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DEVELOPING AN ASSESSMENT SYSTEM FOR DOD DEMAND REDUCTION INITIATIVES

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SYSTEMS ENGINEERING CAPSTONE REPORT

DEVELOPING AN ASSESSMENT SYSTEM FOR DOD DEMAND REDUCTION INITIATIVES

by

Nathanael B. Achor, Courtney N. Franks, William N. Gillogly, and Randall P. Groller

June 2022

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13. ABSTRACT (maximum 200 words)

The Department of Defense (DOD) developed a new Joint Warfighting Concept (JWC) to address how the United States will confront the Nation’s most pressing national security challenges. The importance of logistics during combat operations and the ability to sustain a large force over strategic distances was the focus of the JWC. The DOD’s shift of focus to near-peer threats requires sustainment demand reduction across the services. Many demand reduction initiatives (DRI) are under consideration to lessen the burden of logistics at the strategic, operational, and tactical levels. Due to the relative newness of the JWC, the LOG FCB does not have a quantitative, credible, repeatable process to effectively assess, compare, and prioritize implementation of demand reduction initiatives.

This study implemented several Systems Engineering (SE) concepts which include the completion of stakeholder analysis, functional analysis, mapping of function to form, creating a top-level and detailed systems design, the use of value modeling, and the application of sensitivity analysis. The use of these SE tools and processes resulted in the development of a DRI Assessment System which includes instructions for use of the system, questionnaire for data collection, Excel calculation sheets, and the metrics and definitions for the selected attributes. These products provide the LOG FCB the capability to objectively prioritize current and future DRIs to implement across the DOD.

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DEVELOPING AN ASSESSMENT SYSTEM FOR DOD DEMAND REDUCTION INITIATIVES

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ABSTRACT

The DOD developed a new Joint Warfighting Concept (JWC) to address how the United States will confront the nation's most pressing national security challenges. The focus of the JWC was the importance of logistics during combat operations and the ability to sustain a large force over strategic distances. The DOD's shift of focus to near-peer threats requires sustainment demand reduction across the services. Many demand reduction initiatives (DRI) are under consideration to lessen the burden of logistics at the strategic, operational, and tactical levels. Due to the relative newness of the JWC, the LOG FCB does not have a quantitative, credible, repeatable process to effectively assess, compare, and prioritize implementation of demand reduction initiatives.

This study implemented several systems engineering (SE) concepts that include the completion of stakeholder analysis, functional analysis, mapping of function to form, creating a top-level and detailed systems design, the use of value modeling, and the application of sensitivity analysis. The use of these SE tools and processes resulted in the development of a DRI Assessment System which includes instructions for use of the system, questionnaire for data collection, Excel calculation sheets, and the metrics and definitions for the selected attributes. These products provide the logistics functional capability board (LOG FCB) the capability to objectively prioritize current and future DRIs to implement across the DOD.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	anti-access/area denial
AHP	analytic hierarchy process
AoA	analysis of alternatives
APM	autonomous predictive maintenance
BLS	biomanufacturing of lubricants from seawater
CF	combat feeding
COIN	counterinsurgency
DAS	DRI assessment system
DOD	Department of Defense
DODAF	Department of Defense Architecture Framework
DRI	demand reduction initiative
FBSE	functions-based systems engineering
FOB	forward operating base
FoM	freedom of maneuver
FTE	full-time equivalent
GAO	governmental accountability office
JCCL	joint contested concept of logistics
JP-8	jet propellant 8
JPAS	joint precision air drop system
JWC	joint warfighting concept
LINER	Energy Efficient Expedient Shelters with Non-woven Composite Insulation Liners
LoC	lines of communication
LOG FCB	logistics functional capability board
LSCO	large scale combat operations
MACK	modular appliances for configurable kitchens
MAFFS	mobile advanced fuel filling station
MNPP	mobile nuclear power plants
MPBR	modular photobioreactor
MOE	measure of effectiveness
MOP	measure of performance
MRE	meals ready-to-eat
OE	operating environment

OV	operational view
ORSA	operations research and systems analysis
OWA	ordered weighted averaging
POC	point of contact
PSHADE	powershade cost reduction
PV	photovoltaic
R & D	research and development
REIC	rapid expeditionary ice construction
ROI	return on investment
SE	Systems Engineering
SMA	spatial multi-criteria analysis
SPSWH	self-powered solar water heater
STAMP	secure tactical advanced mobile power
T & E	test and evaluation
TaCV-E	tactical and combat vehicle-electrification
TRL	technology readiness level
UAAPU	under armor auxiliary power unit
UCA	underwater cure adhesives
USPS	united states postal service
VAULTIS	visible, accessible, understandable, linked, trustworthy, interoperable, secure
WFA	water from air

EXECUTIVE SUMMARY

A. PROJECT OBJECTIVE

Due to the relative newness of the Joint Warfighting Concept (JWC), the Logistics Functional Capability Board (LOG FCB) does not have a quantitative, credible, repeatable process to effectively assess, compare, and prioritize implementation of demand reduction initiatives (DRI). The primary objective of this research project is to develop a process system that can assess, compare, and prioritize different demand reduction initiatives. The research team facilitates meeting the objective by accomplishing the following sub-objectives.

(1) Identify common demand reduction initiative attributes.

(2) Develop value models to score different initiative attributes on a common scale.

(3) Test the assessment system using historical programs. Present an example of prioritizing DRIs to J-4 Operations Research and Systems Analysis (ORSA) and LOG FCB.

(4) Document and develop a manual for implementing the DRI Assessment System (DAS).

(5) Provide the assessment system and tools to J-4 ORSA and LOG FCB.

B. BACKGROUND

The Department of Defense (DOD) developed a new JWC to address how the United States will confront the nation's most pressing national security challenges. Over the last five years, the DOD shifted from counter insurgency operations in Iraq and Afghanistan to a focus on near-peer competition. This change resulted in new sustainment needs, which require an investment in new technology. The shift of focus to near-peer adversaries requires a new, fundamental, demand reduction across the services (M. Webb, personal communication, 6 October 2021).

As the adversaries the United States faces change, the method of warfare changes, resulting in new needs to sustain United States forces. Demand reduction initiatives can universally affect the current, large in scope, logistics needs to support the mission in the new threat environment. The 20 years of contingency operations have reduced and created a less capable sustainment force, resulting in capability gaps in supporting large-scale combat operations (LSCO) (Lundy et al. 2019). Current logistics are infeasible and likely to result in failure if entering a fight with China and demand reduction is necessary to enable freedom of maneuver (FoM) and increase operational tempo, reach, and endurance (DOD 2021).

To meet these new sustainment needs, potential initiatives have been identified and initial testing of some proposed DRIs completed. Reducing demand increases the logistic capability and provides unencumbered FoM to the force by not requiring a large supply chain or frequent resupply. Drawing upon the new sustainment needs on the battlefield will help identify key parameters that impact attributes assessed within this system.

The JWC stressed the importance of logistics during combat operations and the ability to sustain a large force over strategic distances. To help reduce the burden of strategic, operational, and tactical logistics, proposals are submitted for a variety of demand reduction initiatives (M. Webb, personal communication, 6 October 2021). Due to the relative newness of the JWC, LOG FCB does not have a quantitative, credible, repeatable process to effectively assess, compare, and prioritize implementation of DRI. The team developed primary and secondary research questions that must be answered to ensure development of an effective and usable system.

Research Questions:

(1) How can we develop an assessment system that is applicable to a range of DRIs?

   a. What attributes are common to DRIs?

   b. Which identified DRI attributes are most valued by the stakeholder?

   c. How do we overcome the challenges in developing our DRI assessment system?

(2) What is the system scope to determine eligibility of DRIs for assessment?

C. ANALYSIS AND OUTCOMES

The team used a Systems Engineering approach, based on the Systems Engineering "Vee" Model, to develop this tool for the J-4 Analysis Branch. This study implemented several Systems Engineering concepts. Those methods include the completion of stakeholder analysis, the completion of functional analysis, mapping of function to form, creating a top-level system design, the use of value modeling, and the application of sensitivity analysis.

To develop a functioning system that met the objectives of the stakeholder, the team first identified the top-level requirement and completed a functional analysis of what the DAS must accomplish. This led to a functional decomposition of each provided DRI to identify and narrow attributes that were common and applicable. The team next identified "Reduce Weight," "Reduce Volume," "Reduce Fuel Consumption," and "Reduce Manhours" as the final four attributes to use within the system. The immaturity of DRIs hindered the ability to develop metrics based on data from the DRIs. This resulted in the decision to research how industry has increased efficiency in similar attributes. Finally, it was determined that information gathered through research on industry efforts could provide metrics for use in the DAS. These metrics were developed to assess both qualitative and quantitative inputs on a value scale to assess future DRIs, understanding that the DAS must have the capability to compare a wide range of DRIs with varying TRLs.

Overall, the completed functional analysis of the system and the application of value modeling resulted in the functioning DAS. The team provided the DAS tool to the stakeholder which includes instructions for use of the system, questionnaire for data collection, Excel calculation sheets, and the metrics and definitions for the selected attributes. By providing these products, the team accomplished the primary objective of developing a system that can assess, compare, and prioritize different demand reduction initiatives using a Systems Engineering approach.

D. CONCLUSIONS AND RECOMMENDATIONS

The efforts of this study provide a method for objective assessment of disparate DRIs that can be revised as the OE changes. This will be invaluable to providing all branches of the military with the most impactful technologies and equipment to reduce demand at the individual warfighter level through large units. Additionally, it provides the LOG FCB with the ability to fulfill their task of objectively prioritizing disparate DRIs. Most importantly, the LOG FCB will be utilizing the DAS in their upcoming Capability Portfolio Management Review this fall.

There are opportunities to refine and improve the DAS for future use. Those areas include questionnaire refinement for data collection, collecting more data on the initial DRIs or new DRIs to improve scoring and curve accuracy, developing benefit analysis, categorization of DRIs based on TRLs, and implementing communication best practices to filter initiatives for use within the system. These recommendations will increase the accuracy of the assessment system and the ability to change or redefine attribute values as DRI priorities change.

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I. INTRODUCTION

A. BACKGROUND AND PROBLEM STATEMENT

The Department of Defense (DOD) developed a new Joint Warfighting Concept (JWC) in 2020 to define how the United States will address the nation's most pressing national security challenges. The importance of logistics during combat operations and the ability to sustain a large force over strategic distances is the focus of the JWC. The DOD's focus on near-peer adversaries has required demand reduction across the services. DOD is evaluating demand reduction initiatives (DRI) proposals to help reduce the burden of strategic, operational, and tactical logistics.

Due to the relative newness of the JWC, Logistics Functional Capability Board (LOG FCB) does not have a quantitative, credible, repeatable process to effectively assess, compare, select, and prioritize implementation of DRI. Five major causes of this problem have been identified: the warfare focus shift to near-peer competition; the needs of the force and emerging DRI solutions; the range of DRIs; an absence of an assessment system for the initiatives; and the need to assess and compare the initiatives. With initiatives containing unique requirements and varying maturities, there is a lack of research to determine a commonality among them so that they can be assessed and prioritized. The understanding of these difficulties led to the development of primary and secondary research questions that must be answered to ensure an effective and usable system was developed.

Research Questions:

(1) How can we develop an assessment system that is applicable to a range of DRIs?

   a. What attributes are common to DRIs?

   b. Which identified DRI attributes are most valued by the stakeholder?

   c. How do we overcome the challenges in developing our DRI assessment system?

(2) What is the system scope to determine eligibility of DRIs for assessment?

There are several reasons why no current framework to aid in prioritizing proposed DRIs exists (M. Webb, personal communication, 6 October 2021). The primary cause is that this is the first time the LOG FCB has been asked to prioritize DRIs and no DRI assessment method exists. Secondly, previously used assessment methods are not applicable because of the wide range of initiatives under review that aim to reduce logistics demands in the operating environment (OE). These initiatives are either new and may contain emerging technology, or technology that has not been applied to a sustainment environment. Therefore, there is no current method to evaluate new technology that meets new needs within the demand reduction environment.

The DOD has become accustomed to fighting asymmetrical warfare. Fighting from a forward operating base (FOB) with air superiority made it easier to supply the warfighter with logistical support. The transformation from counterinsurgency operations (COIN) to large-scale combat operations (LSCO) in the near-peer threat environment regenerates logistics issues from the past that must be taken into consideration when evaluating reduction initiatives. According to Lieutenant General (Retired) Lundy et al.'s (2019, 2–3) article discussing LSCO impacts on sustaining the force, "Our sustainers will need to keep most supply commodities mobile…resupply missions will be done while in contact with the enemy." The ideas brought forth in this article lend themselves to the Acquisition Corps' need to develop and field new logistics capabilities to support and sustain operational units effectively.

Another issue is that each Service has its own mission and doctrine on how to fight the next war, thus creating its own priorities. As stakeholders, each branch of service will influence LOG FCB's prioritization. For instance, the Marine Corps' rapid force restructuring and shift to focusing on Southeast Asia has changed its priorities to light infantry operations on islands with long range fires support (Cancian 2020). Thus, the Marine Corps' focus on demand reduction will not prioritize ice construction or Autonomous Predictive Maintenance (APM) initiatives. The Army, however, will prioritize these initiatives due to their interest in arctic operations and reliance on vehicular transportation. Comparatively, the Navy will likely prioritize initiatives that best support sea operations, while the Army will prioritize initiatives that best support land operations. Therefore, each Service's internal needs and priorities have an upstream influence on the requirements for LOG FCB's priorities.

Developing an assessment system that accommodates the priorities of each service while evenly evaluating each initiative must be considered to provide a successful system. The difficulty in comparing DRIs stems from the large scope and differing requirements and needs of each project. The LOG FCB's projects span from ice construction, a rapid system that turns snow and ice into water, Combat Feeding, Mobile Nuclear Power Plants (MNPP), APM, and Tactical and Combat Vehicle-Electrification (TaCV-E). These initiatives form a large scope with each one targeting different and specific reduction needs. The threat environment also dictates which initiatives to prioritize. For instance, the REIC initiative may have significant impacts on demand reduction in Europe, but not in southeast Asia. This difference in demand reduction impacts highlights the challenge LOG FCB has in comparing and prioritizing initiatives.

This system is scoped to evaluate technology initiatives and will not evaluate process initiatives. The timeline when each initiative will be ready for implementation into maneuver operations vary as each are at different stages in their life cycles. Some initiatives are still in the research and development stage while others are developing a prototype. This variance has made it difficult to prioritize DRIs with various technology readiness levels (TRL) and life cycle stages of the initiatives. The MNPP timeline can have a completed prototype by 2023 while the TaCV-E is pursuing changing the fleet to electric vehicles from 2022 through beyond 2050 (M. Webb, email to authors, 6 October 2021). Overall, a more mature program provides a greater amount of data which allows for a more accurate assessment of the initiative.

The final cause of the identified problem is the lack of a common scale that can be used to evaluate the initiatives. An absent common scale for assessment is due to the initiatives being at different points in the acquisition life cycle, having widely varying purposes, and having different TRLs. To understand the difficulty of this cause, the J-4 Analysis Branch Chief, a project stakeholder, provided a sample of working initiatives which include but are not limited to the list below (M. Webb, email to authors, 6 October 2021):

- Tactical and Combat Vehicle-Electrification (TaCV-E): This initiative applies the use of electric and hybrid vehicles as seen in civilian industry. This initiative reduces the fuel resupply needs across the military, impacting time recouped from fuel transport and amount of fuel resources to be purchased and stored (Maneuver Requirements Division [MRD] 2021).

- Autonomous Predictive Maintenance (APM): Implementation of this system provides a sensor capability to determine equipment condition, then autonomously make maintenance decisions and prioritize maintenance actions. This effort allows reduction of personnel time spent on unnecessary maintenance or on not solving root maintenance issues and keeps equipment at a higher fully mission capable status (DOD 2019).

- Mobile Nuclear Power Plant (MNPP): This system provides an efficient energy source to support ground operations that is immediately ready to operate, does not require refueling, and is retrievable within 24 hours of end of operations (Vitali 2019).

- Combat Feeding (CF): Reduced size and weight Meals Ready-to-Eat (MREs) lighten the load for service members to carry, allowing increased duration and faster unit movement. This initiative also reduces the space required to transport and store MREs needed for operations (OASDHA 2020).

- Rapid Expeditionary Ice Construction (REIC): This initiative applies construction using snow and ice elements to degrade thermal challenges in sustainment operations (JWC 2021).

An absence of an assessment framework and a changing operating environment require a deeper look into LSCO sustainment needs to accurately prioritize differing demand reduction initiatives that are currently in development. Most importantly, the capstone team must develop evaluation criteria to assess the provided initiatives.

B. PROJECT SCOPE AND DELIVERABLES

The scope of this capstone project is bounded by the time available to the team and by the maturity of the DRIs as they range from white papers to technology that is currently being developed and tested. The team began the study in October 2021 and will complete the project in June 2022. Data analysis and ensuing validation of the assessment system will allow the J-4 Analysis Branch to compare initiatives and provide a recommendation to the LOG FCB chair on which initiatives should be prioritized.

The team anticipates some DRIs provided by J-4 Analysis Branch will not be applicable within our system due to issues related to TRL or not being measurable across all developed attributes. The project team will develop an assessment system and value model to translate various initiatives into common characteristics that can then be assessed and compared based on DRI attributes that provide value to the stakeholder. Any initiative that cannot be assessed with this system because of its immaturity is outside the scope of this project and will not be considered by the team.

