 8. Example of Aggregation of Measures for MOE-r

MOE-r - Function Responsiveness						
Function	Sub-Function	Measure	Constructed Table	Sub-Measure Score	Normalizing Measure	Normalized Sub-Measure Score
Find Target	Detect Target	Time to Detect	Objective (Find Target)	9	0.20	1.76
	Track Target	Time to Track		7	0.15	1.07
	Identify Target	Time to Identify		7	0.15	1.07
Transmit Target Details		Success/Fail	Objective (Success/Fail)	10	0.22	2.17
Engage Target		Time to Engage	Objective (Engage Target)	6	0.13	0.78
Assess Target Dmg		% HTK	Objective (HTK)	7	0.15	1.07
					MOE-r SCORE	7.91

D. DEVELOPING THE PROCESS TO TRANSFORM MEASURES INTO A COMMON VALUE SCALE

To transform the measures into value scores the team determined that Parnell's "ideal range" method of constructed value scales for both qualitative and quantitative measures should be used (Parnell, Driscoll and Henderson 2011). This gives the stakeholder flexibility to adjust the scales and criteria according to the capability they are assessing and provides a common method for applying scores to the measures. An example of the constructed scores for objective measures is shown in Table 9. These scales show a range from 0 to 10 but any range can be established by the stakeholder as long as it is the same for every measure transformation. The worst case is scored at 0 and the best case at 10 with intermediate criteria spread between these two values. Exceptions to the constructed scales can be made where it makes sense to utilize mathematical equations to determine the measure score.

Table 9. Example of Objective Scores for Measures

Objective (Comms Reliability)	
Score	Criteria
10	95-99%
8	90-95%
5	85-90%
2	80-85%
0	< 80%

Objective (Decision Time)	
Score	Criteria
10	< 1 min
8	1-2 Min
6	2-4 Min
4	4-7 Min
2	7-10 Min
0	> 10 min

To ensure that the aggregated MOE scores are on the same common scale, each sub-measure score is weighted by summing the sub-measure scores and then dividing each sub-measure score by that sum. The normalizing measure for a specific score is then multiplied by the sub-measure score to get a normalized sub-measure score. The normalized scores are aggregated into a single MOE score.

The MOE scores map one to one to the MOE value scores. Parnell's method of swing-weighting would then be used to assign swing weights to the MOE value scores. The 12 MOEs would be sorted, by the stakeholder into the Parnell Swing Weighting Matrix. Along the top of the matrix are three categories indicating the importance the stakeholder places on the individual MOEs. The left side of the matrix has three categories for the variation in range of the MOE. The variations can be determined in different ways. It can be indicated by the variation of the range of the data set, by the impact it has on a decision, or even the impact it has on the effectiveness of a system (Parnell, Driscoll and Henderson 2011). Variation may even be computed using a simple equation: (high value–low value) / average value. The thresholds for low, medium, and high would be designated by the stakeholder and the analysts. Because the MOEs in this project represent an aggregation of multiple measures and multiple functions, the impact the MOE has on the ability to complete a mission was utilized by the stakeholder for the distribution. The score the stakeholder assigns an MOE within the matrix can be in a range of their choice, in the Table 10 example, a range of 0 to 20 was used. An MOE with a high importance and a high variation would be assigned the highest score in the range and decreasing in value as scores are assigned diagonally down to the lowest value in lower right block.

Table 10. Swing Weight Matrix Example. Source: Parnell, Driscoll, and Henderson (2011).

	Importance of Value Measure		
Variation in Range	**High**	**Medium**	**Low**
High	Measure #1	Measure #2	
	20	10	
Medium	Measure #4	Measure #3	Measure #6
	15	8	5
Low	Measure #5		
	5		

If more than one person is providing input into the weights being applied, a means to check for consistency was provided. Table 11 shows the same matrix with letter indicators in each block.

Table 11. Consistency Example for Value Measure Placement in the Swing Weight Matrix. Source: Parnell, Driscoll, and Henderson (2011).

		Level of importance of the value measure		
		Very important	**Important**	**Less important**
Variation in measure range	**High**	A	B_2	C_3
	Medium	B_1	C_2	D_2
	Low	C_1	D_1	E

According to Parnell, Driscoll, and Henderson (2011), there are strict relationships in inequalities that have to hold. These are: “A > all other cells; B_1 > C_1, C_2, D_1, D_2, E; B_2 > C_2, C_3, D_1, D_2, E; C_1 > D_1, E; C_2 > D_1, D_2, E; C_3 > D_2, E; D_1 > E; D_2 > E.”

The swing weight values are then normalized by dividing the swing weights of each measure by the sum of all the swing weights resulting in normalized measure weights that sum to 1.0, as exemplified in Table 12.

Table 12. Swing Weights to Measure Weights Example

Evaluation Measure	Swing Weight	Measure Weight
Measure #1	20	0.32
Measure #2	10	0.16
Measure #3	8	0.13
Measure #4	15	0.24
Measure #5	5	0.08
Measure #6	5	0.08
TOTAL Weight:	63	1.00

E. DEVELOPING THE PROCESS TO AGGREGATE VALUE SCORES

The total operational effectiveness score is calculated by multiplying the MOE value scores by the measure weights to derive a weighted value score (WVS). The sum of the WVSs, as shown in Table 13, results in a total effectiveness score for the desired capability.

Table 13. Effectiveness Score Computation Table Example

Evaluation Measure	Value Score	Measure Weight	Weighted Value Score
Measure #1	4.0	0.32	1.28
Measure #2	2.0	0.16	0.32
Measure #3	5.0	0.13	0.65
Measure #4	3.0	0.24	0.72
Measure #5	3.0	0.08	0.24
Measure #6	4.0	0.08	0.32
		TOTAL EFFECTIVENESS SCORE:	**3.53**

To enable the stakeholder to determine where the total effectiveness score falls within the possible range of scores, a worst to best case effectiveness scale can be generated by dividing the difference between the highest and lowest values of the common scale by the number of levels the stakeholder desires. Table 14 shows an example of how the operational effectiveness scale could look at three levels if the lowest possible score is 0 and the highest a 10.

