DISSERTATION

APPLYING MODEL-BASED SYSTEMS ENGINEERING IN SEARCH OF QUALITY BY DESIGN

Submitted by

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In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Spring 2022

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ABSTRACT

APPLYING MODEL-BASED SYSTEMS ENGINEERING IN SEARCH OF QUALITY BY DESIGN

Model-Based System Engineering (MBSE) and Model-Based Engineering (MBE) techniques have been successfully introduced into the design process of many different types of systems. The application of these techniques can be reflected in the modeling of requirements, functions, behavior, and many other aspects. The modeled design provides a digital representation of a system and the supporting development data architecture and functional requirements associated with that architecture through modeling system aspects. Various levels of the system and the corresponding data architecture fidelity can be represented within MBSE environment tools. Typically, the level of fidelity is driven by crucial systems engineering constraints such as cost, schedule, performance, and quality. Systems engineering uses many methods to develop system and data architecture to provide a representative system that meets costs within schedule with sufficient quality while maintaining the customer performance needs. The most complex and elusive constraints on systems engineering are defining system requirements focusing on quality, given a certain set of system level requirements, which is the likelihood that those requirements will be correctly and accurately found in the final system design.

The focus of this research will investigate specifically the Department of Defense Architecture Framework (DoDAF) in use today to establish and then assess the relationship between the system, data architecture, and requirements in terms of Quality By Design (QbD). QbD was first coined in 1992, Quality by Design: The New Steps for Planning Quality into Goods and Services [1]. This research investigates and proposes a means to: contextualize high-level quality terms within the MBSE functional area, provide an outline for a conceptual but functional quality framework as it pertains to the MBSE DoDAF, provides tailored quality metrics with improved definitions,

and then tests this improved quality framework by assessing two corresponding case studies analysis evaluations within the MBSE functional area to interrogate model architectures and assess quality of system design. Developed in the early 2000s, the Department of Defense Architecture Framework (DoDAF) is still in use today, and its system description methodologies continue to impact subsequent system description approaches [2]. Two case studies were analyzed to show proposed QbD evaluation to analyze DoDAF CONOP architecture quality. The first case study addresses the analysis of DoDAF CONOP of the National Aeronautics and Space Administration (NASA) Joint Polar Satellite System (JPSS) ground system for National Oceanic and Atmospheric Administration (NOAA) satellite system with particular focus on the Stored Mission Data (SMD) mission thread. The second case study addresses the analysis of DoDAF CONOP of the Search and Rescue (SAR) navel rescue operation network System of Systems (SoS) with particular focus on the Command and Control signaling mission thread. The case studies help to demonstrate a new DoDAF Quality Conceptual Framework (DQCF) as a means to investigate quality of DoDAF architecture in depth to include the application of DoDAF standard, the UML/SysML standards, requirement architecture instantiation, as well as modularity to understand architecture reusability and complexity. By providing a renewed focus on a quality-based systems engineering process when applying the DoDAF, improved trust in the system and data architecture of the completed models can be achieved. The results of the case study analyses reveal how a quality-focused systems engineering process can be used during development to provide a product design that better meets the customer's intent and ultimately provides the potential for the best quality product.

ACKNOWLEDGEMENTS

The author would like to thank all who contributed, supported, and motivated (removed ’for’) the creation of this work. Of note, are Mrs. Ashley L. Miller PMP., Mr. Russell F. Miller, Mr. Kirk Moen, and Mr. Brian Rosa. Mrs. Miller serves as the Director of Missile Defense Agency (MDA) Programs Teams Contract for the Modern Technologies Solutions Inc. (MTSI) Company. Mrs. Miller provided motivation and technical engineering evaluation of this works methodology in application. Mr. Miller serves as Sr. Technical advisor to MDA for the Parson Corporation, and provided technical guidance and motivational support to complete this work. Mr. Moen serves as Sr. System Engineering Team Lead / Architecture Lead at the Boeing Company, and helped provide case studies for analysis within this work. Mr. Rosa serves as Sr. Engineering Manager for Ground Based Midcourse Defense (GMD) program at the Boeing Company, and without his early approval embarking on this journey would not have been possible.