This project will follow the System's Engineering Vee-Model to design and develop the DRI Assessment System (DAS), shown in Figure 1.

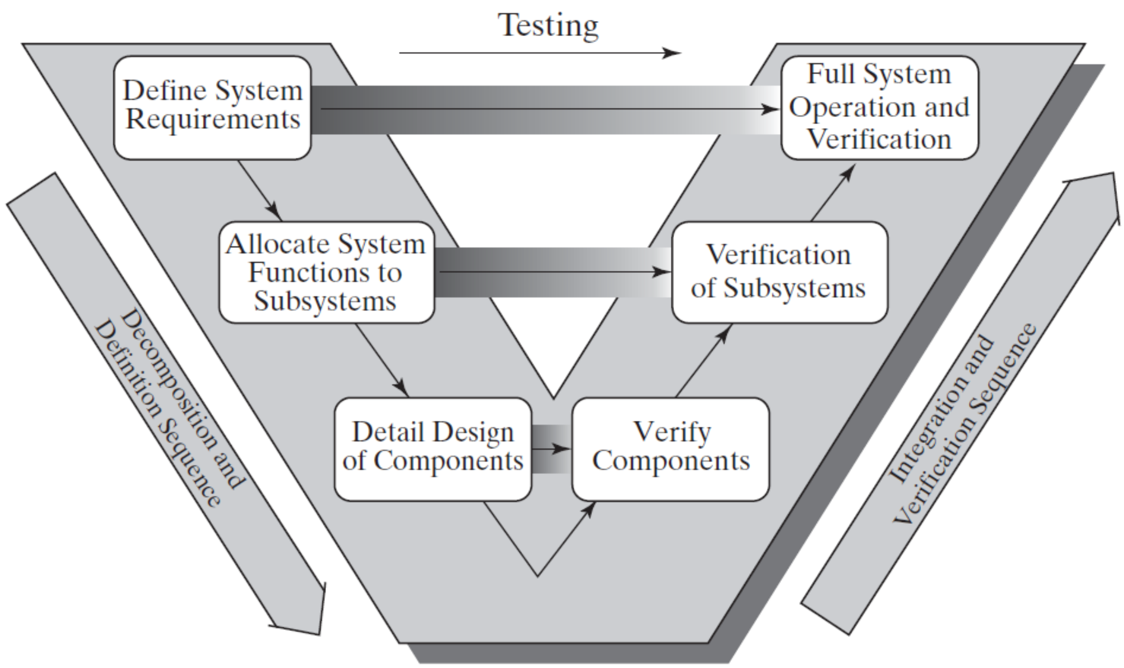

Figure 1. System's Engineering Vee-Model. Source: Blanchard and Fabrycky (2014).

The overall project deliverable will be a fully functional assessment system that supports an analysis of alternatives (AoA) and value analysis of each DRI. The functional system is essentially a methodology in a step-by-step process. To provide background understanding to the end user, the team will develop and provide the functional hierarchy, functional analysis, system architecture, and system test plan with results. Included with the system is information to aid the end user in understanding how to effectively input DRIs for prioritization. The provided information includes requirements for the system; a step-by-step set of instructions; explanations for each DRI common attribute with examples of data that does and does not work for each; and an example of a final DRI prioritization list with the data to support it. The tools provided will include value models for each DRI attribute and the measures to evaluate the system for any future changes. This system will be validated prior to providing it to the end user by inputting DRI data received from stakeholders to assess initiatives, as well as inputting data to assess historical DRI systems with known performance impacts.

The outcome of this project is an assessment system that produces a prioritization of DRIs to recommend to the LOG FCB chair. With the finalized system information and tools, the end user will have the ability to identify accurate DRI data to input into the developed value models and create a prioritization based on common, quantifiable attributes. Prioritizing the most effective initiatives in reducing logistical needs will ultimately benefit the warfighter by reducing the need for resupply missions in a contested environment. The LOG FCB can further refine the system to maximize accuracy in assessing future initiatives.

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II. LITERATURE REVIEW

A. LITERATURE REVIEW METHODOLOGY

The study team applied an incremental process to prepare for and complete a literature review on the given problem. The development of an annotated bibliography provided an organized source selection bank of knowledge, methods, and lessons learned to draw upon during literature review and future development of the assessment system. Criteria to select articles from this document consisted of selecting those that provided the most quantifiable material: explored assessment of technology, energy, and/or logistics related efforts; those which discussed multiple criteria decision modeling; and those that developed a framework for assessment. Each of the five major causes examined in this review break down the selected sources to provide understanding of the history of the topic, variables and relationships, and previously used research methodologies and techniques.

The following sections of this chapter discuss the five identified causes of the given problem: first, how the shift in warfare to focus on near-peer adversaries has changed the logistics needs of the Department of Defense (DOD) and the importance of reducing the demand on logistics; second, identified needs and emerging demand reduction initiative (DRI) solutions; third, the various demand reduction initiatives the DOD is currently pursuing; fourth, how assessment frameworks have been used in the past to aid decision makers in complex environments; and finally, various techniques researchers have used to assess and compare items with similar functions.

B. SHIFT IN WARFARE

The last two decades of war have focused on counterinsurgency (COIN) warfare in the Middle East, a stark contrast to the near-peer adversaries that dominate the threat environment today (Lundy et al. 2019). While the DOD has refocused on near-peer adversaries, the threat environment and potential enemy capabilities are also much different than in the past. In addition, continuous technological changes have outpaced DOD strategy, doctrine, and force structure. As described by MAJ Webb (J-4 Analysis Branch Chief), a primary stakeholder, the Joint Warfighting Concept (JWC) and the Joint

Contested Concept of Logistics (JCCL) are new Joint Operation Concepts that have recently been published (M. Webb, email to authors, 6 October 2021). Both concepts require changes to logistics operations in the next war. These changes in operations lead to rapidly developing techniques, technologies, and strategies to overcome current capabilities gaps. The bottom line is that there is a new threat environment, causing a change in current mission and force structure, thus creating new needs, with new operational solutions and logistics demands to identify. The large scale of new logistics demands has led to difficulty in the prioritization of demand reduction initiatives currently in development.

A rapidly closing capability gap with near-peer adversaries is creating a new threat environment. This change to the operational and strategic threat environment has major implications for logistics; the JCCL states, “the Joint Force requires fundamental demand reduction across the Services… As part of this effort, the Joint Force should prioritize and target specific reductions in support forces and material required forward to reduce sustainment demands” (DOD 2021, 22). The two main contributors to the new operating environment (OE) are Russia and China. Russia is modernizing its land-, air-, and sea-based intercontinental nuclear forces, while China is combining its industrial and economic growth to fulfill its desire to become a regional hegemon and global power once again. This change in circumstances has increased the threat to United States forces (DOD 2016).

The risk units face when conducting missions in operational areas has been greatly increased by the technological advancements, which resulted in falling costs and increased availability of highly effective anti-aircraft, anti-ship missile, and associated sensor networks (Haddick 2016). Haddick further states that these technological advancements will contest major ports and airfields which are in range of the enemy and threaten friendly lines of communication (LoCs). As a result, these advancements drive the United States forces to change how it conducts logistics operations. Haddick argues the United States can no longer expect to rely on helicopter sustainment due to air defenses, and traditional maritime techniques are likely infeasible against an enemy with significant naval power and surveillance. The future delivery methods in hyper-sonics, long-range missiles, and ballistic missiles designed to penetrate United States defenses will allow threats to attack major nodes of global trade and logistics (DOD 2016). Due to the precision of long-range missiles, the DOD must reduce demand or decrease the pressure on the LoCs (Haddick 2016).

In essence, all major seaports required by a Joint Force are now within reach of enemy capabilities. The United States has not contended with threats to logistics from the United States shore to the OE since World War II. Any concentration of supplies in a single place is under threat and will be targeted. In addition, cheap systems have complicated the OE. Adversary fires can extend to friendly resupply points, placing them in contact with the enemy (Lundy et al. 2019). To provide a deeper understanding, Lundy et al. (2019, 3) stated that, "In 2015, a Russian-made unmanned aerial vehicle dropped a single thermite grenade on a Ukrainian ammunition supply point," destroying nearly all Ukrainian multiple-rocket launcher ammunition. Large Scale Combat Operations with uncontested LoCs are obsolete. Now every LoC and base will be under threat. The proliferation of anti-access/area denial (A2/AD) capabilities has degraded logistics and jeopardizes mission accomplishment in practically any situation (DOD 2015). The next war will likely be centered on denial within OEs that no one owns, but everyone operates (DOD 2016). This rapidly evolving threat environment has resulted in a change to mission needs. Understanding the shift in warfare and the corresponding sustainment needs, facilitates development of demand reduction attributes, which impact the maneuver force.

Understanding changes on the battlefield enables further insight to develop a system that compares, assesses, and prioritizes the initiatives to fulfill these operational warfighter needs. Review of the of the shift in warfare will aid in identifying the DRIs that best impact these changes. The analysis of this shift also provides the ability to recognize emerging technologies that can close the identified capability gaps.

C. IDENTIFIED NEEDS AND EMERGING DRI SOLUTIONS

The 20 years of contingency operations reduced and created a less capable sustainment force, resulting in capability gaps in supporting LSCOs (Lundy et al. 2019). In addition, current logistics are infeasible and likely to result in failure if entering a fight with China (DOD 2021), due to the A2/D2 network and long-range fires coupled with satellite surveillance. The following needs must be met to remedy the stretched LoC, A2/AD threats, and current large logistics footprint: first, logistics must enable flexibility, speed, and freedom of action (Lundy et. al 2019); second, logistic initiatives and systems must increase logistics capacity due to the growing complexity of the force and the DOD need for a rapid transport system (DOD 2015); third, logistics needs transformative changes to culture, how the DOD operates, and acquisition of new systems; finally, demand reduction is necessary to enable freedom of maneuver (FoM) and increase operational tempo, reach, and endurance (DOD 2021). This research has resulted in a common theme of what the DOD needs for the maneuver force in enduring operations and what sustainment DRIs should aspire to enable: required freedom of action by increasing the logistic capabilities in speed, reach, endurance, and flexibility. Central to increasing logistic capabilities, the DOD must initiate a reduction in demand and change in the capability process to reduce requirements on the supply chain (DOD 2021). Emerging DRIs can universally affect the current, large-in-scope, logistic needs to support the mission in this new threat environment.

To meet these needs, various organizations have developed/proposed potential DRI solutions. In the last 20 years, the DOD has relied upon contracted sustainment to fill the capability gap, resulting in a less capable force and an unsustainable solution for the future (Lundy et al. 2019). Therefore, due to the new threat environment, the DOD's contracted sustainment may be limited due to the greatly increased risk to the contractor. This limitation only further puts pressure on the DOD's sustainment capability. The continual force structure evolution and new technologies have resulted in increased demand and constrained resources throughout the force (DOD 2015). The growing complexity of the force creates a greater demand for repair parts and energy, as well as a requirement for dispersed, flexible, and mobile platforms to support these sustainment needs. Combined with longer LoCs, the Joint Force's ability to close with and destroy enemy forces is jeopardized (DOD 2021).

Although the solution to A2/AD is to operate multiple, independent sites of operations (DOD 2015) and to have highly mobile logistic units (Lundy et al. 2019), this only increases demand on an already outpaced logistics structure. Unmanned helicopters were used in Afghanistan for resupply missions as a solution to this issue (Haddick 2016). Possible future solutions of utilizing new delivery techniques with small, hard to detect unmanned systems (such as drones, submarines, or vessels) will require packages to be smaller and lighter, like highly nutritious food for example (Haddick 2016). Other recommended solutions include developing unmanned undersea cargo vehicles and utilizing expeditionary additive manufacturing tools. There are specific solutions for sustainment demand reduction that have been provided to the DOD for possible implementation: development of long endurance batteries; highly concentrated food and nutrition products that reduce the current weight and size; tools to aid in foraging for nutrition from local sources; and precision small-scale munitions to reduce munition demands. In addition, the force must be able to move supplies rapidly in austere conditions with limited port availability by utilizing smaller prepositioned and float stocks (DOD 2015).

Future sustainment packages must supply as many goods per package as possible in a limited amount of space. Coupled with sustainment packages, capability development processes must change to reduce requirements on sustainment (DOD 2021) and initiatives must reduce the logistics requirements for deployment, distribution, supplies, and services (DOD 2015). Sustainment reduction can be accomplished by creating a leaner force in which energy consumption, maintenance, and other support are required in force planning and acquisition (DOD 2015). Demand reduction for sustainment is central to these efforts. Reducing demand in material required in an operational area, increases the logistic capability, and provides unencumbered FoM to the maneuver force by reducing the need for a large supply chain or frequent resupply.

Drawing upon these new sustainment needs on the battlefield allows the identification of key parameters that impact initiative attributes to be assessed within the system. As the JCCL and Lundy stated, the parameters for new initiatives must increase FoM by enabling speed, reach, endurance, and flexibility. Review of the varying initiatives will aid in identifying the DRIs that best impact these areas.

D. RANGE OF DEMAND REDUCTION INITIATIVES

The J-4 Analysis Branch receives many DRIs which contain significant variance in reducing logistics demand, their life cycle stages, and data available. The Army is looking to reduce sustainment demands at camps to minimize the amount of resupply operations needed. This would also minimize the associated ground and air protection needed for operations. Sustainment covers a vast number of operations and resources. It can refer to any of the classes of supply, maintenance operations, or waste removal. Limiting these logistical demands can potentially save the lives of soldiers. The demand reduction initiatives seek to accomplish that mission, but they have such a wide scope that it is difficult to determine which are most beneficial. The "Modeling and Simulation Analysis of Fuel, Water, and Waste Reductions in Base Camps" report determined that fuel, water, waste, and quality of life were key metrics in the sustainment of a base (Gildea et al. 2017). It states further that, "Water is the largest resource transported to a base camp in terms of volume. Solutions that reduce the need for potable water to be transported to and gray and black water transported from the base camp play a significant part in meeting the overall logistic reduction metrics" (xi). Using this analysis and an understanding of how water and fuel reduction efforts are prioritized will be beneficial when evaluating a system with a primary purpose to reduce those sustainment needs. Although fuel, water, and waste are considered key metrics, there are other attributes that should be considered when determining reduction initiatives.

The different types of DRIs are in various stages of acquisition life cycle maturity. The systems' maturity is measured by technology readiness levels (TRL). A TRL of one is the lowest level of technology readiness, and a TRL of nine is the highest (Gildea et al. 2018). For example, the MNPP has components that are TRL six through nine, so it is closer to being implemented with full technology readiness (Vitali 2019). The Rapid Expeditionary Ice Construction initiative is at a TRL of four and five, so it is further from technological development which will delay implementation (JWC 2021). Understanding the impact of immature technology and how it affects an initiative in production or an initiative still in the research phase will help scope the initiatives to be assessed.

Energy efficiency is an important attribute that could assess the demand initiatives. It results in less fuel usage which results in lower cost and less tonnage being delivered to bases throughout the area of operations. The following systems' main intentions are to reduce energy needs on a base. The PowerShade Cost Reduction (PSHADE) is described as "a fabric structure with built-in photovoltaic (PV) array that is designed to shade and provide power to tents" (Gildea et al. 2018, 21). This shelter is intended to reduce costs by providing a better electrical generation capability and would decrease a need for traditional fuel powered electrical generators. The Self-Powered Solar Water Heater (SPSWH) technology project seeks to "develop alternative energy technology to enhance the capability to reduce fuel required for heating and pumping water by concentrating solar energy to heat water and generate electric power for a pump" (2018, 23). The authors' assessment of the system noted that it was still in the prototype phase with a TRL of four. Due to its immaturity, it had multiple safety hazards and it was determined that more evaluation is needed once it was enhanced in the next phase of development. The Energy Efficient Expedient Shelters with Non-woven Composite Insulation Liners (LINER) is a non-woven, composite insulation liner that would be put in soft wall shelters to increase energy conservation. This system would give soldiers a higher quality of life with better climate control and reduce the shelter's infrared signature. It is at TRL nine and has been fielded. It was determined that the LINER system is bulkier than the original which could cause issues by taking up too much space in a container when it needs to be shipped. The Modular Appliances for Configurable Kitchens (MACK) was designed for safety, energy efficiency, and cost savings reasons. The current appliances are loud, expensive, inefficient, and exhaust heat and combustion into the workspace. The MACK is currently at TRL six and has demonstrated that it performs well with very few issues (Gildea et al. 2018).

The "Selected Technology Assessment," report also studied systems that focused on water reduction. The Modular Force Water Generation Storage and Analysis (Water from Air or WFA) system generates up to 500 gallons per day from the atmospheric humidity. The results from the analysis of this system determined that, although it is promising, there are some human factors engineering issues with the WFA that make it difficult to operate, and some effort could be put into redesign for improvement. The need for bulk water storage would be reduced by 50 to 75% with this system. It would also reduce any efforts to resupply the base with water (Gildea et al. 2018). One of the water-reducing technologies examined was as simple as a shower head. The WFA system discussed above is a large container that would be difficult for transport; however, the shower head is very small and could be transported more easily. A comparison of the transportability and efficiency of the system to reduce water demands could help to develop our system (Gildea et al. 2018).