Table 14. Operational Effectiveness Scale Example

S2S Operational Effectiveness Scale			
High Operational Effectiveness	6.66	to	10.00
Medium Operational Effectiveness	3.33	to	6.66
Low Operational Effectiveness	0	to	3.33

F. VERIFICATION

When verifying the conceptual assessment framework, each component was mapped back to the functions of the framework's functional decomposition. A mapping of these functions to components is shown in Table 15. The components are traceable to the stakeholder's objectives hierarchy and have the flexibility to assess any joint capability that PC21 wants to assess. This also provides the methodical method of assessment desired in the problem statement discussed in Chapter I.

Table 15. Tracing of System Functions to Conceptual Assessment Framework Components

Function	Conceptual Assessment Framework Component
Develop Good Measures	Function decomposition of desired capability
	Value Hierarchy of Capability
	Stakeholder objectives hierarchy of desired capability
	Modified Langford Integrated Framework
Transform Measures into Value Scores	Constructed value scales for MOE Measures
	Mathematical function for measure
	Measure weights for MOE Measures
Quantify Importance of Measures	Parnell Swing Weight Matrix
	Table of normalized swing weights
Aggregate Weighted Scores	Additive value model

The conceptual assessment framework has two basic components addressing one or more functions. The first component is a process to get good measures. Completing a functional decomposition of a capability narrows down the independent functions to specific objectives that must be met and can be measured. The modified integrated framework for MOE development takes these measures from the decomposition and other factors, like cognition and procedures, into consideration in determining operational effectiveness. Both components used together determine good measures to see if the capability is fit for purpose (Langford 2012). They are also flexible and methodical ways to determine measures for any capability.

The second component of the assessment framework is to aggregate the scores. The "ideal range" constructed value scale is flexible in range and criteria and therefore, adaptable to any capability. Mathematical functions can be used where a scale of values does not seem appropriate, like determinations of mission time vs task time. Both provide methodical means to develop value scores. Parnell's swing weight method discussed in Section D of this chapter, is a SE tool for quantifying the importance a stakeholder places on an MOE, and in the case of this project the variation of the impact it has on mission completion or success. The additive value model provides the means to aggregate all the weighted scores into the total effectiveness score, using the mathematical function discussed in Chapter III:

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i)$$

G. VALIDATION

As part of the validation of the assessment framework, the team applied the framework to a PC21 use case to test the process for producing a single operational effectiveness score. The Stakeholder selected a Joint S2S capability. The scenario involves multiple sensors, C2 systems and weapon systems across the domains of ground, air, and space. The components of the Joint SoS synchronize to neutralize multiple hostile targets within three named areas of interest. Two different AI decision aides are also utilized within the mission. The first is used to detect anomalies from space domain reconnaissance which is the lead-in to the mission scenario. The second is a decision aid that can take target characteristics and pair them with available weapon teams based on the team's distance from the target, munition capability and other factors. The use case will not be tested in the field until October 2021. Therefore, at this point, the team made some assumptions about the use case in order to apply value scores to the measures. These assumptions are:

- During the scenario, it is expected that the C2 COPs for the MDTF, Advanced Operations Base, and Joint Forces will auto-update throughout the mission creating convergence of the Joint Forces.
- The Joint systems will be able to communicate with each other by proper formatting/translation of messages sent between components.
- The use of AI decision aids and sensor target identification capability will reduce the time needed to assess available and suitable resources.
- The optimal shooter will be matched to a target to ensure neutralization.

To start utilizing the conceptual assessment framework, a functional decomposition was performed on the S2S capability and is shown in Figure 6. This represents the high-level functions that the team has determined must happen to complete a S2S timeline.

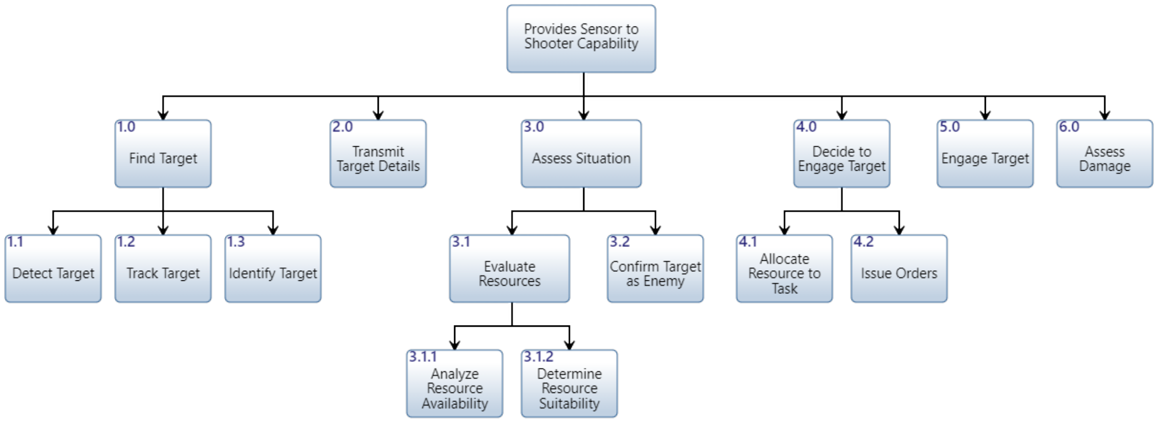

Figure 6. S2S Capability Functional Decomposition

With the functional hierarchy created, the team then generated a value hierarchy which identifies the objectives of the lowest level functions and the corresponding relevant measures that need to be collected. The objectives in this value hierarchy start with the word "minimize" or "maximize" indicating the desired goal for that measure. As shown in Figure 7, all time related objectives have a goal to minimize the time it takes to perform that function. Larger views of the S2S Capability are shown in Figures 8 and 9.