The author would also like to thank Dr. George Collins, members of the committee, and staff of the system engineering department at Colorado State University for expert guidance and quality responsiveness. The author would like to thank Dr. Daniel Herber for picking up where Dr. Collins left off by providing technical guidance allowing the author to complete this work. Finally, the author would also like to thank his spouse and children, whom with their love, support, and sacrifice have made this amazing opportunity possible for the author to achieve.

DEDICATION

I would like to dedicate this dissertation work to my loving family Ashley, Parker, Payton, Piper, and Paxton. Without your love, encouragement, support, and sacrifice I could never have completed this amazing accomplishment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

As systems engineering exists today, difficulties exist in the reasoning to justify the application of using MBSE for the system design process. It is impossible to overstate the speed with which the fourth industrial revolution Industry 4.0 is gaining pace as a growing and increasing component of information with an emphasis on merging the physical-to-digital and digital-to-physical worlds is gaining momentum [12]. According to an article, recently published January 2022 in *An Introduction to Cyber Analysis and Targeting* stated the Department of Defense Architecture Framework (DoDAF) is still in use today, and its system description methodologies continue to impact subsequent system description approaches [2]. The struggles stem from the many interpretations of the Unified Modeling Language (UML) and Systems Modeling Language (SysML) base languages, application to system design, and evaluation methods. Even with many frameworks or architectures following the same general design process, there is still a lack of understanding of a system's model "good" quality design. Additionally, questions arise on how the design team knows if the design is good? What are some of the contributing factors for driving quality? And what methods exist for trend evaluation of the system design process? The lack of tying systems engineering quality methodologies to analyze the design development process lacks an MBSE application to DoDAF architecture's. Quality tie in the MBSE environment and provide a unique ability to interpret how well a model design meets the customer expectations. This dissertation aims to provide a methodical, researched, re-contextualized technical approach to DoDAF architecture quality within MBSE architecture practices. The dissertation provides validation quality and confidence in the system design to all stakeholders. This initial chapter provides background context to frame the content of the study and dissertation work.

1.1 Background

The re-contextualized concept mapping of Quality By Design (QbD) includes a high-level definition of terms, outline for conceptual framework, tailored quality metric definitions, and corresponding case study evaluation within MBSE practices providing a proven validation of the quality of the system requirements and ultimately the design. The technical approach enables engineering teams to truly understand where quality comes into play for the system design in developing a model. The high-level definition of terms helps to understand the technical data needed to meet the QbD [1]. The QbD phase was first coined in the 1992 publication of *Juran on Quality by Design: The New Steps for Planning Quality into Goods and Services* [1]. The paper describes a method for understanding knowledge-based decisions associated with quality, systematic approaches to process development for quality, and continuous process improvement [1]. The dissertation outlines a conceptual framework consisting of model-based delineation of Juran's quality ontology mapped to the DoDAF architecture ontology. A tailored quality metric definition process illustrates how to define metrics in terms that identify quality aspects for DoDAF Architecture. Case studies illustrate the practical application of a quality-based conceptual framework application to designed systems for evaluation purposes. The primary elements of the dissertation include literary review supported by practical application of the conceptual framework to DoDAF architecture case study models evaluating quality.

1.2 Literary Review

The following section contains the literary review conducted to investigate solutions to the problem presented in this dissertation.

1.2.1 Literary Review Methodology

The literary review was conducted following a systematic review process designed by Denyer and Tranfield tailored to fit the author's need [13]. The research was driven by research questions formulated during the preliminary exam process and presented to the dissertation committee during the formal presentation. The review process followed a pre-established protocol for analyzing each document or material to provide a broad scientific basis of the current state of academia and industry around model-based systems engineering within the context of quality. The methodology consists of several steps described in Table 1.1 located in this section and attempts to answer research questions using a formulated step process through the collection of data sources, a selection evaluation process, a data recording template, and a results area where the details of the literature review will be discussed.