Examining how the systems intend to reduce sustainment needs was beneficial to determine how to scope future DRIs. Most of the initiatives were designed to reduce energy needs such as fuel, which would also reduce cost. Reducing fuel on a base will decrease the need for resupply convoys, so these systems are important to consider. Immature TRL levels of an initiative should also be considered because they consistently had safety issues associated with them. Some of the systems are bulkier and larger than the systems they are replacing which is a concerning factor while shipping. The more containers that are needed to ship the system will decrease its transportability. Moreover, this report had many more systems that were introduced and studied that will be helpful when developing the team's common scale and system (Gildea et al. 2018).

Understanding the range in DRIs and their associated data, facilitates creation of guidance to identify initiatives which will not work within the system due to a lack of development. Additionally, the surviving initiatives and understanding of future sustainment needs creates further exclusion guidance. Further, the remaining initiatives and understanding of needs fully develops the assessment system with common DRI attributes and their associated scales to evaluate demand reduction.

E. REVIEW OF POTENTIAL, SUITABLE, ASSESSMENT FRAMEWORKS FOR DRIS

The development of assessment frameworks to assist decision makers in complex environments is not a new concept. Assessment frameworks provide a way to solve complex problems by distilling numerous problems or initiatives into like ideas or groups that can then be compared based on the predetermined requirements of the system (Bohanec and Rajkovic 1999; Mitgutsch and Alvarado 2012). The assessment framework takes the desired characteristics from the customer and applies them to the varying alternatives. It provides order in an otherwise chaotic environment and ultimately ensures the decision maker is well informed. The outcome of this process is a tool that assists the decision maker in understanding the trade-space between the alternatives (Narrei and Osanloo 2011).

Assessment frameworks have been utilized successfully in a variety of environments, including emerging technology, urban sustainability, mined land suitability, and serious game design. Ivanova and Gallasch (2015) developed an assessment framework to compare current and anticipated requirements of the Australian military against emerging technology. Their framework utilized three key questions with corresponding sub questions to understand how an emerging technology would benefit the military and if it was feasible and attainable. These questions allowed their team to look at varying technologies through the lens of current doctrine and compare them against each other. Ivanova and Gallasch utilized questionnaires, workshops, and scenarios to both understand the needs of the customer and validate the framework. Their team did not, however, include a weighted preference as part of the checklist because they did not want numbers to impact the judgement of the decision makers. Not using weights is a major disadvantage of this method because it does not reflect the importance of DRI attributes to the stakeholder. However, there is an advantage to using interviews and surveys as it allows the team to gather timely and accurate data from stakeholders.

An urban sustainability assessment framework was developed by Ameen and Mourshed (2019) to address characteristics of urban development in developing countries. As assessment frameworks identify attributes and their relationships (Mitgutsch and Alvarado 2012), Ameen and Mourshed argued urban sustainability assessment frameworks used in developed countries would not prove successful when used in developing countries. Developed countries had far fewer characteristics of interest than undeveloped countries did. Unlike Ivanova and Gallasch, Ameen and Mourshed's assessment framework did apply weights to score the identified characteristics to help determine areas of emphasis based on stakeholder priorities. Their goal was both to rank and then weight their attributes to establish a way to compare them. Likewise, looking at successful assessment frameworks in a variety of environments provides examples of advantageous methods that can be applied to this project. Both Ivanova and Gallasch (2015) and Ameen and Mourshed (2019) placed an emphasis on understanding the stakeholder's need before developing a framework. Ameen and Mourshed stressed the importance of engaging with both the general population and decision makers. This method provides the advantage of clear communication with the stakeholder, J-4, and organizations developing the DRIs to determine which characteristics or attributes are most valuable.

Post-mining land use is another complex environment in which assessment frameworks have successfully been used to identify which attributes are important and how to effectively compare them (Narrei and Osanloo 2011). Narrei and Osanloo took four main attributes of mined land suitability analysis to create their initial categories and decomposed these four categories to determine the attributes of this system. These attributes, when weighted, are combined with different land use possibilities to produce recommendations for the decision maker. They rely on a mathematical approach to provide the best combination of attributes that satisfy their parameters. This is in contrast with Ivanova and Gallasch's technique, in which they state weights can create bias in the decision maker; they believe not using numbers ensures the decision maker is well informed and unbiased (Ivanova and Gallasch 2015). This is another example of weights being used successfully and reinforces the advantage of this method.

Knowledge of how assessment frameworks have been developed in the past will help our team assess the DRI alternatives provided to United States by the J-4 and develop a system that specifically addresses this project's problem statement. Comprehension of the scope of the DRI across the joint force allows the assessment of the provided DRIs based on desirable characteristics, thus illuminating duplicative efforts or gaps not currently being pursued by the DOD (McLeod 2011). This insight will help the team develop the system to compare the DRI and propose desired characteristics to the J-4 Analysis Branch which reflect both risk management and current joint doctrine (Bond et al. 2015). Methods applied in the discussed frameworks can be used to create a well-scoped system with relevant attributes and measurable units of scale.

F. ASSESSING AND COMPARING DRIS

Developing an initiative prioritization requires an equal assessment and comparison of all DRIs. When assessing and comparing like items, several considerations and methods can be applied. There are three areas to develop for accurate assessment and comparison: identification of common attributes; determining if quantifiable and/or qualitative information will be used; multi-attribute assessment if more than one attribute is used; decisions on what type of scale to use; and weighting of attributes if some are deemed more important than others.

A well-balanced framework that is flexible and executable contains scalable criteria, a sound and detailed construct, and simple visual display and guidance. Successful frameworks strike a balance between being too complicated to understand or execute and being too vague with a lack of instruction and constraints (Carter 2014). The Functions-Based Systems Engineering (FBSE) Method, as described in *The Systems Engineering Handbook*, serves as an approach to develop systems. This method focuses on tasks, actions, and activities. The FBSE begins with top level function created based on known objectives and decomposes functions into smaller subfunctions of a system. This method is visualized in the form of a functional hierarchy; a representation of how to develop a functional hierarchy from *The Systems Engineering Handbook* is shown in Figure 2.

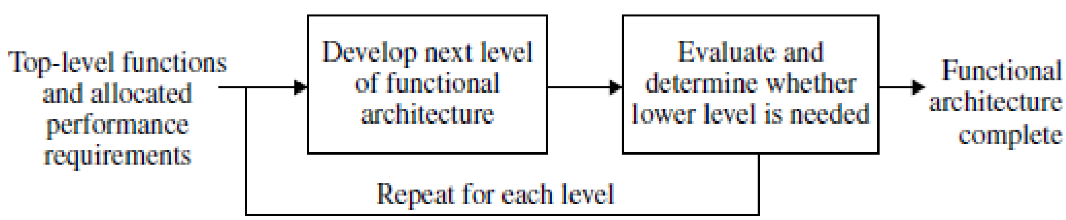

Figure 2. Forsberg et al.'s Functional Hierarchy Development. Source: Forsberg et al. (2015, 190).

Spatial Multi-Criteria Analysis (SMA) within a framework of the Analytic Hierarchy Process (AHP) is a method used to develop Ordered Weighted Averaging (OWA) and decision maps to support decision-making. This process is appropriate to apply to the project's problem because it useful for “fuzzy sets.” These “fuzzy sets” are alternatives being evaluated which consist of multiple criteria, unquantifiable criteria, and criteria that has varying degrees of importance to decision makers (Silva 2020). Additionally, AHP is a structured and organized method of evaluation to support decision making. This structure and organization enable development of a framework that is easily understandable, an important characteristic for a framework being developed for others to use (Ameen and Mourshed 2019). The four main steps in AHP to developing this structured framework are to “define the problem…structure the decision hierarchy…[develop] pairwise comparison matrices…[and] use the priorities obtained from the comparisons” to apply weighting in evaluation (Saaty 2008, 85).

When assessing like items, attributes must be developed to compare, and the attributes used for comparison must be applicable to every item. Attributes can be broken down into three types. Those types are natural, constructed, and proxy (Keeney 1992, 101–103). Natural attributes are those commonly understood by all, like “weight in pounds.” Constructed attributes do not have a common understanding of what and how to measure. They require a written description and often have levels for evaluation. As an example of a constructed attribute, levels with associated descriptions for the attribute of transportability were developed: 1—easily moved with foot, vehicle, and air transportation, 2—easily moved with vehicle and air transportation, and 3—easily moved with air transportation. Lastly, proxy attributes, like constructed attributes, do not have a common understanding or measurement. Rather than identifying an effect with a level, proxy attributes are determined by relationships between objectives and the attribute. To provide an example, an attribute of “return on investment” would be determined based on how much energy the system provides, compared to what is put into it in resources (e.g., cost, fuel). This type of attribute is only used when natural or constructed attributes are not able to be applied to a functional objective.

A plethora of academic studies into energy initiatives and sustainment priorities provide a foundation of attributes to select from or refine to fit within the created assessment system. A DOD operational energy strategy identifies three key areas where reduction focuses can greatly impact military operations. The three efforts are to “reduce the demand for energy…expand and secure the supply of energy…[and] build energy security into the future force" (DOD 2011, 1). The United States Government Accountability Office (GAO) completed a report discussing energy reduction efforts in the military and providing fuel efficiency, weight, and logistics as recommended focus areas to reduce the energy demand (Solis 2008). The various attributes gathered from completed research in this paragraph, combined with new sustainment needs of warfare and knowledge of the provided DRIs, will facilitate the finalization of common initiative attributes assessed in our system.

Keeney (1992) found value modeling to be an effective method for evaluation as it provides the opportunity to assess both qualitative and quantitative information. While quantitative scales provide obvious numerical measurability, there is the ability to use ordinal qualitative scales to assess attributes which lack evenly comparable numerical information. This can come in the form of rating each initiative on a scale of "low impact," "medium impact," and "high impact" with preference relation analysis (Ehrgott 2010, 273). The SMA process supports the needs of this system as it allows the use of quantifiable and qualitative data to evaluate and order alternatives. Additionally, the SMA applies the OWA, a method of weighting the criteria based on importance (Silva 2020). Weighting criteria is a proven method to ensure the ranking of alternatives provided to a decision maker is accurate to the most highly desired capabilities.

Attribute types, FBSE, SMA, AHP, and value modeling are all proven and effective methods designed to support decision-making. Understanding their purposes, how to use each method, and their expected outcomes are important in selecting which methods to use. Utilizing some of the discussed approaches to create an assessment system will result in the identification of attributes common to all DRIs and facilitate a reasonable comparison of the DRIs using numerical values for prioritization purposes. The team will be able to apply and test the effectiveness of these methods by inputting data of given initiatives into the developed system.

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III. METHODOLOGY

This chapter provides the process through which the team developed and validated the DRI Assessment System (DAS). This methodology identifies five key areas of discussion: interaction with stakeholders; defining system requirements; allocating system functions/ performance requirements; developing the assessment system through top-level and detailed design; and validating the assessment system through operations tests. A visual representation of the methodology developed for the DAS is shown in Figure 3. This model is adapted from multiple systems engineering vee models, using relevant parts of each for the complete model. This adapted version of the model for the capstone project and is explained in further detail throughout this chapter.

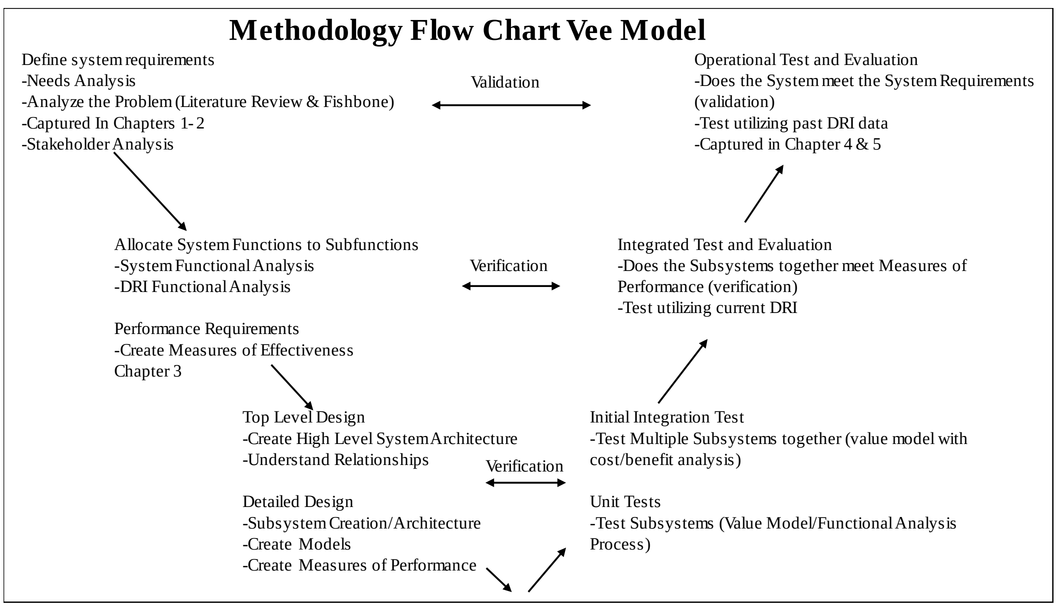

Figure 3. Adapted Methodology Flow Chart Vee Model

This adapted methodology contains several stakeholder objectives that supported project success. The main objectives for this system are to analyze DRIs, create a repeatable process, and expedite DRI decision-making. These main objectives were further decomposed into sub-objectives with metrics for evaluation, creating an objectives hierarchy. This objectives hierarchy is shown in Figure 4.

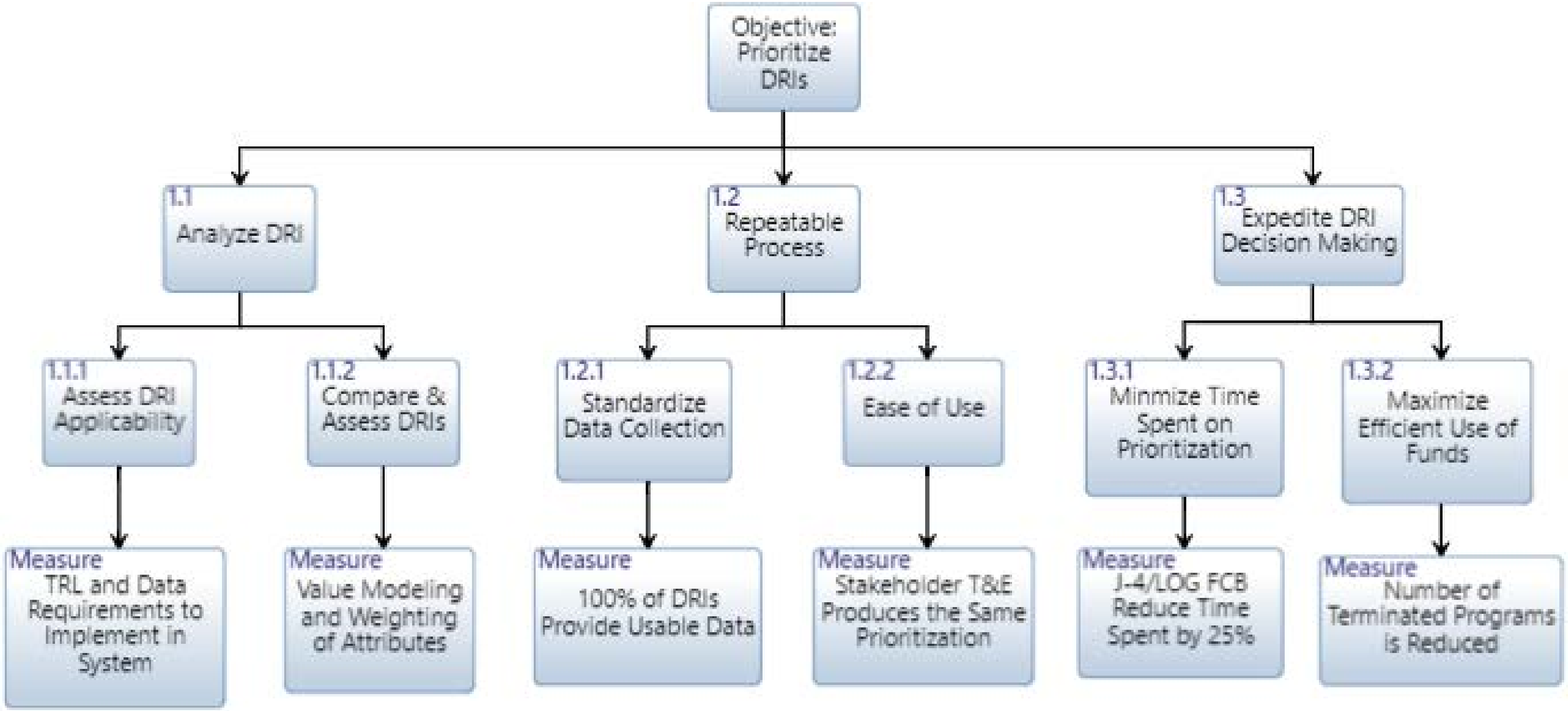

Figure 4. Stakeholder Objectives Hierarchy for DAS

A. STAKEHOLDER ANALYSIS AND PROCESSES

The Joint Staff, J-4 Analysis Branch provided initial guidance to develop a system capable of assessing and prioritizing DRIs to present to the Logistics Functional Capability Board (LOG FCB) for future use (M. Webb, personal communication, 6 October 2021). Subsequent in-process reviews (IPR) were held through the initial development of the assessment system for two purposes. The first purpose was to clarify stakeholder needs of the system. The second purpose was to better understand their current processes. From primary stakeholder information, the team obtained an understanding of how the J-4 Analysis Branch receives initiatives, current methods/gaps in assessment of initiatives, and boundaries to work within while developing our system (J-4, IPR meeting, 4 February 2022):

(1) The J-4 receives initiatives that are related to demand reduction in varying stages of development and in different forms of documentation. All DRIs may not have robust data or strong demand reduction impacts.