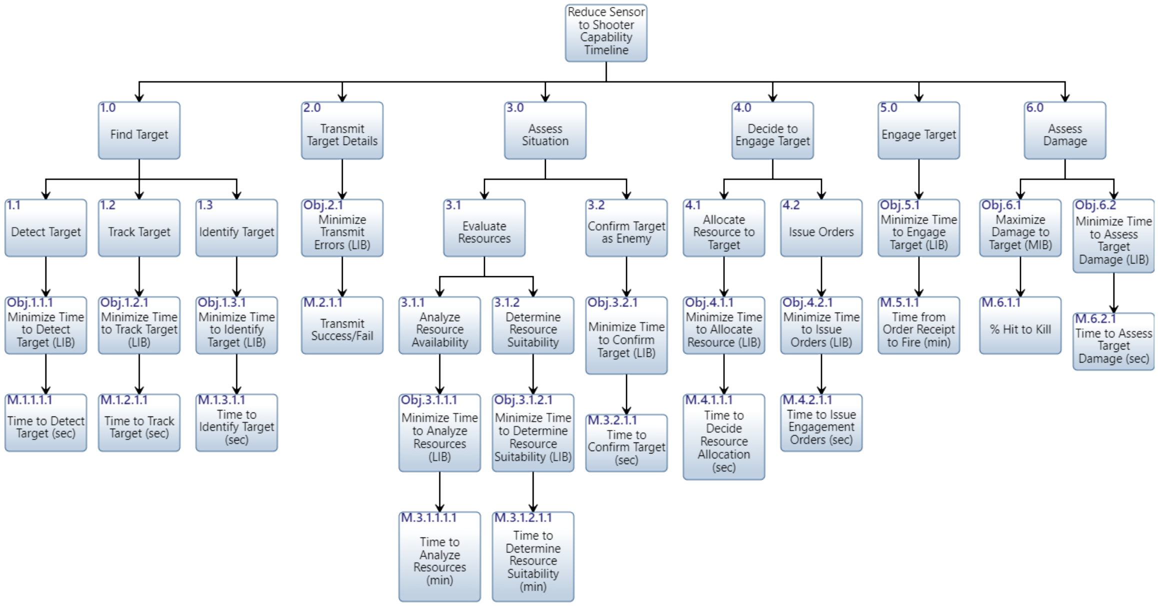

Figure 7. Value Hierarchy for S2S Capability

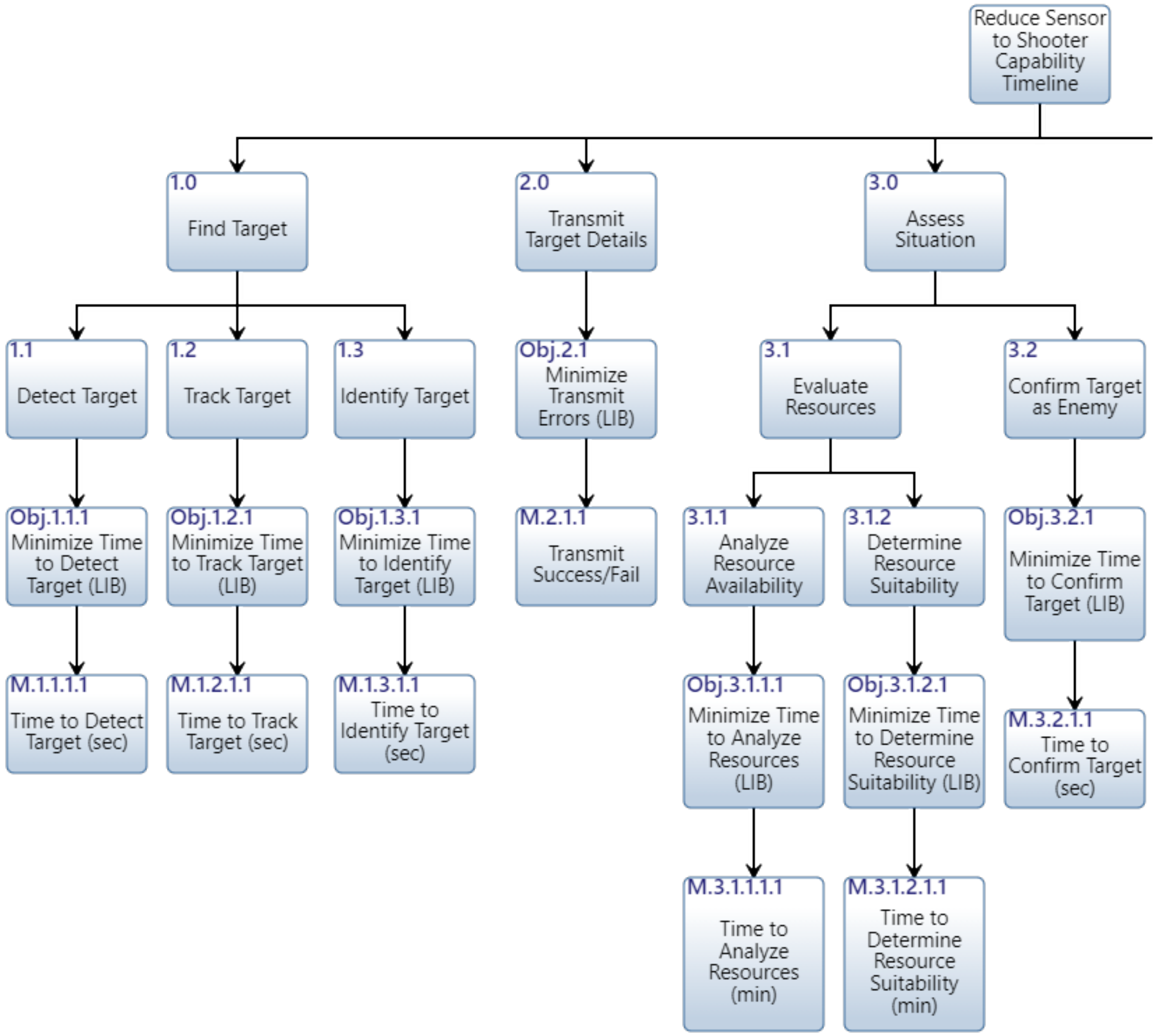

Figure 8. View of First Three Top Level Functions of the S2S Capability

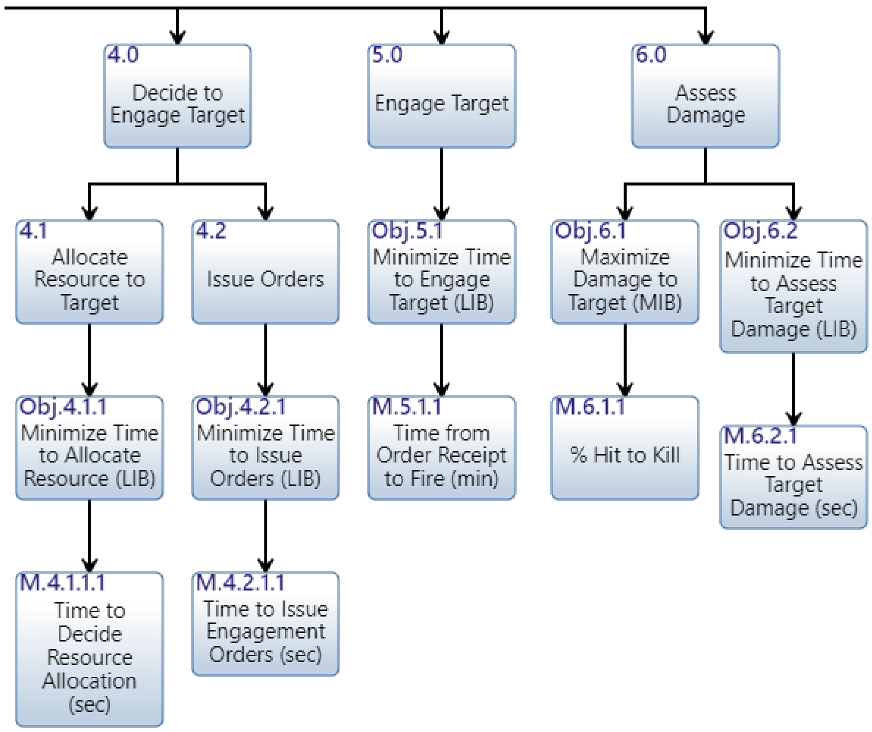

Figure 9. View of Last Three Top Level Functions of the S2S Capability

Next, the team determined the questions to be answered for each nexus of the modified integrated framework. The modified framework is shown at Table 17 with the questions each intersection addresses about the S2S capability. By posing the questions in this manner, it aided in the selection of which measures in the S2S value hierarchy are relevant to that nexus.

Table 16. S2S Operational Effectiveness Questions Addressed

			Subjective Frame			
			Social and Management			
			Cognition		Procedures	
Objective Frame	Product or Service Domain	User behaviors (associated with or due to product*service)	MOE-a	Time from Start of S2S Timeline to End When Joint systems are Used	MOE-i	How Procedures Influence the S2S capability when Joint systems are used
			MOE-p	Time from Start of the S2S Timeline to End when Joint systems are **NOT** Used	MOE-f	How Procedures Influence the S2S capability when Joint systems are **NOT** used
		Functions (associated with or because of objects that comprise product*service)	MOE-g	How effective are the predicted joint function interactions to achieve Mission Completion?	MOE-u	Were the procedures that determine resource utilization effective?
			MOE-c	How much are the functions of the S2S Capability expected to contribute to mission Completion?	MOE-b	Did the procedures that define the boundary conditions of the S2S capability enable Mission Completion?
		Physical entities (associated with or because of objects that comprise product*service)	MOE-e	How well do users interact with the physical components that comprise the functions of the S2S Capability?	MOE-s	Did the functions of the capability to select suitable resources enable mission success?
			MOE-r	Are the functions of the S2S capability operating effectively?	MOE-x	Did the limitations of any of the functions prevent mission success?