Table 1.1: Steps of Evaluation

Step Number	**Description**
Step 1	Formulation of research questions. Guiding research questions were formulated. (Section 1.2.1)
Step 2	Selection of data sources. A set of reference materials were selected from various DoD sources, Libraries, and Databases were selected for the search. (Section 1.2.1)
Step 3	Selection and evaluation of literature. An initial evaluation to confirm that the selected material met the inclusion criteria was performed. (Section 1.2.1)
Step 4	Data recording. Relevant papers identified in Step 3 were evaluated, extracting and recording data addressing MBSE benefits and the potential benefits provided by quality metrics. (Section 1.2.1)
Step 5	Reporting of results to contextualize the Problem Statement. (Section 1.2.2)

Research Questions

The literary review and research questions were established to understand the existing evidence about quality related to MBSE with a particular focus on the DoDAF architectural framework. Three central research questions help to guide the context of the literary review. The questions are as follows:

1. **Research Question 1:** How does DoDAF relate to systems engineering methods of analysis for a quality-based design for a weapon system? The question reaches into the multi-objective comparisons of related MBSE architecture data.

2. **Research Question 2:** What are the main factors in developing an MBSE conceptual framework that provides good systems engineering analysis? Establish the link between design methodology for a conceptual framework and how it relates or can relate to quality.

3. **Research Question 3:** What are the metrics that are significant in assessing an approach that correlates quality of design with an MBSE architecture? Systems engineering and programmatic are critical to the establishment of effective quality management. The quality metrics help translate stakeholder needs into acceptable measures of both products and processes for a system design.

The literary review's primary focus was to survey current literature to evaluate the extent of evidence about quality related to MBSE and DoDAF (see Section 1.2.2).

Data Sources

For the literature review, several different data sources focused on systems engineering, architectural design, systems engineering quality, and architectural design quality. These areas helped to narrow the focus for digital database searches, library reference material, DoD manuals, and military standards specifications and are described as follows:

- **Journals, Articles, and Conference Proceedings:** Journals and conference proceedings were selected based on search criteria associated with keywords and phrases listed in Section 1.2.1 related to quality literature. Some sources include Institute of Electrical and Electronics Engineers (IEEE), American Institute of Aeronautics and Astronautics (AIAA), International Council on Systems Engineering (INCOSE), etc.

- **Military document and standards:** Military standards are typically referred to as a means for the Department of Defense to standardize information associated with a particular category. Some of these articles are released by various military branches, including Army, Navy, Air Force, and Marine Corps. These documents help ensure Department of Defense-generated products meet certain commonality, reliability, compatibility, and other aspects of the design of the system.

- **Databases:** Several databases, including the Colorado State University library, were accessed to obtain materials for reference. These databases include Springer link, Wiley online, and many others.

This election does not cover all the potential outlets where the material is published surrounding the topic for this dissertation. The author did consider Government Accountability Office (GAO) reports, PowerPoint presentations, books, and other miscellaneous data sources containing applicable information and cited throughout the dissertation. The data represented in this review is merely a sampling of the overall collective knowledge available within the industry and academia. The author does recognized that some outlier proceedings such as company or organizational private data may exist, but for this literary review, only open-source material or material to which the author had access and permission to use was considered for literary analysis. No proprietary information or other such type-controlled information was analyzed for this literary review.