(2) The LOG FCB previously used operational military characteristics from the new DOD Data Strategy to assess initiatives. This system is called VAULTIS (Visible, Accessible, Understandable, Linked, Trustworthy, Interoperable, and Secure). That however proved unsuccessful due to difficulties producing values applicable to all demand reduction initiatives and difficulty in developing the follow-on comparisons.

(3) The stakeholders provided guidance to narrow the scope of the system to technology DRIs and exclude process DRIs. Other than this specification, there are no other constraints to dictate initiatives applied in the system or how they are assessed.

(4) The team will communicate with DRI points of contact (POC) through the primary stakeholder (J-4) to receive data to analyze and test the system. This data will be collected via a questionnaire developed explicitly for the DAS. The questionnaire gathers data specific to attributes within the DAS that

will be used to compare and assess the DRIs. The expected turn-around time is two to three weeks to receive data after distributing the questionnaire for data collection.

With this guidance, the team completed functional analysis of the DAS functions. This facilitated the conceptual design, preliminary design, and finally the development of the DAS. The stakeholders assisted during these stages by sending the finalized questionnaire to the POCs for all of the DRIs, consolidating all of the data and returning it to the team for analysis. The J-4 office then reviewed the final product with the testing prioritization to ensure it met their needs. Once approved, the system was deemed ready for official use in prioritizing DRIs for the LOG FCB.

B. DEFINING SYSTEM REQUIREMENTS

The first phase in this project analyzed the problem to gain insight into the development of the assessment system. The team first defined system requirements to support the following functional analysis and design. In order to define the requirements, several steps were taken, as outlined the Figure 5. This figure includes a key which is also applicable to Figures 7–9.

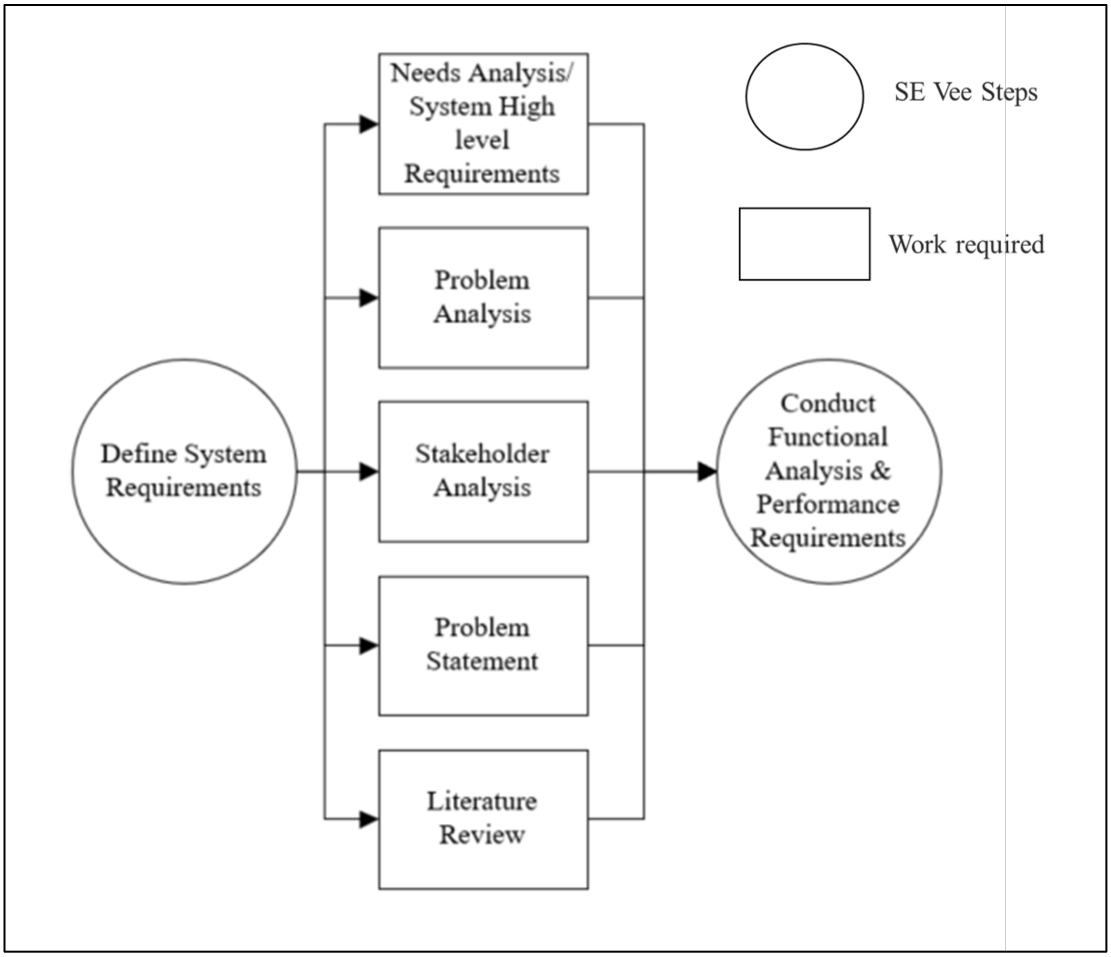

Figure 5. Phase 1: Define System Requirements Flow Chart

The first step in this phase was to complete stakeholder analysis. This provided background on the end user needs and their current capability gaps. This was followed by conducting needs analysis to establish the baseline against which the design configuration was evaluated. Completion of needs analysis resulted in translating the defined need of the stakeholder into specific system requirements (Blanchard and Fabrycky 2014). Following this process ensured the developed requirements of this system were traceable to the original needs of the stakeholder. This section of work is an iterative process to determine the root causes of the problem and the needs of the stakeholder. The team developed a deeper understanding of the problem through utilization of a cause-and-effect diagram, or Ishikawa diagram, which is depicted in Figure 6. This technique was useful in identifying potential causes that contributed to the overall problem this project was solving. In this diagram, the problem is the "head" of the diagram on the right side of the model, and each fin identified potential causes contributing to the problem. After the fins were identified, potential causes for each fin were determined and this process continued, resulting in the diagram in Figure 6. This process helped create shared understanding of the problem and isolate causes that shaped the literature review and problem statement. These completed actions enabled creation of a high-level system requirements hierarchy.

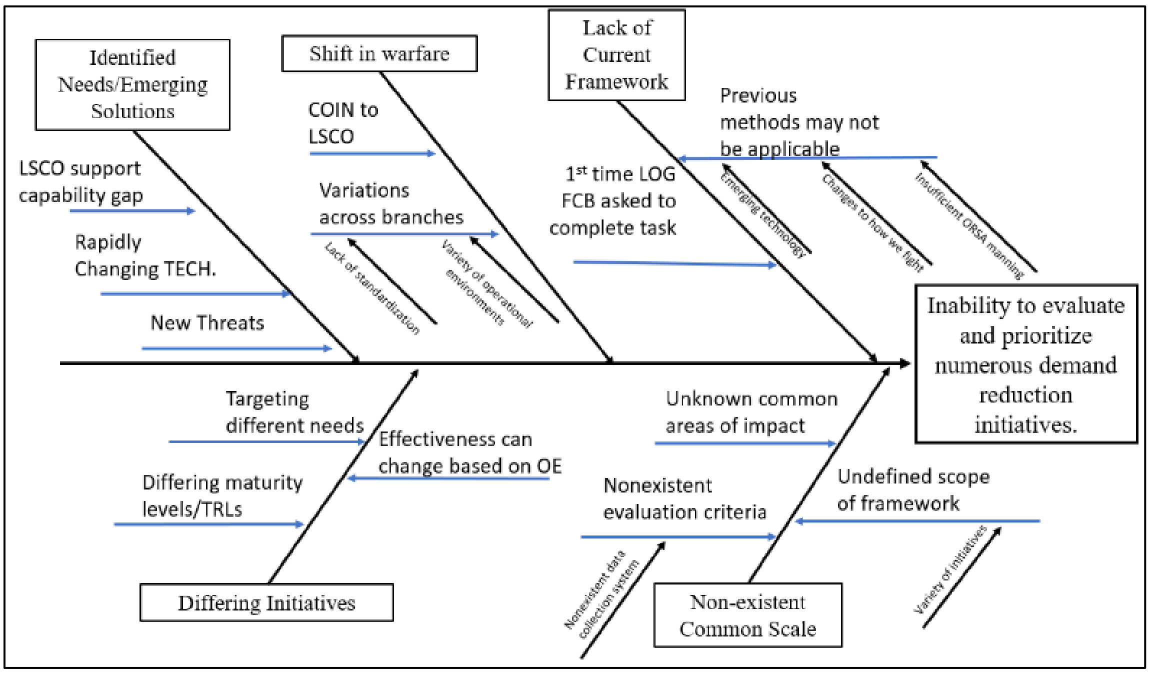

Figure 6. Cause-and-Effect Diagram. Adapted from Ishikawa (1974).

Overall, the combination of the steps in Figure 6 resulted in problem clarification and a deeper understanding of problem causation, creating the systems' foundation. This base of understanding allowed for functional analysis to commence in the iterative process, ensuring an integrated, functional architecture and baseline for all subsequent design (Blanchard and Fabrycky 2014). The completion of this phase provided a scope and the ability to further decompose initiatives in accordance with systems engineering (SE) fundamentals.

C. ALLOCATE SYSTEM FUNCTIONS/PERFORMANCE REQUIREMENTS INTERACTING WITH STAKEHOLDERS

This next phase began with conducting functional analysis and ended with the creation of performance measures. As explained by Blanchard and Fabrycky, "Functional analysis is an iterative process of translating system requirements into detailed design criteria" (2014, 86). While conducting functional analysis, requirements were broken down from the system level to the subsystem level to identify input design criteria and create a high-level system architecture (Blanchard and Fabrycky 2014). The purpose of this analysis was to create a functional hierarchy and establish the baseline from which all future physical requirements are justified through mapping function to form. The functional analysis is solution agnostic, allowing for a wide array of solutions. The steps in this phase are identified in Figure 7.

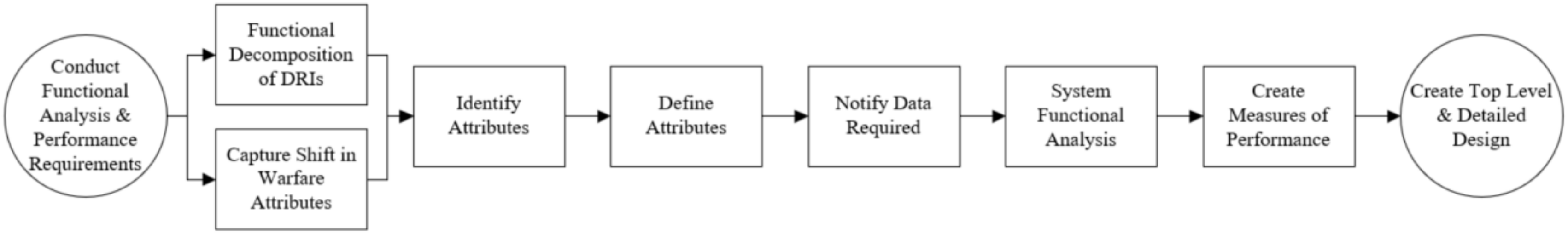

Figure 7. Phase 2: DAS Functions and Performance Requirements Flow Chart

Functional analysis of the DAS began with the identification of the top-level requirement for the system. From that point the team developed a functional hierarchy and requirements for the system. This facilitated creation of the architecture of the system and allowed traceability of functions once the system was fully designed. The team further mapped the functions required of the system to the component that would execute that function. As an important part of the assessment system was having a method to assess DRIs, the team conducted additional functional analysis of each provided DRI to determine which reduction attributes the DRIs contained in their demand reduction role. Review of all the discovered attributes enabled identification of attributes common to all initiatives for use within the system. The attributes were compared against the real-world operational needs to verify they had the intended positive impact on operational needs. Following identification of the attributes, each attribute was defined, the attribute definitions were deemed acceptable by the primary stakeholders, and the data required to measure them was established.

The final step in this phase was to create the performance requirements. These are known as measures of effectiveness (MOE). They are the preliminary design criteria of the assessment system, are compatible with the system's top-level requirements, and are tied to a function from the previous decomposition (Blanchard and Fabrycky 2014). These MOEs allowed for the start of top-level design and facilitated the matching of function to form when combined with the system functional analysis.

D. DESIGNING THE ASSESSMENT SYSTEM

The third phase completed the assessment system architecture by conducting top-level design and detailed design. With the functional baseline complete, the team matched function to form (Blanchard and Fabrycky 2014). The steps in this phase are outlined in Figure 8.

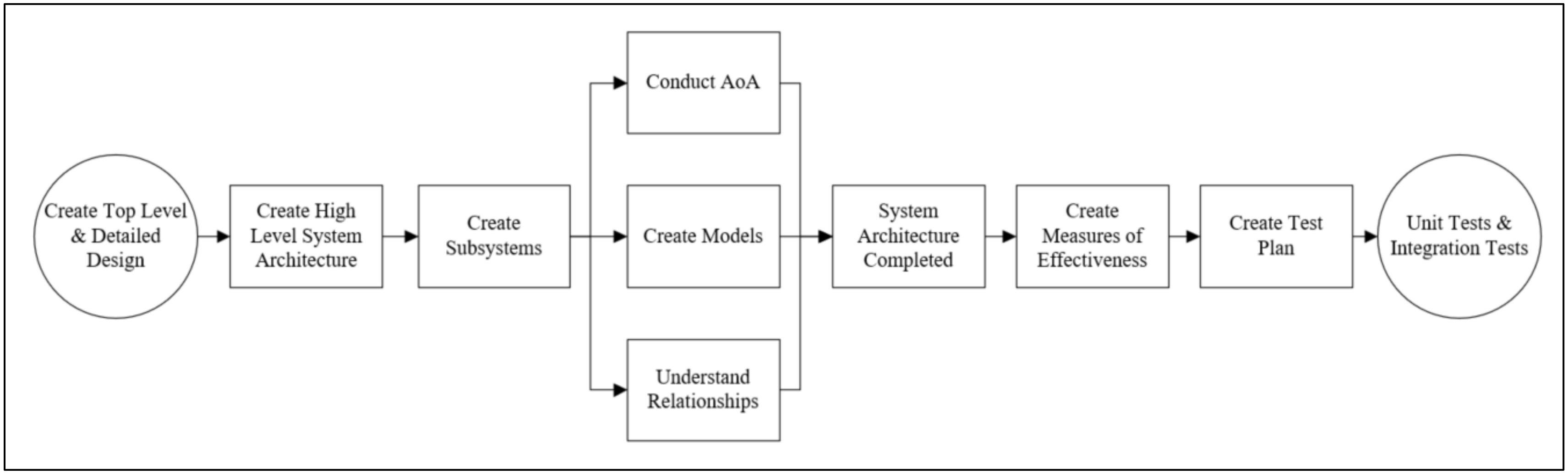

Figure 8. Phase 3: Designing the Assessment System Flow Chart

This phase began with creating the top-level design. Top-level design included developing the high-level system architecture. The team also identified relationships both between and external to the system necessary for system integration. Innoslate is "a full life cycle software for model-based systems engineering, requirements management, verification and validation, plus Department of Defense Architecture Framework (DODAF) with a powerful ontology at its core" (Innoslate n.d.). Innoslate was the selected design tool to match function to form through Operational View (OV) models. By mapping function to form, the links between form and process were identified and the first physical solution assigned to fulfill the function, facilitating the completion of detailed design (Crawley et al. 2016).

The detailed design enabled the creation of subsystems in the assessment system, articulated by different models. In particular, detailed design developed the level 2 architecture to ensure the level 1 architecture was decomposed properly and met the system intent and objectives (Crawley et al. 2016). Within the detailed design, the team conducted an AoA of the detailed forms or solutions. This AoA evaluated what type of value model would best assess and prioritize the DRIs to meet the system objectives. The completion of these steps resulted in a full system architecture ready to assign measures of performance (MOP).

The MOP is a further iterative process decomposed from the MOEs. The MOPs fulfill the MOEs, and the MOEs fulfill the system requirements. In addition, MOEs and MOPs are the requirements of the system and the baseline to test the system against. The system requirements and a system baseline facilitated the team's creation of the test plan and enabled the testing of the assessment system. The test plan outlined the developed tests to ensure the system was verified and validated prior to delivery. The completed design and system architecture are captured in Chapters IV and V.

E. VALIDATING THE ASSESSMENT SYSTEM

Phase 4, validating the assessment system, began with verification. Verification of the system began with unit and initial integration tests and ended with integrated test and evaluation. According to Blanchard and Fabrycky (2014), "This meets the internal objective to adopt a 'progressive approach' that will lend itself to continuous implementation and improvement of the system design and development process evolves" (158). The steps in this phase are outlined in Figure 9.