The cognition-behavior intersection of the integrated framework looks at the effectiveness of a function or service when it is available and when it is not available. In the context of this project, we are looking at a joint S2S capability and the effects on a S2S mission time. MOE-a looks at how much time it takes to complete an S2S mission when joint capabilities are available, and MOE-p looks at how long the same S2S mission would take if joint capabilities were not available. The comparison of the two MOEs would show if the joint capabilities are instrumental in reducing the S2S timeline.

The MOE-a is calculated with the formula:

$$vMOE\text{-}a = \frac{xMOE\text{-}a}{yMOE\text{-}a}$$

where *xMOE-a* is the time from mission receipt to mission completion when all component functions are available, and *yMOE-a* is the time from S2S task receipt through task completion within the overall mission. If multiple tasks are needed to complete the mission, the start to complete times are calculated separately and then aggregated. The use case provided by the stakeholder has a timeline of 218 minutes from the start of the mission until the final target is destroyed. There are six S2S timelines involved in this mission totaling 20 minutes. When calculated the score for MOE-a is 10.9

$$vMOE\text{-}a = \frac{218}{20} = 10.9$$

MOE-p is calculated with the formula:

$$vMOE\text{-}p = \frac{xMOE\text{-}p}{yMOE\text{-}p}$$

where, *xMOE-p* is the time from mission receipt to mission completion when joint functions are not available, and *yMOE-p* is the time from task receipt through task completion. If multiple tasks are needed to complete a mission, the start to complete times are calculated separately and then aggregated. A larger value for MOE-a is a good indication that the availability of joint capabilities reduces the S2S mission timeline. The team assumed an additional five minutes if joint systems are not used to offset a potential limited pool of resources, and quicker approval of resource allocations. The resulting score is:

$$vMOE\text{-}p = \frac{218}{25} = 8.7$$

To bring MOE-a and MOE-p within the common scale of 0 to 10, a constructed table is generated with criteria and then normalizing measures determined. Table 17 shows the formula calculation values, the measure score, normalizing measure, normalized measure scores and final MOE score. Table 18 shows the constructed scores based on criteria and the weights for those scores.