Selection and Evaluation

To perform a broad search of the material available, the author used keywords to help scope the return result for the documents and materials to be analyzed. The following phrases were used to provide the return result from database searches, Department of Defense (DoD) libraries, and journal articles. The phrases are as follows:

- Model-Based Systems Engineering (MBSE) methods for quality
- DoDAF models system architecture quality
- Department of Defense (DoD) architectural quality
- Model-Based (MB) quality metrics

- Systems engineering quality metrics
- Design Quality
- Department of Defense (DoD) System Requirement Generation

Once an article was selected, the author performed a read of the body of the paper. Papers used contain closely related information directly to the critical phrases identified above which provided substantial detail relating to the topic of this dissertation. Papers excluded from the literary analysis did not contain any information relating to the understanding of quality within an architectural development understanding. No restriction was placed on the type of architecture quality or associated claim of a quality evaluation. Additionally, no exclusions were based on differentiation of definitions or understanding or context interpretation of what quality means in model-based systems engineering architecture. The author believes that the data sources referenced in the paper contributed the dissertation's overall topic and proof.

For this literary review, the author specifically focused on data related to developing model-based systems engineering DoDAF architecture, in an un biased environment free from tool implications that might have been used for the development of the architecture, and specifically focused on the Concept of Operations (CONOP) requirements (one of several typical DoD requirements categories used) developed within the architecture to narrow the scope of analysis for each article during the literary review. For the overall development of the CONOP, the CONOP development standard used by the DoD to outline the development of a DoDAF architecture was used to analyze each of the quality understandings for the presented material.

Data Recording

The author, in order to perform a thorough analysis of each paper, a literary template was created, and each document or research material was used to fill out the corresponding template. The criteria that the template help to capture included the following:

- **Research Article:** the research article section included the name, author, title, and a citation for later use within this dissertation.

- **Problem addressed/identified:** this section contained a summary of the problem that the paper attempted to address for later reference by the author.
- **Research contribution:** a research contribution section helps to identify what contributing factors the article or research material provided to academia or industry relating to the topic.
- **Aim and objectives:** the aim and the objective section helped to better describe what the authors were attempting to accomplish with the article.
- **Novelty/rationale and significance:** this section helps to capture the critical reasons for understanding the research and focusing on answering why the research was conducted.
- **Limitations and weakness:** the limitations and weakness section help to describe where the authors found any weakness within the article presented.
- **Finding and conclusions:** defining a conclusion section help to provide a summary of the article's overall findings and includes any significant conclusions that the author reached.
- **Future work:** the section of the template included a future work area to understand the potential benefit for future research that was suggested to continue as described in the article.

1.2.2 Literary Analysis Results

The following section of Chapter 1 provides an synopsis of current literature in academia and industry to provide a contextual framework for the problem statement in section 1.3. The literary review outlines topics related to quality to provide context and overall understanding of how this dissertation's DoDAF conceptual quality framework meets the needs of defense industry system engineers. The literary review covers various topics associated with quality for MBSE related to engineering practices specifically addressing DoDAF and the development of Concept of Operations within the DoDAF framework to scope and scale data analysis for the case study applications. The topics associated with quality and addressed within the literary review include: 1) Quality of Models, 2) MBSE Benefits that Drive Quality, 3) MBSE Quality in Defense, 4) MBSE Architectural Frameworks and Quality, 5) MBSE Quality Role in DoDAF Application, 6) MBSE Metrics and Quality, 7) MBSE Modularity Addressing Quality, 8) MBSE Quality Architecture, and Literary Review Final Conclusion. These topics help to outline understandings and critical concepts the conceptual framework needs to address for DoDAF quality analysis, which are discussed further in Chapter 2.