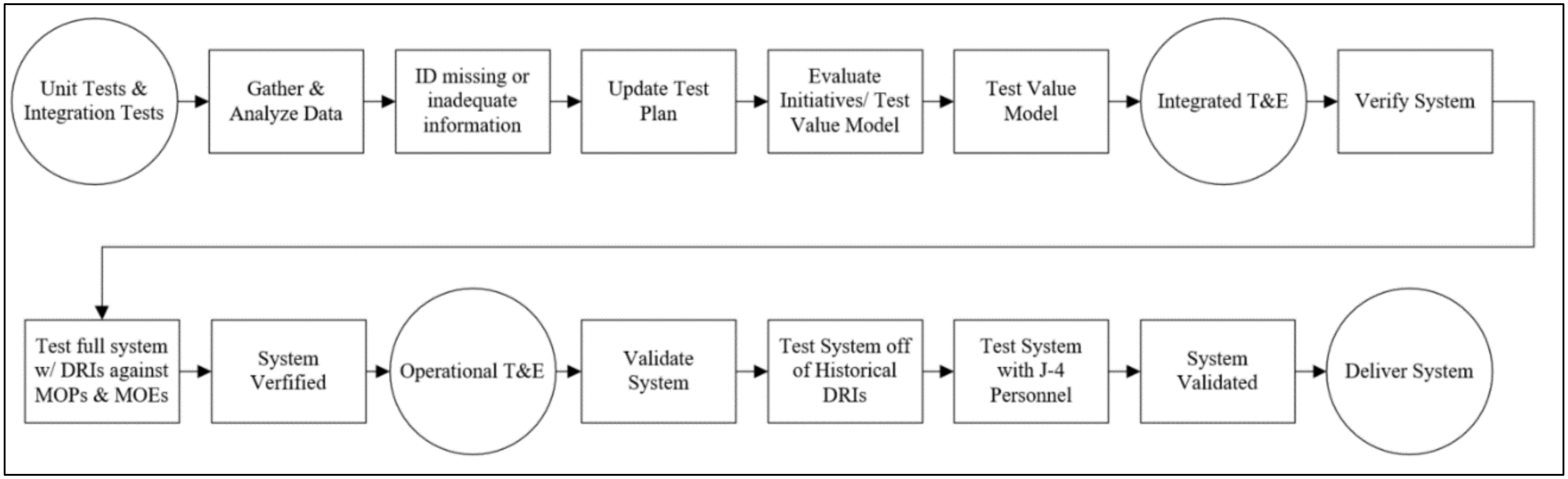

Figure 9. Phase 4: Validating the Assessment System Flow Chart

Data was gathered from the primary stakeholders with a questionnaire. The intent of the questionnaire was to learn more about each DRI: its current TRL; where it is in the acquisition life cycle; what it is looking to reduce or improve; any identified tradeoffs; and any data associated to quantify the DRI. This information was critical to ultimately compare quantifiable data. The questionnaire data was analyzed and identified any missing or inadequate data required to perform the tests. After identification of missing or inadequate data the team updated the test plan and initiated unit testing, which included the testing of subsystems, or the value models. This updated test plan allowed the initial integration testing and testing of multiple subsystems together to begin. In the case of the assessment system the two subsystems to test together were the DRI functional analysis process that identifies a DRI's attributes and the value model. This testing ensured that the core of the system functioned properly and completed the first step of verification.

The next step in the verification process was an integrated test and evaluation (T&E) process. This included testing the full system by inputting the received data for the DRIs that the stakeholder provided. This portion of the test answered whether the integrated subsystems and the system architecture met the DAS MOPs.

Operational T&E made up the validation portion of testing. This type of testing and evaluation answered whether the system met the MOEs and system requirements as well as the overall accuracy of the system in prioritizing DRIs. The first method of operational T&E used data from DRIs already in use operationally to determine the accuracy of the DAS. This included identifying currently operational DRIs, inputting data on each DRI into the DAS, and then comparing the produced prioritization to results of how the DRIs impacted operations in the OE. Additionally, J-4 Analysis Branch was given the assessment system with data from the given DRIs. They input the data into the system to prioritize the initially provided DRIs and compared their results to the research team's results with the same data, which determined if the results are repeatable and accurate. This provided real-time feedback on the repeatability of the system. The testing results are captured in chapters four and five of this report. Successful completion of the verification and validation process provides a fully functional assessment system that is repeatable for future DRI prioritization. The system with instructions and testing results were provided to the J-4 stakeholders for further use.

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IV. DATA COLLECTION AND ANALYSIS

A. FUNCTIONAL ANALYSIS OF THE DAS

The stakeholder specified that the top-level function of the system is to prioritize the Demand Reduction Initiatives (DRI) their office receives, to provide the Logistics Functional Capability Board (LOG FCB) with recommendations on DRIs to implement. This resulted in the following top-level system requirement: Prioritize disparate DRIs. Understanding the top-level requirement enabled the development of a top-level operational view of the process system. This operational view, or OV-1, is shown in Figure 10. The OV-1 provides a high-level visual representation of how the system functions. The figure first depicts DRI data received into the system in the blue arrow. The data is then analyzed to complete individual DRI assessment followed by a comparison of DRIs in the teal arrow. Finally, the comparison produces a prioritization of DRIs to recommend for funding as an official program to field to the force in the green arrow.

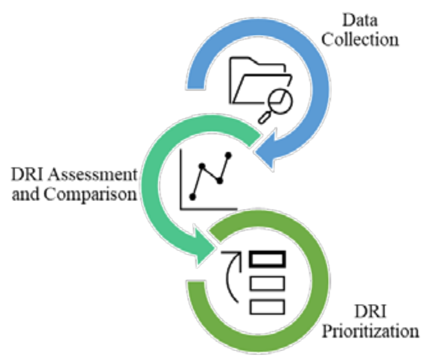

Figure 10. OV-1

The next step was to complete functional analysis of the system to determine specific functions the system must perform to achieve the top-level requirement. This functional analysis is shown in Figure 11. The top-level requirement is located at the top of the hierarchy tree with its three subfunctions being gather data (1.1), identify measurable data (1.2), and rank DRIs (1.3). The three subfunctions were broken down further into their most basic functions.

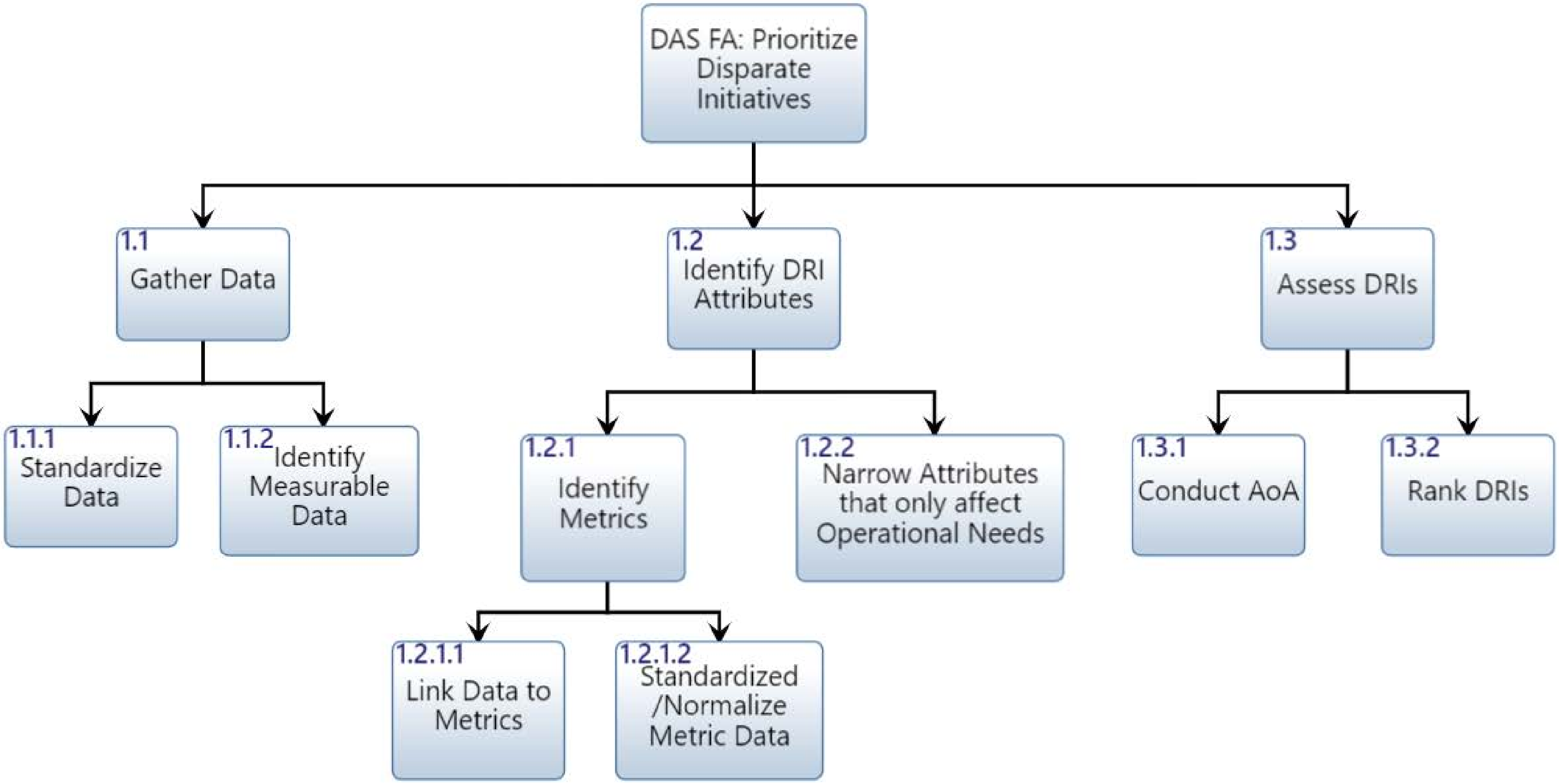

Figure 11. Functional Analysis Hierarchy

This functional analysis is also shown in Table 1. The composition level and function/subfunction shown in the first two columns match the functions identified in the hierarchy in Figure 11. The descriptions on the right-hand side explain what the system is required to do to achieve each of the desired functions.

Table 1. DAS Functional Analysis Requirements Table

Composition Level	Function/Subfunction	Requirements
1.0	Prioritize Disparate Initiatives	The DAS shall provide a repeatable process resulting in prioritized DRIs.
1.1	Gather Data	The DAS shall gather data from DRI sponsors.
1.1.1	Standardize Data	The DAS shall standardize data received from DRI sponsors.
1.1.2	Identify Measurable Data	The DAS shall provide instruction on applicable quantitative or qualitative data.
1.2	Identify DRI Attributes	The DAS shall provide and/or identify DRI attributes.
1.2.1	Identify Metrics	The DAS shall implement appropriate quantitative and/or qualitative metrics for assessment.
1.2.1.1	Link Data to Metrics	The DAS shall provide metrics specific to each attribute.
1.2.1.2	Normalize Metric Data	That DAS shall include a scaling of attributes to assess all DRIs evenly, in a repeatable manner.
1.2.2	Narrow Attributes that only effect Operational Needs	The DAS shall eliminate non-technology DRIs and out-of-scope attributes.
1.3	Rank DRIs	The DAS shall provide a prioritization of DRIs.
1.3.1	Support AoA	The DAS shall support AoA to enable the assessment and comparison of DRIs.
1.3.2	Compare DRIs	The DAS shall compare DRIs.

Completion of the requirements and desired functions of the system provided the foundation to develop the DAS. The requirements and functions enabled traceability for the system, which allowed the team to later assess the developed system by verifying that it performed every identified function. Using the functions in Table 1, the next step was to determine the physical forms needed to complete that function.

B. MAPPING FUNCTION TO FORM

Using the functions from the previous section, the team developed a variety of physical forms to carry out those functions. The forms include questionnaires, tables, matrices, and value scoring, all of which are outlined in Table 2. The far-left column identifies the system function. The remaining columns are the methods generated to perform that function. From this table, the team reviewed all generated ideas and selected one instantiation of the many possible systems versus conducting a full analysis of alternatives for all the possible systems. With the stakeholder, the team defines a reasonable system that would be able to perform all the identified system functions. The chosen physical forms are located in the "green" boxes.

Table 2. System Functions Traceability Matrix

Function	Form Options			
Gather Data	Questionnaire	Interviews	Standard for Receiving DRIs	Research
Standardized Data				
ID Measurable Data				
Identify DRI Attributes	Attribute Comparison Tool	DRI Functional Analysis	Research	Historical
Identify Metrics	Value Modeling Tool			
Link Data to Metrics				
Normalize Data				
Narrow Attributes	Attribute Comparison Tool			
Rank DRIs	List			
Conduct AoA	KVA Tool	Total Value Tool	Multi-Objective Optimization Framework Tool	MILP Tool
Compare DRIs	Total Value Ranking Tool	Cost Reduction Estimate	Benefit vs Cost	Modeling and Simulation

Using the selected physical forms in Table 2, the team next created a physical decomposition of the physical forms used to create the DAS, shown in Figure 12. The primary physical forms that fulfill functions 1.1, 1.2, and 1.3 from Table 1 are reflected as physical forms 1.1, 1.2, and 1.3. The lower levels provide an overview of all physical methods used to create the DAS from data collection through full system development.

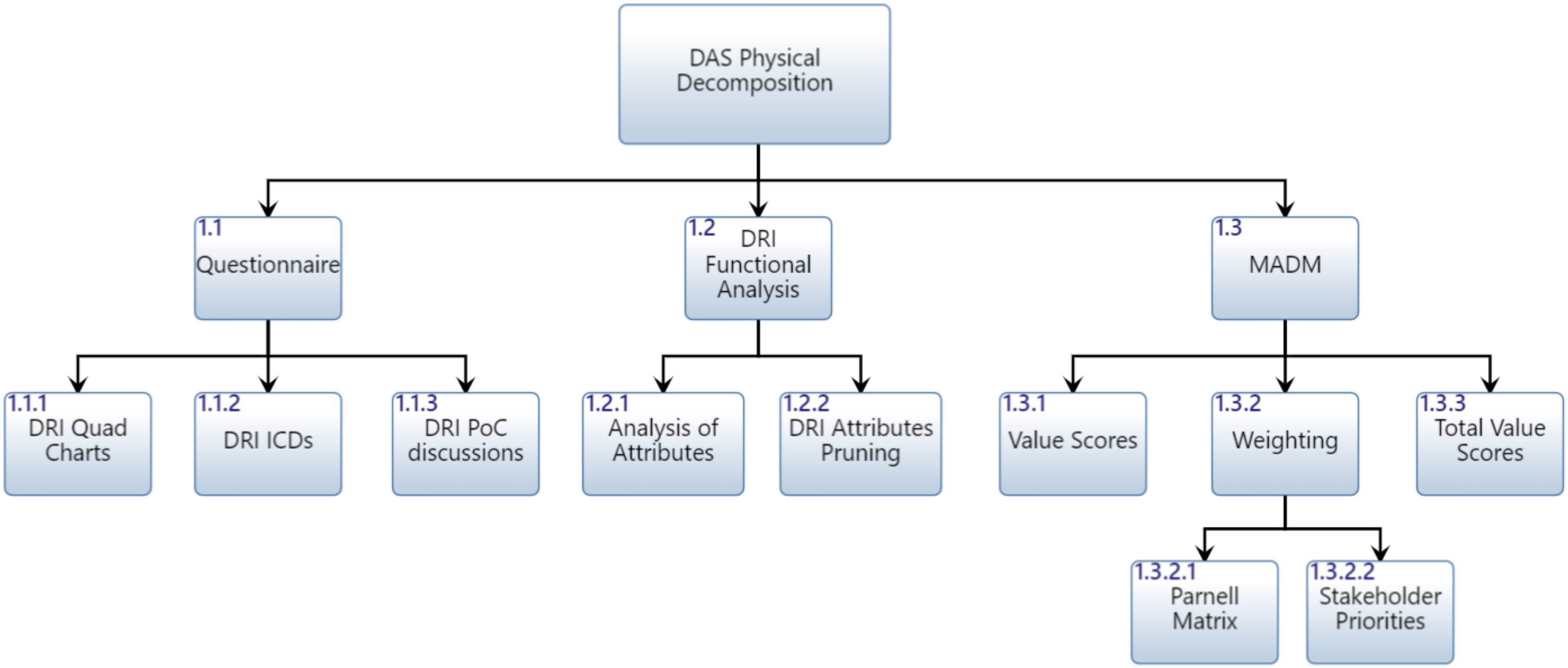

Figure 12. Physical Hierarchy

The team developed a functional flow block diagram to illustrate the functionality of the system and show the steps to take to prioritize DRIs. Beginning with Figure 13, DRIs are received and reviewed to determine if they are a technology or process DRI for applicability in the system. Once three or more technology DRIs are available, the questionnaire is sent for data collection and the end user reviews the DRI to understand what the expected demand reduction impacts are, as well as the associated attributes.