Table 17. MOE-a and MOE-p Score Generation

MOE-a and MOE-p Weighted Value Scores					
MOE		Calculation	Measure Score	Normalizing Measure	Normalized Measure Score
MOE-a	Time taken from Mission Start to Mission Completion with Joint S2S Capability	10.9	10	1.00	10.00
MOE-p	Time taken from Mission Start to Mission Completion without Joint S2S Capability	8.7	8	0.80	6.40

Table 18. Constructed Scores for MOE-a and MOE-p

Score	Criteria	Normalizing Measure
10	Calculation >10	1.00
9	Calculation 9-10	0.90
8	Calculation 8-9	0.80
7	Calculation 7-8	0.70
6	Calculation 6-7	0.60
5	Calculation 5-6	0.50
4	Calculation 4-5	0.40
3	Calculation 3-4	0.30
2	Calculation 2-3	0.20
1	Calculation 1-2	0.10
0	Calculation 0-1	0.00

The cognition-function intersection looks at the predicted interactions and expected effectiveness of functions. MOE-g asks the question "how effective are the predicted joint function interactions to achieve mission completion?" To answer this question, the scores for predicted interactions within the S2S capability functions of find target, transmit details, decide to engage the target, and engage the target are summed. Table 19 shows the functions, the predicted interaction, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 20 shows the constructed score tables and the criteria for the scores that were used.

Table 19. MOE-g Score Generation

MOE-g - Predicted Joint Function Interactions to Achieve Mission Completion						
Function	Predicted Interaction	Measure	Constructed Table	Sub-Measure Score	Normalizing Measure	Normalized Sub-Measure Score
Find Target	Sensor interacts with target, tracks and IDs it	Predicted Interaction	Objective (Sensor to Target)	10	0.29	2.94
Transmit Details	Sensor interacts with Command	Predicted Interaction	Objective (Sensor to Command)	8	0.24	1.88
Decide to Engage Target	Command interacts with Allocated Resource	Predicted Interaction	Objective (Command to Resource)	10	0.29	2.94
Engage Target	Allocated Resource interacts with Target	Predicted Interaction	Objective (Resource to Target)	6	0.18	1.06
					MOE-g SCORE	8.82

Table 20. Constructed Scores for MOE-g

Objective (Interaction - Sensor to Target)	
Score	Criteria
10	Detects, Tracks and IDs
7	Detects and Tracks
3	Detects and ID
0	Doesn't Detect

Objective (Interaction - Sensor to Command)	
Score	Criteria
10	Transmits with all required Target Information
8	Transmits with Target Location Only
6	Transmits with Target ID Only
0	Transmission Fails

Objective (Interaction - Resource to Target)	
Score	Criteria
10	Target Engaged and Destroyed
6	Target Engaged and Damaged
0	Target Missed

Objective (Interaction - Command to Resource)	
Score	Criteria
10	Orders Transmit with all required Engagement Information
5	Orders Transmit with Only Target Location
0	Transmission Fails

MOE-c answers the question "How much are the functions of the S2S capability expected to contribute to mission completion?" This MOE is measured by observation during capability testing and is a helpful indication if functions within the capability may not be necessary. In the S2S capability the assess damage function is not highly valued for mission completion and could be removed from the capability; however, it is an indication of mission success and a possible need for re-engagement. Table 21 shows the functions, the expectation of the function, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 22 shows the constructed score table and the criteria for the scores that were used.

Table 21. MOE-c Score Generation

MOE-c - Expected Contribution of S2S Functions to Mission Completion						
Function	Expectation	Measure	Constructed Table	Sub-Measure Score	Normalizing Measure	Normalized Sub-Measure Score
Find Target	Target will be detected, tracked and identified	Contribution to Mission	Subjective (Expected Contribution)	10	0.17	1.67
Transmit Details	Target details will be sent to Command	Contribution to Mission	Subjective (Expected Contribution)	10	0.17	1.67
Assess Situation	Target will be Confirmed by Command	Contribution to Mission	Subjective (Expected Contribution)	10	0.17	1.67
	Appropriate Resources will be Identified	Contribution to Mission	Subjective (Expected Contribution)	8	0.13	1.07
Decide to Engage	Appropriate Resource will be Issued Orders	Contribution to Mission	Subjective (Expected Contribution)	8	0.13	1.07
Engage Target	Resource will Effectively Engage Target	Contribution to Mission	Subjective (Expected Contribution)	8	0.13	1.07
Assess Damage	Target will be Neutralized	Contribution to Mission	Subjective (Expected Contribution)	6	0.10	0.60
					MOE-c SCORE	8.80

Table 22. Constructed Scores for MOE-c

Subjective (Expected Contribution)	
Score	**Criteria**
10	Critical to Mission Completion
8	Essential to Mission Completion
6	Required for Mission Completion
4	Needed for Mission Completion
0	Not Required for Mission Completion

The cognition-physical intersection is an indication of how users interact with the components involved in the S2S functions and the effectiveness of those functions that do not deal with procedures involved in resourcing. MOE-e addresses the question "how well do the users interact with physical components that comprise the functions of the S2S capability?" This helps identify efficiencies/inefficiencies in component selection and any potential human systems interface (HSI) issues that may be affecting the S2S timeline. The data is collected from user feedback and observations made during testing. Table 23 shows the functions, the description of the user interaction, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 24 shows the constructed score tables and the criteria for the scores that were used.