Quality of Models

Models and their quality have been a significant part of the systems engineering paradigm for many years. Models allow engineering teams to analyze complex problems and develop representative expansive solutions. For several decades, the systems engineering paradigm has relied heavily on computer-based models to provide the analysis and documents to capture the complexity and mathematics associated with system performance and model development. For the most part, the document based data captured resided in disparate locations which made it difficult for engineers and customers to follow the implementation or translate customers' design requirements from one to the other [14]. Quality of the document based models often does not provide a clear picture of how quality engineering of the model is captured or accurately reported. With the advancement of computer technology, modeling the engineering task became easier and was able to graphically relate and connect the disparate data. Even with the advancement of MBSE, maintaining cost still affects how detailed a model can be to capture the complexity of systems or their quality. The American Society for Quality translates a Cost of Quality (CoQ) for development as usually around 15 – 20% of product development cost, often as high as 40% in some cases [15]. CoQ is defined as reflects the financial burden that an organization has as a result of the creation of inferior goods and services [15]. CoQ deals with four aspects of quality 1) prevention, 2) appraisal, 3) internal failure, and 4) external failure [15]. The first two aspects are proactive in nature, in that they work to prevent the faulty items from ever being produced [15]. The latter two aspects are reactive in nature and entail the management of faulty items after they have been produced [15]. In addition to CoQ an inherent problem exists in the establishment of a Configuration Managed (CM) baseline for a systems engineering program digital model. How to maintain the complexity of baselines while giving the customer control without completely stifling the ability of engineers for rapid analysis or development as well as maintaining quality. Typically, the ability to meet the complexity of system's performance while maintaining cost and schedule is difficult for engineering teams [16]. Handling changes can be simplified by an MBSE approach and was formalized to provide that capability for requirements, analysis, design, verification and validation as early as the conceptual design phase [16]. Model-based methodology developers sought to integrate software, system understanding, and architecture into one tool that would be convenient for engineers and customers [16, 17]. The integration efforts helped to provide an increased rigor to engineering activities essential to improving quality model-based centric approaches [16]. However, even with the combination of Digital Engineering (DE) integrated activities and increased design rigor, adequate model quality can still be lost in the complexity of architecture [16]. Navas continues to state that even with MBSE methodologies being able to connect disparate data in a digital engineering environment, improved quality understanding still needs to be addressed within academia and industry [16].

MBSE Benefits That Drive Quality

As MBSE advanced, many benefits were noticed by the systems engineering academia and industry. These benefits include several advantages over that of typical document basis engineering. The reliance on bookform documents scattered throughout a program with varied interpretations of text can be avoided by the MBSE approach to requirement iteration. Parth Shad research into US defense spending found that nearly 60% of all United States Defense Acquisition Programs are either over budget or have schedule delays [18]. Shad's analysis found that the Government Accountability Office (GAO) found that 61 of 86 programs evaluated showed cost growth of 62.4% or $542.1 Billion and schedule overruns of 35 months on an average [18]. The remaining 25 programs observed a cost growth of 2.1% or $5.3 billion and schedule overruns of 9 months [18]. To better understand the disadvantage of traditional systems engineering, the Madni and Purohit paper provides industry knowledge surrounding costing aspects. Typically, document centric approaches to systems engineering traditionally have hidden costs associated with them [6]. Madni and Purohit showed that document based systems engineering methods had a considerable amount of cost developed over time [6]. The savings delivered via MBSE are approximately a 55% reduction in development costs of the typical bookform development [6]. The application of visual and semantically rich modeling language to the systems engineering challenge reduces cost by reducing the effects of system complexity and engineering productivity. The typical concept, design, and development phase were mostly below 10% of the total cost; however testing, and operation of a system through disposal comprised of nearly 80% of the total cost of the program in development [6]. Figure 1.1 below shows the average percentage cost of these engineering phases of a system development over time.