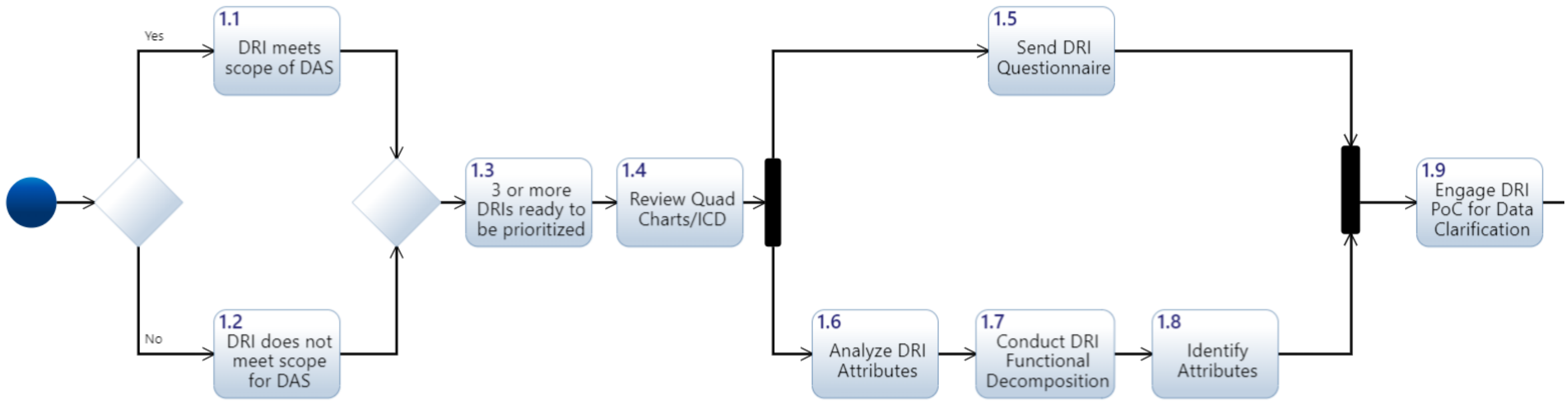

Figure 13. Functional Flow Block Diagram – Section 1 (Activity Diagram)

The final steps to use the system are shown in Figure 14. This diagram begins with using the gained understanding and the data from the questionnaire to review and consolidate the data. If any data is unclear or lacking, the research team contacts the DRI POC for clarification. From this point, the data is applied to the value scale to identify a score for each attribute of the DRIs. The scores are then input into the tool for weighting calculation, resulting in an overall benefit score. Once each DRI has a benefit score, the DRIs are ranked with the highest score being number one. This ranking can be compared against technology readiness levels (TRLs), cost, and return on investment (ROI) if the user has the information available. If the additional data is not available, the process is complete and the ranking of DRIs becomes the recommended prioritization to provide to the LOG FCB.

Figure 14. Functional Flow Block Diagram – Section 2 (Activity Diagram)

Table 3 depicts the Measure of Performance (MOP) and Measure of Effectiveness (MOE) developed based on the requirements of the DAS. MOEs are linked to what a system must do to meet the top-level system objective and must be measurable and observable. MOPs are a type of MOE and quantifiably measure the performance of the system to determine its success. The MOPs and MOEs in Table 3 can be utilized by both the stakeholder and follow-on teams to measure how well the DAS prioritizes disparate DRIs. These measures are after the DAS has been implemented for a given period and appropriate data has been collected to compute the measures.

Table 3. MOPs/MOEs

Measures of Performance	Measures of Effectiveness
0.0 Shall Prioritize Disparate Initiatives	
1.0 Shall Standardize DRI Data	
1.1 Shall Exclude Out of Scope DRIs	
	1.1.1 Shall be 100% accurate at excluding out-of-scope DRIs between Users
	1.1.2 DAS Shall provide Questionnaire that allows for quantifiable Data Collection
2.0 Shall Identify DRI Attributes	
2.1 Shall Identify Metrics to Evaluate Attributes	
	2.1.1 Shall Provide List of Attributes that correlate to 90% of DRIs
	2.1.2 Shall Provide Instructions of how to identify Attributes with 90% accuracy between Users
2.2 Shall Narrow Attributes to Operational Needs	
3.0 Shall Access DRIs	
3.1 Shall Conduct AoA	
	3.1.1 DAS Value Curves Shall Provide distinct difference in DRI values
	3.1.2 DAS Weighting Shall Provide analytical weighting and be quantifiable
3.2 Shall Rank DRIs	
	3.2.1 DAS Shall be 80% accurate at choosing the best DRIs
	3.2.2 DAS Shall be 90% accurate at DRI ranking between users
4.0 DAS Shall reduce time spent by J-4 for prioritization by 25%	

C. SYSTEM DEVELOPMENT

To develop the DAS, the team broke the system into three components to build, first shown as the three subfunctions in Figure 12. Those components were "Gather Data," "Identify DRI Attributes," and "Assess DRIs." This chapter section explains the development of each component in the system and how together they create the fully functioning system.

1. Attribute Identification

The first two components of "Gather Data" and "Identify DRI Attributes" were completed simultaneously. To begin the data collection process, the team conducted functional analysis of 10 Demand Reduction Initiatives (DRI): Underwater Cure Adhesives (UCA); Autonomous Predictive Maintenance (APM); Biomanufacturing of Lubricants from Seawater (BLS); Modular Photobioreactor (MPBR); Mobile Nuclear Powerplant (MNPP); Secure Tactical Advanced Mobile Power (STAMP); Rapid Expeditionary Ice Construction (REIC); Combat Feeding – Meals Ready-to-Eat (CF); Mobile Advanced Fuel Filling Station (MAFFS); and Tactical and Combat Vehicle-Electrification (TaCV-E). The completed functional analysis of the given DRIs facilitated the identification of areas the DRIs impacted, resulting in identification of possible attributes to use within the DRI Analysis System (DAS). An example of this DRI functional analysis is shown in Figure 15.

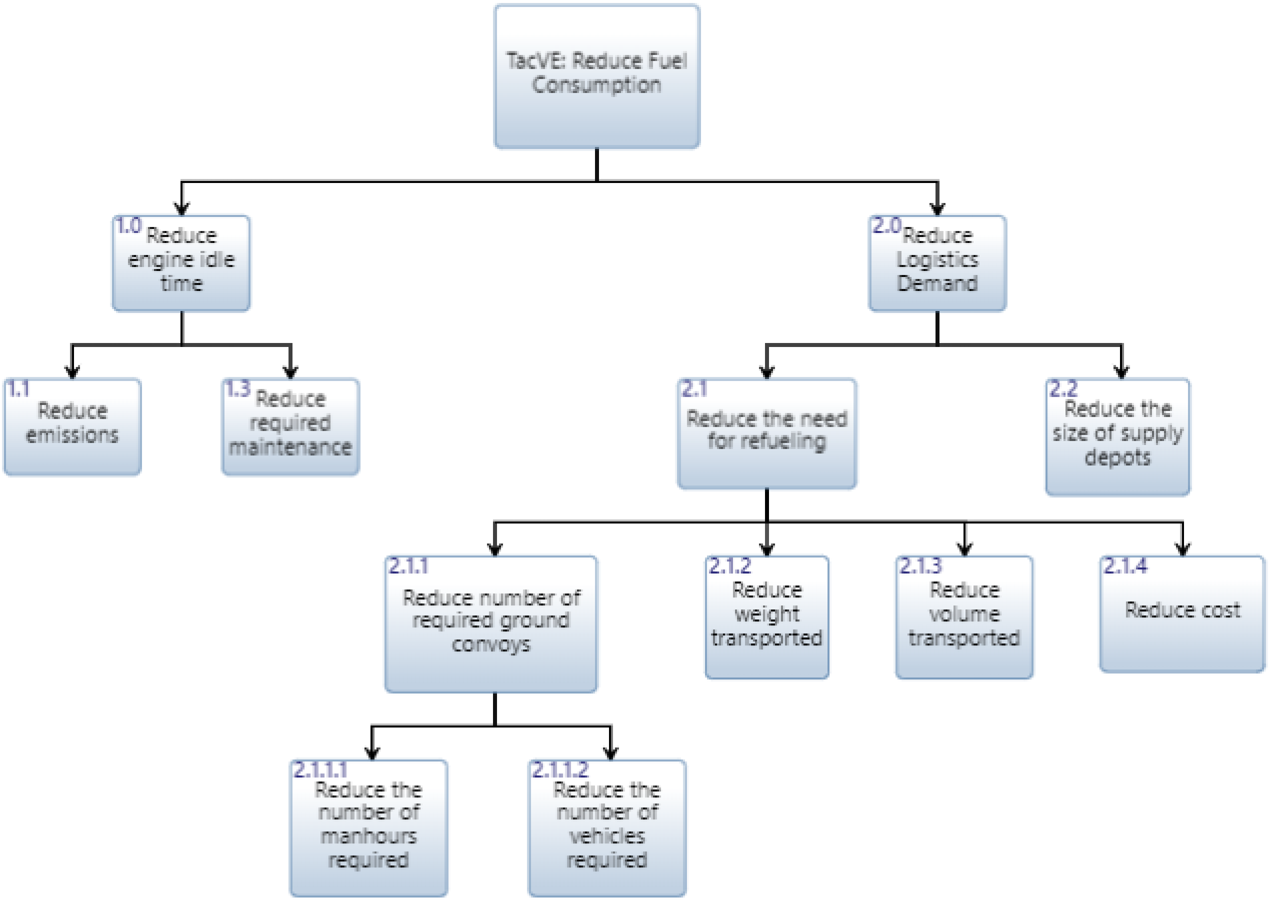

Figure 15. Functional Analysis of the TaCV-E

2. Narrowing of Attributes

Once all possible attributes of the 10 DRIs were identified, the attributes were placed in a table to compare all initiatives and identify which attributes were common to DRIs, shown in Table 4. Those attributes which demonstrated affected at least nine DRIs are highlighted in green as the top common attributes, that are significant in measuring demand reduction. Those attributes which affected 6–8 DRIs are highlighted in yellow and those attributes which affected fewer than six DRIs are not highlighted. Additionally, attributes which would have an impact on operations but did not impact sustainment areas are shown in red and ruled out from consideration. However, these attributes were left in the table to demonstrate DRIs may have influence in areas outside of demand reduction. The remaining nine attributes were carried forward as possibilities to use in the DAS: "Reduce Weight"; "Reduce Volume"; "Reduce Fuel Consumption"; "Reduce Resupply Platforms"; "Reduce Costs"; "Reduce Manhours"; "Increase Availability"; "Reduce Augmented Power Sources"; and "Reduce Storage." This initial set of nine attributes was used to develop a questionnaire for data collection on the ten DRIs. This questionnaire was sent out by our primary stakeholders to the DRI points of contact (POCs) to receive data on their respective technology. The questionnaire is located in Appendix A of this report.

Table 4. DRI Comparison of Attributes

	DRIs									
	STAMP	**MNPP**	**CF**	**REIC**	**APM**	**TaCV-E**	**MAFFs**	**MPBR**	**BLS**	**UCA**
Reduce Weight	X	X	X	X	X	X	X	X	X	
Reduce Volume	X	X	X	X	X	X	X	X	X	
Reduce Fuel Consumption	X	X	X	X	X	X	X	X	X	X
Reduce Resupply Platforms	X	X	X	X	X	X	X	X	X	
Reduce Costs	X	X	X	X	X	X	X	X	X	X
Reduce Manhours	X	X			X	X	X	X	X	X
Increase Availability	X	X			X	X	X			X
Reduce Augmented Power Sources	X	X				X				
Reduce Storage							X	X	X	
Reduce Heat Signature	X	X		X		X				
Reduce Noise	X	X				X				X

The team continued narrowing the number of attributes used for assessment from nine to four. These four attributes were selected for assessment using two methods. The first method to narrow attributes was to compare the attributes to their effect on operations to determine which attributes impacted maneuverability the most. The operational areas the attributes were compared against were speed, reach, endurance, and flexibility. These operational methods of assessment were chosen after researching the Joint Concept of Contested Logistics and research by Lieutenant General (Retired) Lundy regarding logistical requirements in future warfare. The operational areas were compared using a scale of low (1), medium (3), and high (5). I accordance to the DRI proposal descriptions, the team scored each attribute in the four areas. Adding the scores for each attribute determined which attributes would likely have the greatest impact on operations. These scores are shown in Table 5 which suggests that removing "Reduce Storage," "Reduce Augmented Power Sources," and "Reduce Costs" from the DAS is warranted. After consultation with the primary stakeholders, the team removed the three attributes from the DAS.

Table 5. Top Attributes from Impact on Operations

		Speed	Reach	Endurance	Flexibility	Score
DRI Attributes	Reduce Volume	med (3)	high (5)	high (5)	high (5)	18
	Increase Availability	high (5)	med (3)	high (5)	high (5)	18
	Reduce Weight	high (5)	med (3)	med (3)	high (5)	16
	Reduce Resupply Platforms	med (3)	med (3)	high (5)	high (5)	16
	Reduce Manhours	high (5)	low (1)	high (5)	high (5)	16
	Reduce Fuel Consumption	low (1)	high (5)	high (5)	med (3)	14
	Reduce Storage	med (3)	low (1)	low (1)	high (5)	10
	Reduce Augmented Power Sources	low (1)	low (1)	low (1)	high (5)	8
	Reduce Costs	N/A	low (1)	med (3)	med (3)	7

high	5
med	3
low	1

Once the data was received from the DRI points of contact, the second method to narrow attributes was to review the data to determine which attributes provided usable data and which attributes did not receive usable data for input in the system. From this review, the team determined the attributes of "Reduce Resupply Platforms" and "Increase Availability" did not receive adequate data to use within the DAS. Several returned questionnaires either stated the attribute impact was unknown or did not provide supporting data to substantiate their claim. The team discussed the two attributes with the primary stakeholders, who did not view the two as great value added and agreed to remove them from use within the system.

With the final four common attributes selected, the team created definitions to provide clarity into how to assess DRIs against the attribute. The definitions were developed using metrics of time, weight, and space to keep the measurements even for all DRIs. These definitions are displayed in Table 6. Defining the attributes completed the first two components of system development from Figure 12, "Gather Data" and "Identify Attributes."

Table 6. Attribute Definitions

ATTRIBUTE	DEFINITION
Reduce Volume[a]	The amount of space occupied by a three-dimensional object as measured in cubic units. Does not include volume of fuel.
Reduce Fuel Consumption[b]	The amount of fuel the engine of a system burns each hour in gallons or amount of fuel no longer required to transport.
Reduce Weight[a]	The amount that an object weighs as measured in pounds (lbs). Does not include weight of fuel.
Reduce Manhours[c]	The number of hours required for military and civilian personnel that are required, authorized, and potentially available to train, operate, maintain, and support the system. (1 FTE = 40 hrs work week)

[a] Adapted from Merriam-Webster (n.d.a, n.d.b).

[b] Adapted from NASA.gov.

[c] Adapted from Gildea et al. (2018).

3. Value Modeling

With development of the first two components of system development complete, the team moved into the final component, "Assess DRIs." Constructing this component began with developing a subjective common scale for each attribute, with input from the stakeholder, to evaluate and prioritize the DRIs. The subjective common scales provided a repeatable and accurate method to assess DRIs against the same criteria for each attribute.

The team first selected a common scoring range of 1–20 to assess the DRIs with one being the lowest amount of reduction and twenty being the highest amount of reduction. A score of zero was given to attributes not associated with the DRI. The stakeholders approved the 20-point value score range prior to the team developing individual attribute scores.

To develop the metrics supporting value scores, the team researched organizations that assessed the attributes within their products to improve efficiencies and business practices. This research included reviewing studies from Ford, Amazon, Tesla, Dell, and other commonly known companies. In conducting this research, data points related to the attributes were found, providing the ability to average the data and develop a threshold reduction goal for each attribute. This method is demonstrated step-by-step below to explain how the scale for the attribute "Reduce Fuel Consumption" was developed, using information obtained from the research. Each value scale was provided to the stakeholder to receive their feedback and approval of the scales.

The value scales and attribute metrics were then used to create value curves for each attribute. The value curves provide a visualization of how the attribute data is related is to the scores. The x-axis represents the metric, very low through very high, while the y-axis represents the determined value score for each measure level, resulting in the value curve. Figure 16 shows the developed value scale and the correlating value curve for the attribute of "Reduce Fuel Consumption." This same process was applied to produce value curves for each of the attributes and their associated value scale.