Table 23. MOE-e Score Generation

MOE-e - User-Component Experience						
Function	**Description of User Interaction**	**Measure**	**Constructed Table**	**Sub-Measure Score**	**Normalizing Measure**	**Normalized Sub-Measure Score**
Find Target	Using the Sensor Controls	User Feedback	Subjective (Sensor Controls)	8	0.27	2.13
Transmit Target Details	Message Generation User Interface	User Feedback	Subjective (Message GUI)	6	0.20	1.20
Assess Situation	COP Displays Critical Information	User Feedback	Subjective (COP Display)	8	0.27	2.13
Engage Target	Weapon System Controls	User Feedback	Subjective (Weapon Controls)	8	0.27	2.13
					MOE-e SCORE	7.60

Table 24. Constructed Scores for MOE-e

Subjective (Sensor Controls)	
Score	**Criteria**
10	Controls are Intuitive, Ergonomic, Responsive
8	Controls are Intuitive and Responsive
6	Controls are Intuitive with < 2 sec Response Delay
4	Controls are Complicated and Responsive
2	Controls are Complicated with < 2 sec Response Delay
0	Controls are Complicated and Unresponsive

Subjective (Message GUI)	
Score	**Criteria**
10	Message form intuitive, drop downs available, < 20 sec to generate
8	Message form intuitive, drop downs available, 20-30 sec to generate
6	Message form intuitive, 30-45 sec to generate
4	Message for unintuitive, drop downs available, 30-45 sec to generate
2	Message form unintuitive, 45-60 sec to generate
0	Message form unintuitive, > 60 sec to generate

Subjective (Weapon Controls)	
Score	**Criteria**
10	Intuitive, < 10 sec to prepare
8	Intuitive, 10-30 sec to prepare
6	Intuitive, 30-45 sec to prepare
4	Unintuitive, 45-60 sec to prepare
2	Unintuitive, 60-90 sec to prepare
0	Unintuive, > 90 sec to prepare

Subjective (COP Display)	
Score	**Criteria**
10	All criticial battlefield information displayed
8	Navigation to 1 additional screen to see all critical information
6	Navigation to 2 additional screens to see all critical information
4	Navigation to 3 additional screens to see all critical information
2	Navigation to 4 additional screens to see al critical information
0	Does not integrate all critical battlefield information

MOE-r addresses the question "are the functions of the S2S capability operating effectively?" This MOE is determined by system logs and other data collected on specific measures from the functional decomposition. Table 25 shows the functions, sub-functions (if applicable), the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 26 shows the constructed score tables and the criteria for the scores that were used.

Table 25. MOE-r Score Generation

MOE-r - Function Responsiveness						
Function	**Sub-Function**	**Measure**	**Constructed Table**	**Sub-Measure Score**	**Normalizing Measure**	**Normalized Sub-Measure Score**
Find Target	Detect Target	Time to Detect	Objective (Find Target)	9	0.20	1.76
	Track Target	Time to Track		7	0.15	1.07
	Identify Target	Time to Identify		7	0.15	1.07
Transmit Target Details		Success/Fail	Objective (Success/Fail)	10	0.22	2.17
Engage Target		Time to Engage	Objective (Engage Target)	6	0.13	0.78
Assess Target Dmg		% HTK	Objective (HTK)	7	0.15	1.07
					MOE-r SCORE	7.91

Table 26. Constructed Scores for MOE-r

Objective (Find/Engage Target)	
Score	**Criteria**
10	0-10 Sec
9	11-20 Sec
8	21-30 Sec
7	31-40 Sec
6	41-50 Sec
5	51-60 Sec
4	61-70 Sec
3	71-80 Sec
2	81-90 Sec
1	91-100 Sec
0	> 100 Sec

Objective (HTK)	
Score	**Criteria**
10	99%
9	98-99%
8	96-98%
7	94-96%
6	92-94%
5	90-92%
4	88-90%
3	86-88%
2	84-86%
1	82-84%
0	< 82%

Objective (Success/Fail)	
Score	**Criteria**
10	Successful Transmission
0	Failed Transmission

The procedure-behavior intersection looks at the influence of procedures when joint services are involved in a S2S mission, and when they are not. This helps determine if the procedures involved lengthen or shorten the S2S timeline. MOE-i looks to answer the question "how procedures influence the S2S capability when joint systems are used" and is measured by looking at the reliability of communications between joint systems and the time involved when chain of command and decision making across services comes into play. Table 27 shows the procedure, influence on the procedure, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 28 shows the constructed score tables and the criteria for the scores that were used.

Table 27. MOE-i Score Generation

MOE-i - Influence of Procedures when Joint S2S Capability is used						
Procedure	**Influence on Procedures**	**Measure**	**Constructed Table**	**Sub-Measure Score**	**Normalizing Measure**	**Normalized Sub-Measure Score**
Transmission of Data	Joint System Interoperability	Comms Reliability	Objective (Comms Reliability)	8	0.500	4.00
Decisions	Chain of Command Decision Making	Time to Receive Decision	Objective (Decision Time)	8	0.500	4.00
					MOE-i SCORE	8.00

Table 28. Constructed Scores for MOE-i and MOE-f

Objective (Comms Reliability)	
Score	**Criteria**
10	95-99%
8	90-95%
5	85-90%
2	80-85%
0	< 80%

Objective (Decision Time)	
Score	**Criteria**
10	< 1 min
8	1-2 Min
6	2-4 Min
4	4-7 Min
2	7-10 Min
0	> 10 min

MOE-f answers the question "how procedures influence the S2S capability when joint systems are not used" and is measured by looking at the reliability of communications between systems within the same service and the time involved with chain of command decision making. Table 29 shows the procedure, influence on the procedure, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. The constructed scores and criteria are the same as depicted in Table 28.

Table 29. MOE-f Score Generation

MOE-f- Influence of Procedures when Joint S2S Capabilities are NOT used						
Procedure	**Influence on Procedures**	**Measure**	**Constructed Table**	**Sub-Measure Score**	**Normalizing Measure**	**Normalized Sub-Measure Score**
Transmission	System Interoperability	Comms Reliability	Objective (Comms Reliability)	10	0.500	5.00
Decisions	Chain of Command Decision Making	Time to Receive Decision	Objective (Decision Time)	10	0.500	5.00
					MOE-f SCORE	10.00

The procedure-function intersection assesses the processes that assess the battlefield situation and allocates resources, as well as the functional boundary conditions of the SoS. In the context of this project, we are looking at the procedures to assess and allocate resources and the boundaries of the functions to assess situation and decide to engage target interactions with external systems. MOE-u addresses the question "were the procedures that determine resource utilization effective?" and is measured by the objective data indicated in the functional decomposition which pertains to determining and allocating resources. Table 30 shows the function, procedure, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 31 shows the constructed scores table and the criteria for the scores that were used.