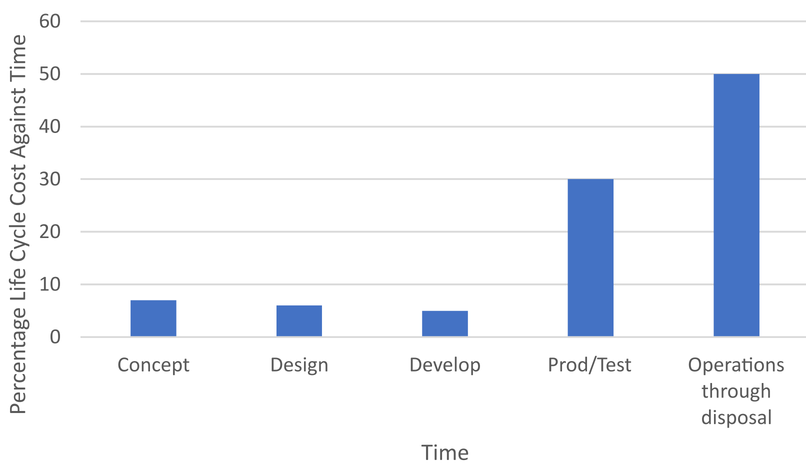

Figure 1.1: Percentage Cost of Each Phased Doc-Based Approach [6]

MBSE has shown a trend of cost savings for critical areas of programs as they are developed [19]. One keynote showed that a small investment in a model-based approach could have saved a large amount of money over the systems life [20]. Understanding MBSE cost savings is just part of the triad of systems engineering triangle. The next disadvantage of document based systems engineering is the inability to fully understand complexity. According to the phasing in system life-cycle processes in IEEE 15288, MBSE can be used to address complexity in system design processes [21]. The phases include technical processes, technical management processes, organizational and agreement processes [21]. The sub processes of the technical management and organizational processes include a quality assurance and management processes [21]. The Submarine Warfare Federal Tactical System (SWFTS) averaged an increase of element material by approximately 30% each month by utilizing the MBSE approach [22]. Additionally, the complexity of an average system, in quantity of requirements and defined interfaces, has grown by 7.5% each year [22]. MBSE has allowed an increase in scope of engineering teams to bring more into the model and bring interconnected data to the finger tips of designers and stakeholders [6].

Even with cost savings and complexity reduction of an MBSE approach over document based systems engineering one of the more difficult areas is quality understanding or application for both MBSE and Systems Engineering. Traditionally, document based systems engineering is difficult to maintain synchronization and assess terms associated with quality, correctness, completeness, and consistency [23]. Traditional document based systems engineering everything is located in different documents and hard to flow the material together. In MBSE the complexity reduction helps to bring the data together in one visible model but still is still vulnerable to quality when describing what is to be integrated or produced by the model. In the Sandia National laboratory literary review of case studies on the justification for model-based systems engineering, some of the case studies showed early improvement in overall quality objectives by enabling early fixes or preventing rework [24]. Even with preventing rework, Carroll showed that the apparent low quality exhibited in the studies presented, should be interpreted with caution and that further investigation or research is needed to fully understand the implications of quality in the systems engineering of model based approaches [24].

MBSE provides advantages over traditional document based systems engineering, but with the benefits, limitations still exist. This section focused on the benefit of MBSE over the traditional document-based systems engineering paradigm and provided views into the complexity of the disadvantages in cost, complexity, and quality. Madni, Mitchell, and Carroll showed that even with the benefits that MBSE provides, quality struggles within modeling paradigms needs to be addressed to meet the need of all stakeholders.

MBSE Quality in Defense

As was illustrated in the previous Section 1.2.2, there are extensive benefits of MBSE but also it is difficult to quantify the application of quality in MBSE. 1.2.2. As defense organizations have started to evolve, MBSE has been at the forefront of development. To better understand what was needed to address the complexities of new defense systems, defense organizations investigated Information Age Warfare (IAW) [25]. The IAW included understandings of information superiority in network-centric warfare [25]. For DoD to address the complexity of new defense systems, several understandings had to be developed. Modern systems are now more software-intensive, and typically most of the data does not exist in isolation [26]. Knowing that data does not exist singularly, new approaches were developed to capture data in a more meaningful way to make better informed decisions [26]. The un-isolated data led to a fundamental understanding of the development of architectural frameworks discussed in Section 1.2.2. The development of these architectural frameworks come from increased economic pressures to increase the quality of requirement's frameworks and thereby reduce the cost of defense system development [26].