Reduce Fuel Consumption Value Scale	
Value Score	**Metric**
1	Very Low: 1-4% reduction in fuel per every 16,880 gal
3	Low: 5-14% reduction in fuel per every 16,880 gal
10	Medium:15-27% reduction in fuel per every 16,880 gal
17	High: 28-54% reduction in fuel per every 16,880 gal
20	Very High: 55%+ reduction in fuel per every 16,880 gal

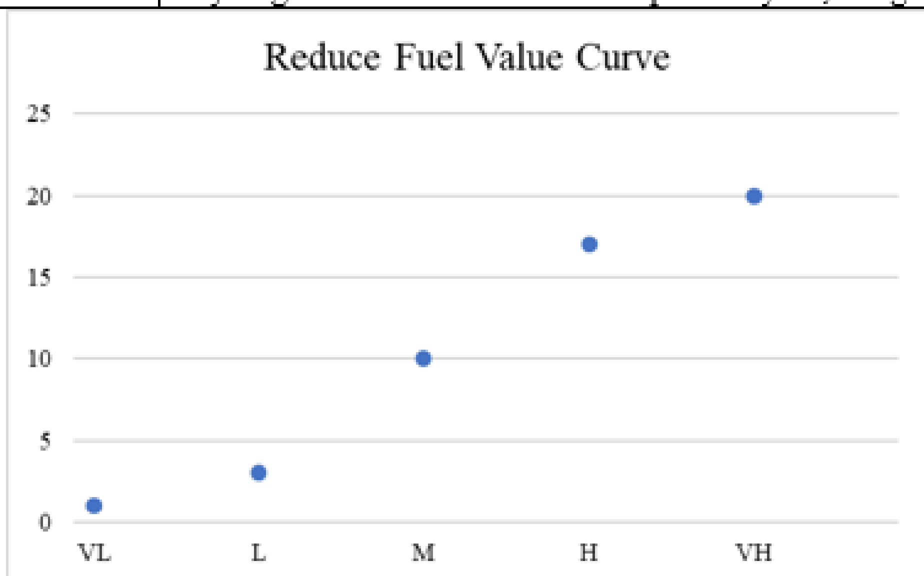

Figure 16. Reduce Fuel Value Scale and Value Curve

To begin building the scale for “Reduce Fuel Consumption,” the team reviewed ten articles and reports relating to industry and DOD fuel reduction efforts. These articles and reports provided the data required to quantify the value scale: Ford switched its body from steel to aluminum which was projected to reduce fuel consumption by 2% and other changes, such as engine options, to further reduce by 5–29% (Woodyard 2014); the new United States Postal Service (USPS) truck designed by Oshkosh will reduce fuel consumption by 5% (Barfield 2022); the Army’s Improved Turbine Engine has a goal of reducing fuel consumption by 25% (NRC 2014); the United States Army’s goal in research of waste-to-energy was to displace 85% of Jet Propellant 8 (JP-8) (NRC 2014); the United States Army’s efficient power train program aimed to develop engines with a 15–20% reduction in fuel consumption (NRC 2014); a microgrid test in Afghanistan had a 17% fuel consumption reduction (NRC 2014); the Marine Corps studied a new Ship to Shore connector that had an 11% better fuel efficiency (NRC 2014); a Bradley replacement engine is predicted to reduce fuel consumption by 50% (NRC 2014); a generator for the United States Army increased fuel efficiency by 21% (USAASC 2022); utilizing the under armor auxiliary power unit (UAAPU) on the Abrams M1A2 SEPv3 provided a 78% reduction in fuel consumption when running the main engine at idle (DOT&E 2021). The average of these numbers was 28% and was used to develop the threshold of the high metric. From this calculated average, the standard deviation of .27 was used to develop the rest of the metrics. As the basis of comparison for the reduction produced, 16,880 gallons of fuel consumed per day in a desert climate of a 5000-person camp was utilized (Gildea et al. 2017).

With the scale complete, the curve was developed. Knowing that data collection would be difficult due to the immaturity of the DRIs, a constructed approach was applied to develop the value curves. The metrics were built to measure DRIs qualitatively and quantitatively, if there is data available. The metrics go from very low (VL) to very high (VH) on the X-axis and the value scores go from 1–20 points on the y-axis. This process resulted in the value curve specific to the attribute. The same process was applied to the remaining 4 attributes and can be found in Appendix B. The resulting Value Scales and Value Curves were provided to the stakeholders for their approval to use in the system.

4. Weighting of Attributes

Following creation of the value scales and curves, the next step was to develop the swing weight to apply to each attribute. Weighting is essential when determining the importance of identified attributes to the stakeholder and allowed the team to assign a measure weight to each attribute. The team accomplished this using a Parnell Matrix depicted in Table 7 (Parnell 2009). Attributes viewed as providing the stakeholder the most value and having the greatest variance are placed in the top left corner of the matrix and assigned the highest value. Conversely, those viewed as least important and having the least variance are placed in the bottom right corner. In collaboration with the team, representatives from the J-

4 Analysis Branch assigned the weights. The stakeholder determined that the attribute "Reduce Fuel Consumption" was of the highest importance to the project sponsor and thus it was placed in the top left quadrant, along with an associated swing weight of 100. Subsequently, the stakeholder assigned the remaining swing weights as shown in Table 7.

Table 7. Parnell Matrix. Adapted from Parnell and Trainor (2009).

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Importance of Metric</td></tr>
<tr><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Variance of Metric</td><td>High</td><td>100 (Fuel)
90 (Weight)</td><td>50
(Volume)</td><td></td></tr>
<tr><td>Medium</td><td></td><td>45
(Manhours)</td><td></td></tr>
<tr><td>Low</td><td></td><td></td><td></td></tr>
</table>

The swing weights assigned to each attribute in Table 7 were then used to calculate the normalized weight depicted in Table 8's measure weight column. The weighting was normalized by adding up the swing weights from each attribute that were identified in the Parnell Matrix and then dividing each by the total. This resulted in a decimal number, which is each attribute's measure weight. The primary stakeholders verified and approved the attribute weighting, as they maintained a deeper understanding of what the Logistics Functional Capability Board (LOG FCB) deemed important to DRIs.

Table 8. Weighting of Attributes

Attributes	**Swing Weight**	**Measure Weight**
Reduce Volume	50	0.18
Reduce Fuel Consumption	100	0.35
Reduce Manhours	45	0.16
Reduce Weight	90	0.31
Total	285	1.00

5. Total Value Scoring

The development of the normalized measure weights led to the final step of creating the tool to produce benefit scores for ranking. The tool is shown in Table 9. The value score for each DRI was multiplied by the attribute weight on the far left. For example, the MAFFS value score of 20 for the fuel attribute measure was multiplied by the Fuel weight score of .35 to receive a weighted value score of 7. Similarly, the other attribute measure scores were applied with their corresponding weight for MAFFS. Adding all the weights for MAFFS resulted in its total value score of 16.26. This same process was applied to each DRI to create an overall DRI value score. The overall benefit scores were the final scores used in the system to rank DRIs from highest to lowest, resulting in a recommended prioritization.

Table 9. Total Value Scoring Matrix

		MAFFS		**BLS**		**MNPP**	
	Weight	Value Score	Weight	Value Score	Weight	Value Score	Weight
Volume	0.18	14	2.52	4	0.72	4	0.72
Fuel	0.35	20	7	1	0.35	10	3.5
Manhours	0.16	15	2.4	10	1.6	10	1.6
Weight	0.31	14	4.34	1	0.31	5	1.55
Total	1		16.26		2.98		7.37

6. Sensitivity Analysis

The team conducted sensitivity analysis to determine if any of the attributes were sensitive to changes in DRI rankings, if weightings were changed. This was done by weighting each attribute being tested as “1” and the remaining attributes as “0.” Th sensitivity analysis showed the differences in the most extreme weighting across each attribute. The only attribute identified as sensitive was the attribute of “Reduce Weight.” As highlighted in Table 10, Combat Feeding now had the highest value score when the weight for “Reduce Weight” was changed from 0.31 to 1.0. This was the only attribute where the MAFFS and the TaCV-E were not ranked number one or tied for number one.

Table 10. “Reduce Weight” Scores with Sensitivity Analysis

	Original	SA (ReduceWeight)
DRI	**Value Score**	**Value Score**
MAFFS	16.26	14
TaCV-E	16.26	14
CF	14.62	20
STAMP	10.96	14
REIC	8.71	14
MNPP	7.37	5
APM	4.92	5
BLS	2.98	1
MPBR	1.64	1
UCA	1.15	0

The graph in Figure 17 depicts where the DRI’s total value score lines intersect when changing the weighting of the attribute “Reduce Weight.” The table shows Combat Feeding surpasses MAFFS and TaCV-E in this attribute when the weighting increases from 0.31 to 0.45 for the attribute. Overall, the stakeholder has no expectation of a 33% weighting change for “Reduce Weight” in the future. However, it is a prudent practice in value modeling to continuously review weights with stakeholders. The team will recommend it in this effort.

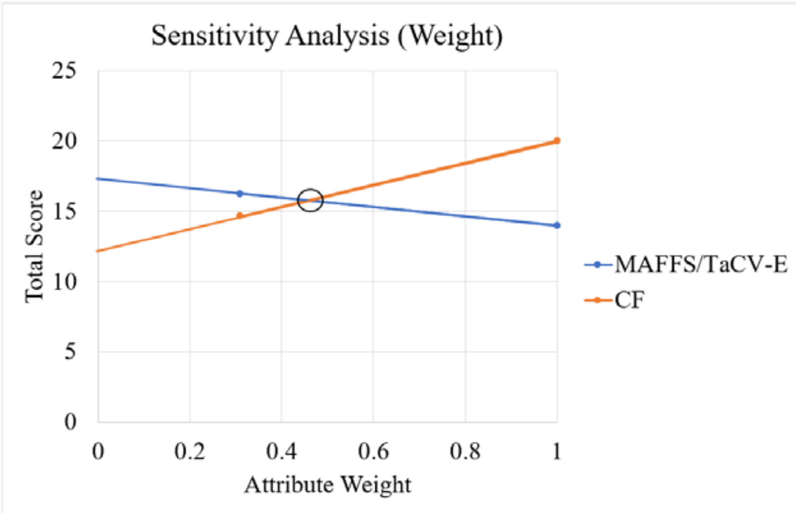

Figure 17. Sensitivity Analysis Graph for "Reduce Weight"

D. SYSTEM TESTING

The DAS was tested using two separate methods. The first method used was to take four historical DRIs that have been implemented into operations, which have real data and run them through the system to see how the results compared to a stakeholder ranking. These historical DRIs included closed-cell polyurethane foam use in forward-deployed structures (Caballero et al. 2015), AA alkaline versus lithium batteries (Beyerl 2019), Kaman K-MAX resupply drone versus the Blackhawk (DOT&E 2021; Lockheed Martin 2010) , and Joint Precision Airdrop System (JPADS) (Benney et al. 2005). The DAS compared and prioritized these historical DRIs, providing the ranking in the DAS column of Table 11. Additionally, the historical DRIs were provided to the stakeholder with background information and data comparable to the DRIs received in this research. The stakeholders provided their ranking of the four DRIs using their previous methods of assessment. Their ranking is shown in the stakeholder column of Table 11. The difference in the two rankings proves the system is ranking DRIs objectively, based on the attributes valued by the stakeholder. Upon review of the DAS ranking, the stakeholders agreed it was accurate to the objective parameters applied within the system and better matched their needs.

Table 11. Test 1 – Historical DRIs Ranking

Historical DRIs Ranking		
Ranking	**Stakeholder**	**DAS**
1	**JPADS**	**JPADS**
2	**K-MAX**	**L. AA**
3	**CCPF**	**K-MAX**
4	**L. AA**	**CCPF**

The second method of testing followed the same process as the historical DRIs but used the ten DRIs provided at the beginning of this research. The objective was to analyze whether there would be a significant difference between the two rankings. First, the stakeholder was asked to rank the 10 DRIs without the use of the DAS; these results are annotated in the "Stakeholder" column of Table 12. Next, the DAS was utilized to rank the 10 DRIs with those results being depicted in the "DAS" column of Table 12. Using spearman's rank correlation, the team discovered that there was a moderate to strong correlation between the two rankings, but this was primarily due to the bottom four rankings which indicated a common recognition that they were not highly desired DRIs. The bottom four DRIs for both the DAS and the stakeholder rankings had high correlation as they remained in positions 7–10. Review of both rankings identified the top six DRIs required further analysis, as they were notably ranked differently. The team then measured the correlation of the selected DRIs to verify how different they were. It was found that there was no significant evidence of correlation (R_s = -0.04) after running the Spearman's Rank Correlation Test for only the top six rankings. This proved the DAS ranking was significantly different from the stakeholder's top rankings. This is illustrated in the yellow cells of Table 12 where the stakeholder ranked the MAFFS sixth, but the DAS tied the MAFFS as the number one DRI. This further verified that the DAS was objectively ranking DRIs by utilizing the stakeholder's valued attributes. It also proved the tool to be useful in providing DRI recommendations to the LOG FCB Chair.

Table 12. Test 2 – Research DRIs Ranking

Research DRIs Ranking		
DRI	**Stakeholder**	**DAS**
TaCV-E	**1.0**	**0.5**
STAMP	**2.0**	**4.0**
REIC	**3.0**	**5.0**
MNPP	**4.0**	**6.0**
CF	**5.0**	**3.0**
MAFFS	**6.0**	**0.5**
MPBR	**7.0**	**9.0**
BLS	**8.0**	**8.0**
UCA	**9.0**	**10.0**
APM	**10.0**	**7.0**

E. SYSTEM VERIFICATION AND VALIDATION

Following successful testing of the DAS, the next step was to verify and validate the DAS. Verification applied a function-to-component check to ensure the DAS and its components accomplished what they were designed to do. When each component of the DAS was completed, it was verified by the stakeholder to ensure it met their requirements. This incremental and iterative approach ensured stakeholder concurrence at each stage of the DAS development. In addition, the sensitivity analysis, the historical DRI test, and the DAS vs stakeholders ranking test served as methods to verify the system. The sensitivity analysis found that the system was overall not sensitive and identified the circumstances that had to occur for the DAS to be sensitive. This verified that the DAS weighting provided analytical weighting and was quantifiable. The historical DRI test and the DAS vs stakeholder ranking both verified that the system ranked DRIs significantly different and objectively prioritized the DRIs.

Validation occurs upon full implementation and the consequent review to assess the effectiveness of the system to meet the stakeholders' objectives and requirements. With the system complete, a total integrated approach for validation will be implemented upon delivery to the J-4 Analysis Branch. The research team is providing a step-by-step manual with instructions on how to use the DAS to ensure the prioritization of future DRIs is a repeatable process.

V. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to develop a system capable of assessing, comparing, and prioritizing disparate DRIs. This system was designed to create a prioritization output the J-4 Analysis Branch can provide to the Logistics Functional Capability Board (LOG FCB) as a recommendation on the best DRI to implement in the military. The team answered the primary and secondary research questions, located in the executive summary. Answering the research questions resulted in a fully functioning system. This chapter further discusses limitations and constraints of the system, as well as recommendations for future work.

A. CONCLUSIONS

The team addressed the primary and secondary research questions defined in this study.

(1) How can we develop an assessment system that is applicable to a range of DRIs?

a. What attributes are common to DRIs?

b. Which identified DRI attributes are most valued by the stakeholder?

c. How do we overcome the challenges in developing our DRI assessment system?

The team answered these questions through functional decomposition of each provided DRI to identify the possible attributes and a series of narrowing attributes to those which were common and applicable. Through discussions with stakeholders, the attributes were narrowed to four to use within the system. The team identified "Reduce Weight," "Reduce Volume," "Reduce Fuel Consumption," and "Reduce Manhours" as the final four attributes to use within the system. The primary stakeholders also gave guidance that "Reduce Fuel Consumption" was of the most value to demand reduction and the system.

This second piece of stakeholder guidance enabled weighting of attributes that reflected their valued attributes.

Development of the system presented numerous challenges. The team identified how to select DRI attributes and develop methods of measurement as the most difficult areas to understand and analyze to build a functioning system. Selection of the attributes required understanding the functions and purposes of all DRIs we received and determining how to choose the attributes used in this system. With the extreme variance of the DRIs, the team determined a functional decomposition of DRIs and frequent communication with stakeholders were necessary to arrive at attributes relevant to demand reduction and of value to stakeholders. The second challenge was to develop metrics for measurement. The immaturity of DRIs hindered the ability to develop metrics based on data from the received DRIs. This resulted in the decision to research data on industry attributes. Industry aims to reduce demand in line with the developed system attributes, so it was determined data from their companies could provide accurate metrics to use in the system.

(2) What is the system scope to determine eligibility of DRIs for assessment?

The team verified stakeholder expectations, resulting in DRIs being narrowed to technology initiatives. Additionally, with an understanding of the number of DRIs the stakeholders would receive in research and development (R & D), the metrics were developed to assess both qualitative and quantitative inputs. This allowed the DAS to be scoped accurately to assess a wider range of TRLs within the system.

Table 13. The DRI Assessment System (DAS)

		MAFFS		BLS		MNPP		REIC		TaCV-E	
	Weight	Value Score	Weight	Value Score	Weight	Value Score	Weight	Value Score	Weight	Value Score	Weight
Volume	0.18	14	2.52	4	0.72	4	0.72	14	2.52	14	2.52
Fuel	0.35	20	7	1	0.35	10	3.5	3	1.05	20	7
Manhours	0.16	15	2.4	10	1.6	10	1.6	5	0.8	15	2.4
Weight	0.31	14	4.34	1	0.31	5	1.55	14	4.34	14	4.34
Total	1		16.26		2.98		7.37		8.71		16.26

		UCA		STAMP		Combat Feeding		APM		MPBR	
	Weight	Value Score	Weight	Value Score	Weight	Value Score	Weight	Value Score	Weight	Value Score	Weight
Volume	0.18	0	0	4	0.72	14	2.52	4	0.72	1	0.18
Fuel	0.35	1	0.35	10	3.5	10	3.5	3	1.05	1	0.35
Manhours	0.16	5	0.8	15	2.4	15	2.4	10	1.6	5	0.8
Weight	0.31	0	0	14	4.34	20	6.2	5	1.55	1	0.31
Total	1		1.15		10.96		14.62		4.92		1.64

B. LIMITATIONS AND CONSTRAINTS OF THE DAS AND THE STUDY

There were a number of limitations (hinderances to assessment from internal or external causes) and constraints (restrictions on the study from stakeholder guidance) which affect this system. These limitations and constraints affect the overall system performance and applicability of DRIs within the system.