Table 30. MOE-u Score Generation

MOE-u - Procedures that Determine Resource Utilization						
Functions	Procedure	Measure	Constructed Table	Sub-Measure Score	Normalizing Measure	Normalized Sub-Measure Score
Assess Situation	Analyze Resources for Availability	Time to Analyze Resources	Objective (Resources)	9	0.333	3.00
	Determine Resource Suitability	Time to Determine Suitability	Objective (Resources)	9	0.333	3.00
Decide to Engage	Decide which Resource to Allocate to Task	Time to Decide Resource Allocation	Objective (Resources)	9	0.333	3.00
					MOE-u SCORE	9.00

Table 31. Constructed Scores for MOE-u

Objective (Resources)	
Score	Criteria
10	0-10 Sec
9	11-20 Sec
8	21-30 Sec
7	31-40 Sec
6	41-50 Sec
5	51-60 Sec
4	61-70 Sec
3	71-80 Sec
2	81-90 Sec
1	91-100 Sec
0	> 100 Sec

MOE-b addresses the question "did the procedures that define the boundary conditions of the joint S2S capability enable mission completion?" which helps discern if the right information is getting to the right shooter at the right time. This MOE is measured by the observed accuracy of the information being transmitted, such as the correct message fields are completed and there are no transposed numbers within coordinates or typos. Table 32 shows the function, the external system, the interaction, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 33 shows the constructed scores table and the criteria for the scores that were used.

Table 32. MOE-b Score Generation

MOE-b - Procedures Defining Boundary Conditions of the S2S Capability							
Function	External System	Interaction	Measure	Constructed Table	Value	Weight	Value Score
Transmit Target Details	Sensors	Transmitting to Assess Situtation Function	Accuracy of information Transmitted	Observed	8	0.444	3.56
Issue Orders	Shooter	Transmitting Engagement Orders	Accuracy of engagement details	Observed	10	0.556	5.56
						MOE-b VALUE SCORE	9.11

Table 33. Constructed Scores for MOE-b

Observed (Accuracy)	
Score	**Criteria**
10	99% Accurate
8	98% Accurate
6	97% Accurate
4	96% Accurate
2	95% Accurate
0	< 95% Accurate

The procedure-physical entity looks at the processes to select suitable objects to perform the capability and the limitations of functions in terms of their operational context. For this use case we are looking at the sensors and lethal effects that are selected and their effective ranges. MOE-s looks to answer the question "did the procedures to select suitable resources enable mission success?" This MOE is measured by the observations of the resources used for scanning and for engaging the target and whether they were capable of the functions they were selected for. Table 34 shows the function, the component suitability, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 35 shows the constructed scores table and the criteria for the scores that were used.

Table 34. MOE-S Score Generation

MOE-s - Suitability of S2S Functional Components						
Function	**Component Suitability**	**Measure**	**Constructed Table**	**Sub-Measure Score**	**Normalizing Measure**	**Normalized Sub-Measure Score**
Find Target	Sensor can Track	Y/N	Observed	10	0.333	3.33
	Sensor can Identify	Y/N	Observed	10	0.333	3.33
Engage Target	Shooter can Hit Target	Y/N	Observed	10	0.333	3.33
					MOE-s SCORE	10.00

Table 35. Constructed Scores for MOE-s

Observed (Y/N)	
Score	**Criteria**
10	Yes
0	No

MOE-x seeks to answer the question "did the limitations of any of the functions prevent mission success?" It is measured by both observed and objective data and limitations of the assess situation function could entail not having available or suitable resources, or difficultly in confirming a target. Table 36 shows the function, the limitations, the measure, the constructed table used, the sub-measure scores, normalizing measures, normalized sub-measure scores, and the total score for the MOE. Table 37 shows the constructed score tables and the criteria for the scores that were used.

Table 36. MOE-x Score Generation

MOE-x - Functional Limitations						
Function	Limitations	Measure	Constructed Table	Sub-Measure Score	Normalizing Measure	Normalized Sub-Measure Score
Assess Situation	Available Resources	Y/N	Observed	10	0.270	2.70
	Suitable Resources	Y/N	Observed	10	0.270	2.70
	Time to Confirm Target	Time to Confirm Target	Objective	9	0.243	2.19
Decide to Engage	Time to Decide	Time to Issue Orders	Objective	8	0.216	1.73
					MOE-x SCORE	9.32

Table 37. Constructed Scores for MOE-x

Observed (Y/N)	
Score	Criteria
10	Yes
0	No

Objective	
Score	Criteria
10	0-10 Sec
9	11-20 Sec
8	21-30 Sec
7	31-40 Sec
6	41-50 Sec
5	51-60 Sec
4	61-70 Sec
3	71-80 Sec
2	81-90 Sec
1	91-100 Sec
0	> 100 Sec

Once the value scores for each MOE were generated, swing weights were applied. This application was executed by utilizing Parnell's swing weight matrix and was based on the level of importance the stakeholder placed on the MOE and its variation in range. Table 38 shows the swing weight matrix, the sorted MOEs, and applied weights.