Using MBSE, the Department of Defense (DoD) saw an opportunity to develop a framework to allow commands, services, and defense agencies to have corresponding data across operational, systems, and technical aspects, including international boundaries [27]. The framework approach allowed for a clear and audible trail of measurable characteristics to be populated within the architecture. It also related the operational understandings for new system development [27]. The DoDAF standard was created to provide a means for presenting architectural descriptions integrated for understanding, comparison, and integration in interoperability System of Systems (SoS) concept [27]. It is notable that in 2013, the Department of Defense (DoD) mandated the submission of DoD Architecture Framework (DoDAF) models during a program's Materiel Solution Analysis Phase (MSPAP), where a CONOP is developed, occurs early in the system life cycle and has historically been marked by a lack of system specification and parametric estimation [28]. Standardizing a common architectural development approach ensures inter-organizational cooperation for operational concepts and capabilities [27, 29]. Standardizing helps implement architectural style in a consistent set of architecture rules for element creation [30]. It also allows for the DoD to anticipate and understand changes in capability needs of currently fielded systems and the need for new systems [27]. The architectural approach allows system designers to simplify, logically, comprehensively, and structurally understand a systems design [27]. By using an architectural framework standard, developed in conjunction with academia and industry for system model development, clear and concise practices can be established. Typically, the translation of architectural standards and traditional systems engineering documentation into the digital engineering model elements introduces ambiguity and programmatic risk to quality of the model is not emphasized [5]. In summation, Kobryn and Sibbald stated that economic pressures help drive the creation of standards for architectonic models to increase quality. Griffin stated that standardization helps to provide approaches and simplification to the development of System Architecture or System Model. However, Miller and Herber stated that even with standardization and simplification for model architecture development, the translation from textual context of document in systems engineering into digital engineering often introduces ambiguity and programmatic risk effecting quality of models developed [5].

MBSE Architecture Frameworks and Quality

As we saw in the previous Section 1.2.2, DoDAF is used to standardize the DoD approach to interoperability of modeling for defense systems [26]. The standardized DoDAF framework provides guidance, ontology, taxonomy, and rules for developing architectural descriptions for defense systems [26]. In addition, the DoDAF standard defines what working products relate directly to architectural development with descriptive views to communicate the intent of the architecture [26]. The DoDAF architectural descriptions have many terms which are associated with descriptive artifacts within the model. The specific terms and views are what convey specific aspects of the architecture to an intended audience [26]. The architecture is based on both UML and SysML languages which provides the associated relationships and stereotypes within the model elements. Views consist of operational, system, standard, and many others [26]. The Operational View (OV) typically evaluates the degree of interoperability between various detailed information exchanges of the system [26]. In contrast, a system view (SV) identifies how the system can support operational requirements and translates those requirements into system data exchanges related to functions or required operational capabilities [26]. Many other views exist within the DoDAF architectural standard and will be discussed later in Chapter 2 to better scope the focus for analysis purposes of this dissertation. Generally, quality is thought to be implied if the process is followed in the application of the standard. Specifically, within the DoDAF standard, there is no view that directly relates to quality. Quality is simply a byproduct and relies heavily on subjectivity or the expertise of the team applying the standard. The subjectivity in application of the standard occurs and our experiences or perspectives influence decisions in the application [31].

Overall, the DoD has begun the implementation of a standardization of processes to develop a system architectures. However, the processes fall short and fail to address quality and the importance that quality can have on the development of an architecture. The DoD developed standard does not address quality but simply assumes as it is implied if the standard application processes are followed. By taking this approach to quality, the DoD has removed objectivity or logical application and introduced a large amount of subjectivity. As Noxolo stated, subjectivity can be based on individual perspectives and influence decision making process removing the point of standardization. The approach is problematic and needs a methodology to assess quality.