The biggest constraint of the DAS is that it was designed to assess only technology DRIs, per guidance from the primary stakeholder. It is not an effective tool to assess, compare, and prioritize process DRIs. The largest limitation in the system development was the limited amount of data received to develop accurate value scores and curves for attributes. The team received a total of ten possible DRIs to use for system development at the start of the study. Following dissemination of the data collection questionnaires for each DRI, the team only received six completed questionnaires out of the ten sent out. The returned questionnaires also contained minimal data due to many immature DRIs in the early stages of research and development.

A second limitation of the DAS is that it only included demand reduction attributes and did not incorporate operational attributes such as reducing noise or reducing heat signatures. This limitation resulted in developing the DAS to meet the needs of prioritizing initiatives impacting demand reduction but does not account for any other positive attributes that may make the initiative of greater value to the force. This is however a purposeful limitation to the system, as considering operational benefits would convolute the isolated demand reduction assessment.

A further limitation of the system is the perceived disconnect between the scientists and/or sponsors developing the DRI and those in the operational force who are considering acquisition of the technology. It was found that those developing the technology at times did not have quantifiable goals related to how it would reduce demand or at what echelon it would operate in. Conversely, operational professionals looking at the system as a possible DRI for acquisition did not have a complete understanding of what the technology aimed to reduce or how they would implement it in the force. This disconnect resulted in a lack of quantifiable or usable data to apply in developing the system, leading to a more theoretical or qualitative approach in the development of assessment methods.

C. FUTURE RESEARCH RECOMMENDATIONS

There are opportunities to refine and improve the DAS for future use. Those areas are the questionnaire refinement for data collection, collecting more data on the initial DRIs or new DRIs to improve scoring and curve accuracy, developing benefit analysis, categorization of DRIs based on TRLs, and implementing communication best practices to filter initiatives for use within the system. These recommendations will increase the accuracy of the assessment system and the ability to change or redefine attribute values as DRI priorities change.

To begin, any additions or removals of attributes should be reflected on the questionnaire to continue receiving the most accurate data for initiative assessment. The questionnaire was developed and finalized based on the attribute identification from DRI functional analysis. Upon receipt of questionnaires with the data for initiatives, areas were identified to specify or provide better examples to the DRI points of contact. It was also determined that as operational tactics update and new technologies emerge, attributes related to demand reduction may change.

Additionally, more robust data collection on DRIs under consideration will only improve the accuracy of the system. Out of the original 10 initiatives received, only six of the initiative sponsors completed and returned the questionnaire developed for data collection. Of the questionnaires received, many did not provide quantifiable data due to many DRIs being in R&D and not having sufficient data to provide. This limited quantity of data resulted in the development of value scales created using metrics found through research.

Thirdly, the team recommends developing post-benefit analysis. There are multiple methods that can be applied. Those methods include benefit to maturity analysis based on TRLs and benefit to the impact across the joint force to understand if the fully fielded system will have appreciable gains across the joint force in demand reduction. If possible, benefit-to-cost analysis to understand the best “bang for the buck” and the overall return on investment (i.e., it does not make sense to invest 30 million dollars if it is only going to reduce 20 million dollars in its lifespan) would be a worthwhile analysis for the system.

The fourth recommendation is comparing DRIs of similar TRLs. As an example, TRL 6 and above could be assessed against each other while TRL 5 and below can be assessed against each other to allow more fair comparisons. As any program seeking to go into Milestone B, must be TRL 6 or higher, greater data is available for comparison of high TRL DRIs. This comparison supports prioritization of high TRL DRIs looking for JCIDS approval. Categorization of lower TRL DRIs facilitates a qualitative comparison to prioritize initiatives for R&D funding.

Lastly, the team identified a disconnect between the POCs for the DRIs and the operational stakeholders considering the DRIs for implementation in the force. The POCs are often scientists, in early stages of R&D, who do not understand force sizes or specific military needs to have data available to assess against those metrics. Conversely, operational stakeholders are receiving information on the DRIs in various formats, at differing states of readiness, and without any metrics on hand to request additional specific data. Using metrics in the DAS, better communication practices should be developed to ensure DRI POCs are providing information on their technology based on military needs to make informed decisions. The team identified two possible solutions to this multifaceted issue. The first possible solution is for the primary stakeholder to influence the next higher level to set standards for submitting any demand reduction initiative. This solution would include requiring the DRI POCs to share their baseline objectives. The second option would be to create a working group with the purpose of information sharing between the DRI owners and the operational stakeholders. This team would be formed by the J4 staff and consist of discussion to share data requirements, desired metrics, goals of the DRIs, and any possible data available.

D. FINAL THOUGHTS

The team used a systems engineering approach, based on the Systems Engineering "Vee" Model, to develop this tool for the J-4 Analysis Branch. This study implemented several systems engineering concepts. Those concepts include the completion of stakeholder analysis, the completion of functional analysis, mapping of function to form, creating a top-level system design, the use of value modeling, and the application of sensitivity analysis. Ultimately, this product will provide the LOG FCB with its first objective tool to provide a DRI prioritization for recommendation.

Demand reduction is becoming an increasingly important concept in daily life and especially within military operations. Emerging technologies are focusing on how to make products lighter, faster, and smaller, while using a lesser amount of energy and resources. Understanding the direction of future technology provides an awareness of the large number of ways technologies can reduce demand in the operational environment (OE). The efforts of this study provide a method for objective assessment of disparate DRIs that can be revised as the OE changes. This will be invaluable to providing all branches of the military with the most impactful technologies and equipment to reduce demand at the individual warfighter level through large units. Additionally, it provides the LOG FCB with the ability to fulfill their task of objectively prioritizing disparate DRIs. Most importantly, the LOG FCB will be utilizing the DAS in their Capability Portfolio Management Review.

Upon completion of the project, the team provided the DAS tool to the stakeholders that includes the instructions to use the system, questionnaire for data collection, Excel calculation sheet, and the metrics and definitions for the selected attributes embedded into the document. By providing these products, the team accomplished the primary objective of developing a system that can assess, compare, and prioritize different demand reduction initiatives using a systems engineering approach.

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APPENDIX A. QUESTIONNAIRE

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Developing an Assessment System for DOD Demand

Reduction Initiatives

Initial Data Collection Questionnaire

by

MAJ Achor, CPT Gillogly, MAJ Franks, and MAJ

Groller 17 March 2022

Prepared for: J-4 Analysis Branch

SUMMARY OF TOPIC

The Department of Defense (DOD) developed a new Joint Warfighting Concept (JWC) to address how the United States will confront the Nation's most pressing national security challenges. This in turn derived the Joint Concept for Contested Logistics (JCCL). The importance of logistics during combat operations and the ability to sustain a large force over strategic distances was the focus of the JCCL. The DOD's shift of focus to near-peer threats requires sustainment demand reduction across the services to increase the forces' ability to maneuver in a contested environment.

Many demand reduction initiatives (DRI) are under consideration to lessen the burden of logistics at the strategic, operational, and tactical levels. Due to the relative newness of the JCCL (still in draft format) and complexity of varying initiatives, the LOG FCB does not have a quantitative, credible, repeatable process to effectively assess, compare, and prioritize implementation of demand reduction initiatives. Our team has been tasked with developing an assessment system as our capstone project which will result in a functional system for the LOG FCB to prioritize the most effective demand reduction initiatives to implement across the DOD.

POC for Questionnaire: nathanael.achor@nps.edu, william.gillogly@nps.edu, courtney.franks@nps.edu, and randall.groller@nps.edu

Initial Stakeholder Demand Reduction Initiatives Questionnaire

The intent of this questionnaire is to gather preliminary information about each demand reduction initiatives (DRI) to enable our capstone team in determining which initiatives fall within the scope of our project. Each question looks to better illuminate *what* each initiative is looking to reduce, and by *how much*. Our team understands the varying levels of development across the initiatives and acknowledge that all organizations may not be able to answer each question.

1. **Demand Reduction Initiative Name:**

2. **TRL Level:**

3. **Where is the initiative in the acquisition life cycle?**

Clear Form

4. **What is the initiative trying to improve? Check all that apply.**

	Additional Notes
Reduce Time (ex: reduce time between schedule maintenance, resupply of fuel/H2O/food, etc.)	No
Increase Transportability (ex: Reduce weight/size/ tonnage)	No
Reduce Required Manpower	No
Reduce Required Storage	No
Reduce Cost	No
Reduce Energy Consumption	No
Increase Survivability	No
Increase Maintainability	No

5. **Does your initiative function to improve any other demand characteristic not included in the question above? If so, please identify that characteristic.**

6. **Are there any tradeoffs (ex. By reducing time it increases manpower requirements)?**

7. **Input quantifiable data in the right-hand column of this slide that correlates to the method of measurement for the reduction in the left-hand column.**

DRI attributes that impact logistics. (method of measurement)	**DATA (include what size unit and time-period if known; this can be data collected or expected results)**
(Example system)	**Example of collected or expected quantifiable data**
Reduce Weight: Measure the amount of weight reduced in a logistics package. (% in comparison to legacy system) **(Example: Rapid Expeditionary Ice Construction)**	**Reduce the need for Class IV stock by 15%**
Reduce Volume: Measure the amount of volume reduced in a logistics package. (% in comparison to legacy system) **(Example: Combat Feeding)**	**New MRE packaging reduces volume by 30% enabling 14 instead of 12 MREs per case.**
Reduce Fuel Consumption / Emissions: Measure the number of gallons reduced. (in gallons / tons) **(Example: Mobile Nuclear Power Plant)**	**MNPP reduces volume of fuel required by xxxx gallons/tactical battalion. Or, MNPP reduces emissions by xxxx% carbon dioxide.**
Reduce Resupply Movements: Estimated reduction of resupply needs. (transportation platforms or movements required) **(Example: Biomanufacturing of Lubricants)**	**Reduces number of weekly resupply convoys from 3 to 2.**
Reduce Costs: Estimated reduction in costs related to production, operation, sustainment, and maintenance. ($$ in comparison to legacy system) **(Example: Photobioreactor)**	**Cost to produce lubricants reduced by xxxx%/unit or location.**

Reduce Manhours: Estimated number of man-hours reduced. (hours required for training, maintaining, and operating) **(Example: Autonomous Predictive Maintenance**	**Man-hours required to maintain xx number of platforms is reduced by xx hours.**
Increase Availability: Estimated amount of time equipment is available for use. (hours available for operation – MTBF/(MTBF+MTTR)) **(Example: Tactical Vehicle Hybridization)**	**Hybrid conversion kits increase vehicle availability by xx hours per vehicle.**
Reduce Augmented Power Sources: Estimated reduction in backup power sources. (number of required back up sources) **(Example: Mobile Nuclear Power Plant)**	**MNPP's reduce the need for diesel generators by xx generators/location.**

8. **Has data been collected for your DRI in any areas not listed in question #7? If so, please provide that data here or attach a file with this document.**

9. **Reference any additional documents here and attach in an email.**

10. **Point of Contact Information for follow up questions.**

APPENDIX B. VALUE MODELING

To begin building the scale for “Reduce Volume,” the team reviewed six articles and reports relating to industry and DOD volume reduction efforts. These articles and reports provided the data required to quantify the value scale: Dell’s redesigned packaging reduced the size enabling it to fit 13% more laptops per pallet during shipping (OptimoRoute 2022); Tesla’s new 4680 battery allows for a 40% smaller battery to meet the same energy density (Ali 2020); Amazon looks to reduce volume by 24% for each box (Mohan 2021); using vacuum packaging for clothing reduces volume by 50% (ThriftyParent 2020.); mattress vacuum bags claim to reduce volume by 80% (Fidelity Seller n.d.); Amazon looks to reduce packaging volume by 40% using conforming/ flexible packaging (Amazon n.d.). As the basis of comparison for the reduction produced, 30,000 cubic feet was utilized as that is the amount of water a Brigade sized element needs per year for drinking.

Reduce Volume Value Scale	
Value Score	**Metric**
1	Very Low: 1-4% reduction
4	Low: 5-17% reduction
14	Medium: 18-40% reduction
17	High: 41-63% reduction
20	Very High: 64%+ reduction

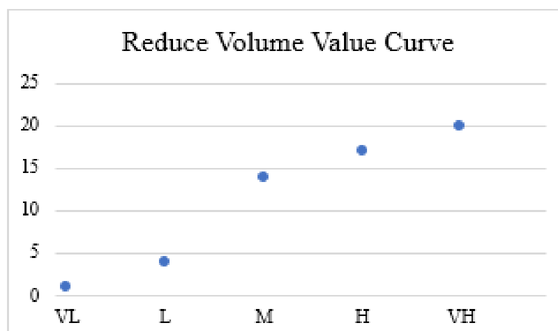

Figure 18. Reduce Volume Value Scale and Value Curve

To begin building the scale for “Reduce Weight,” the team reviewed six articles and reports relating to industry and DOD weight reduction efforts. These articles and reports provided the data required to quantify the value scale: Ford reduced the F-150 weight by 700 pounds which provided a 15% reduction (Woodyard 2014); Tesla’s 4680 battery reduced battery pack mass by 10% (Ali 2020); a study recommended the DOD to switch to polymer case ammunition which would reduce weight by 50% (DOT&E 2021); 500 ml water bottles reduced weight by 72% over 32 years (Sand

2019); the new SIG 6.8mm hybrid round for the Next Generation Squad Weapon is 23.5% lighter than standard ammunition and exceeded the Army's goal of 20% (Graves 2021); The Army's advanced medium mobile power source reduced weight by 10% (USAASC 2022).

Reduce Weight Value Scale	
Value Score	**Metric**
1	Very Low: 1-4% reduction
5	Low: 5-14% reduction
14	Medium: 15-29% reduction
17	High: 30-51% reduction
20	Very High: 52%+ reduction

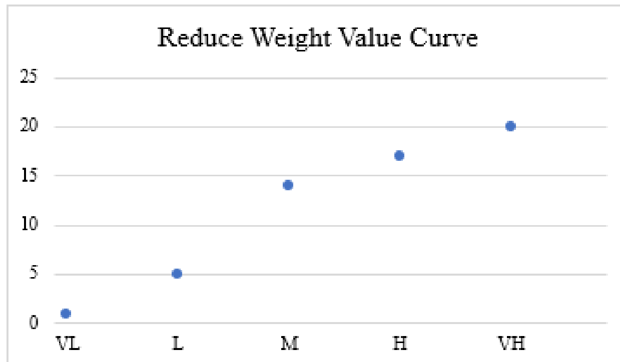

Figure 19. Reduce Weight Value Scale and Value Curve

To begin building the scale for "Reduce Manhours," the team reviewed six articles and reports relating to industry and DOD manhour reduction efforts. These articles and reports provided the data required to quantify the value scale: Training time for unmanned aircraft pilot was reduced by 7.5% when compared to a manned aircraft pilot (Burg and Scharre 2014); graduates of the Air Force's aircraft undergraduate training pipeline receive 60% fewer flying hours than manned aircraft pilots (Burg and Scharre 2014); utilizing lean tools reduced operator time by 10% for textile trimmings (Pinto et al. 2019); the Navy experienced a time savings of 43% using additive manufacturing and reduced operation durations by 39% using Three-Dimensional Laser Scanning (Ford and Housel 2020); a microgrid test in Afghanistan had a 33.5% reduction in maintenance manhours (DOT&E 2021). As the basis of comparison for the reduction produced, a full-time equivalent (FTE) of 40 hours a week was utilized.

Reduce Manhours Value Scale	
Value Score	Metric
5	Very Low: 1-9% reduction in FTEs for a BDE size element
10	Low: 10-14% reduction in FTEs for a BDE size element
15	Medium: 15-31% reduction in FTEs for a BDE size element
18	High: 32-51% reduction in FTEs for a BDE size element
20	Very High: 52%+ reduction in FTEs for a BDE size element

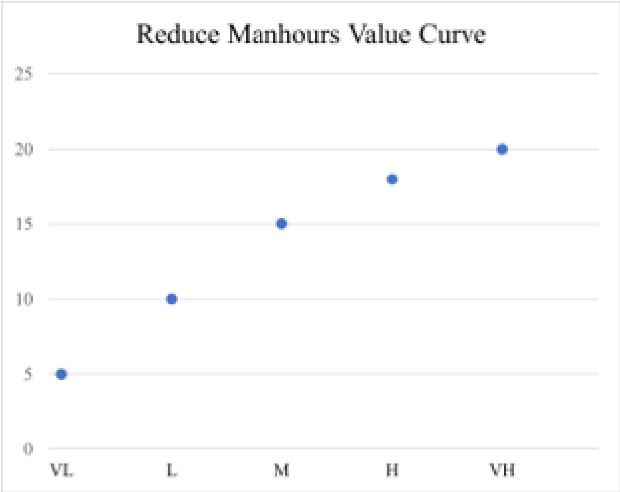

Figure 20. Reduce Manhours Value Scale and Value Curve

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