Table 38. Swing Weight Matrix with Sorted MOEs and Their Values. Adapted from Parnell, Driscoll, and Henderson (2011)

	Importance of Value Measure					
Variation in Range	High		Medium		Low	
High	MOE-r	50	MOE-e	40	MOE-a	25
	MOE-i	50			MOE-p	25
Medium	MOE-b	45	MOE-u	30		
			MOE-x	30		
Low	MOE-s	35			MOE-f	10
					MOE-g	10
					MOE-c	10

Table 39 shows the normalization of the swing weights utilizing formula:

$$\sum_{i=1}^{n} w_i = 1$$

Table 39. Normalized Swing Weights

Evaluation Measure	Swing Weight	Measure Weight
MOE-a - Mission Timeline with full capability	25	0.069
MOE-p- Mission Timeline without full capability	25	0.069
MOE-g - Prediction of Joint Function Interaction	10	0.028
MOE-c - Expectation of Joint Functions to Contribute to Mission Completion	10	0.028
MOE-e - User-Component Experience	40	0.111
MOE-r - Function Responsiveness	50	0.139
MOE-i - Influence of Procedures when Joint S2S Capability is used	50	0.139
MOE-f - Influence of Procedures when Joint S2S Capability is NOT used	10	0.028
MOE-u - Procedures that Determine Resource Utilization	30	0.083
MOE-b - Procedures Defining Boundary Conditions of the S2S Capability	45	0.125
MOE-s - Suitability of S2S Functional Components	35	0.097
MOE-x - Functional Limitations	30	0.083
TOTAL SWING WEIGHT	360	1

The value scores for all MOEs were then put into another table and the measure weights that were calculated in Table 39 were applied to each MOE by multiplying the measure weight by the MOE value score. The resulting weighted scores were summed to create a single total effectiveness score. The table was then sorted from highest to lowest WVS. This identified which MOEs are the most important, which in turn, can assist in the prioritization of data collection efforts. The sorted MOEs and total effectiveness score are shown in Table 40.

Table 40. Application of Measure Weights And Resulting Total Effectiveness score

Evaluation Measure	Value Score	Measure Weight	Weighted Value Score
MOE-b - Procedures Defining Boundary Conditions of the S2S Capability	9.11	0.125	1.14
MOE-i - Influence of Procedures when Joint S2S Capability is used	8.00	0.139	1.11
MOE-r - Function Responsiveness	7.91	0.139	1.10
MOE-s - Suitability of S2S Functional Components	10.00	0.097	0.97
MOE-e - User-Component Experience	7.60	0.111	0.84
MOE-x - Functional Limitations	9.32	0.083	0.78
MOE-u - Procedures that Determine Resource Utilization	9.00	0.083	0.75
MOE-a - Mission Timeline with full capability	10.00	0.069	0.69
MOE-p- Mission Timeline without full capability	6.40	0.069	0.44
MOE-f - Influence of Procedures when Joint S2S Capability is NOT used	10.00	0.028	0.28
MOE-g - Prediction of Joint Function Interaction	8.82	0.028	0.25
MOE-c - Expectation of Joint Functions to Contribute to Mission Completion	8.80	0.028	0.24
		TOTAL EFFECTIVENESS SCORE:	8.60

To give the stakeholder an indication of where the total effectiveness score lies on a range of possible scores for the S2S capability, the team generated a worst-case to best-case operational effectiveness scale divided into three levels based on the 0 to 10 common constructed scale used throughout this application of the assessment framework. This operational effectiveness scale is shown in Table 41.

Table 41. Operational Effectiveness Scale

S2S Operational Effectiveness Scale			
High Operational Effectiveness	6.66	to	10.00
Medium Operational Effectiveness	3.33	to	6.66
Low Operational Effectiveness	0	to	3.33

This completed process validates that the conceptual assessment framework can generate relevant MOEs and produce a single operational effectiveness score for a S2S Capability. The results of the study and the artifacts for the applied use case were sent to the stakeholder, TRAC-Monterey, for their review and concurrence. According to TRAC-Monterey, the ability to evaluate different types of measures on a common scale "provides a huge benefit." TRAC-Monterey is also pleased that the conceptual assessment framework provides the ability to identify the most important measures, which will help focus their limited data collection resources on the most critical data measures.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

During this capstone project, the team completed the following activities:

- Developed a stakeholder-derived objectives hierarchy that deconstructs and baselines the objectives to be accomplished.
- Created a functional hierarchy that decomposes the necessary functions the conceptual assessment framework must perform.
- Developed a conceptual assessment framework that creates good measures, transforms those measures into value scores, quantifies the importance of the measures, and aggregates the resulting values into a single operational effectiveness score.
- Applied a use case to the conceptual design to gauge the robustness of the conceptual assessment framework's ability to produce good relevant measures that aggregate into a single operational effectiveness score.
- Created and received stakeholder concurrence on the conceptual assessment framework implementation plan for TRAC's use during PC21 in October 2021.

A SE methodology was created to produce a conceptual assessment framework for determining operational effectiveness. In doing so, the RM4 Convergence team provided TRAC-Monterey with a methodical process to assess if the new SoS technologies being demonstrated at PC21 meet the operational capabilities required to provide the Joint Force with the necessary speed, range, and convergence, to create future decision dominance and overmatch for the great-power competition. In response to the produced framework TRAC-Monterey stated, "being able to evaluate different types of MOEs on a common scale and being able to identify and rank-order the most critical MOEs are very strong aspects of the conceptual assessment framework." TRAC-Monterey also expressed that with this framework they will be able to focus their limited data collection resources on the most critical data measures and can apply the research to make better informed decisions on further technology development. The metrics developed in this study can also be used as a guide to collect relevant information throughout PC21 and beyond.

B. RECOMMENDATIONS

TRAC and JMC indicated that the efforts of PC are going to help rewrite doctrine in how Joint Operations are conducted. To further test and expand on the assessment framework provided, the RM4 Convergence team recommends the following actions be taken by TRAC-Monterey and JMC.

1. Validate the framework against the S2S use case 1–1 during PC21.
2. Collect data from other use cases during PC21 and apply them to this framework to test the flexibility and usability.
3. Conduct additional research into the cognitive aspects of operational effectiveness and how that information may be utilized to expand the scope of this assessment framework.

C. FUTURE COURSES OF ACTION

Additional studies into the cognitive aspects of operational effectiveness are needed, and according to JMC, "are far more important today than ever." The RM4 team only scratched the surface of this during this project given the timeframe afforded, and feel it is imperative that this broad research area be further and independently explored. Considering JMC's comments, studies that look in depth into the HSI influence on operational effectiveness and procedure/doctrine influence on operational effectiveness of capabilities will continue to be recommended.

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