MBSE Quality Role in DoDAF Application

A few fundamentals must be established first to understand the application process for MBSE within the context of DoDAF standard and quality. There is a critical need for skilled system engineers, systems engineering and MBSE [24]. Carroll made the simple observation for the need for MBSE skilled system engineers. If programs are to reap the benefits of the modeling approach using the DoDAF standard, engineers must have a basic understanding of DoDAF and quality to utilize the information generated and integrate the data throughout the developed models [24]. System engineers and members of the design team, including stakeholders, need a MBSE understanding in order to leverage their knowledge in a meaningful way during the development of the models and resultant system [24]. It is critically important to resist traditional thinking and embrace new knowledge in order to reap the benefits that MBSE provides [24].

As the transition to MBSE takes place, necessary perspectives, roles, and competencies are critical to understanding the standardization for a model-based approach [32]. In applying a model-based approach, it is critical to have staff with the knowledge and application experience of MBSE [32]. Several frameworks exist which discuss role competencies for engineers to understand systems engineering. The frameworks include the INCOSE systems engineering competency framework [33], NASA systems engineering competencies [34], and the MITRE systems engineering competency model [32,35]. Other competencies exist but only the previous list will be addressed. The roles described in each model are defined through a varying methods but include identification, categorization, and association to the appropriate stakeholder responsibility [32].

The MBSE approach highlights an essential role associated with engineering: the Subject Matter Expert (SME) [32]. The SME can provide multiple disciplines within an overall system model and apply detailed decomposition for system elements within a model architecture [32]. Understanding the inter-element dependencies is critical for the quality assessment of models being developed or models that have been developed. Additionally, understanding inter-element dependencies helps to remove the subjectivity and focus on objectivity in a framework application. Without understanding the quality competencies required of system engineers and the MBSE implementation approach, a quality design framework application of DoDAF architecture may lead to ambiguous data or lost context [32]. Highlighting the SME role competencies and relative responsibilities are fundamental to activities necessary to assess quality within a DoDAF architectural model [32].

Engineering competencies relating to systems engineering, quality, and MBSE are critical in implementing a quality DoDAF model architecture. The understanding of interdependent relations between data in a model helps to reduce the amount of subjectivity associated with architecture development. Solely relying on standardization without the knowledge base can lead to volatility or ambiguity in the architecture development process thereby reducing the quality of the architecture.

MBSE Metrics and Quality

While some architecture aspects are difficult to quantify, metric definitions help to provide a sense of where model development is headed [36]. MBSE stems from the adaptation of models in the systems engineering environment. What makes these models worthwhile is their ability to provide a quantitative or qualitative assessment within their application. By utilizing metrics in an MBSE environment, tools can be better utilized to assess the suitability of a system and its models to quantitatively address quality.

Structure diagrams such as a Block Definition Diagram (BDD), Internal Block Diagram (IBD), and requirements diagrams are some of the MBSE system architecture models that are difficult to validate in the typical construct of model validation but are crucial to MBSE and DoDAF architecture. One of the biggest hurdles in applying validation metrics to these models is that the architecture associated with them is based subjectively on the developers' sense of inclusion [37]. Additionally, the tested concepts of verification and validation approaches are not possible in MBSE descriptive models as there is no output data to compare with actual data [38]. Ways to navigate this include conversion of SysML behavioral models into executable models and then performing the V&V, or evaluation of the model using syntax and semantics; however, these techniques generally address the verification of the model, ensuring that the model is appropriate or follows modeling language standard. To evaluate the model, one must look at the international standard ISO/IEC 9126 adopted by the software engineering community and evaluate six attributes in a model [39]. The six attributes are functionality, reliability, usability, efficiency, maintainability, and portability [39]. Although the criteria can be highly subjective, the criteria can be used to establish the validity of the model used in a measurable form [37]. By using MBSE tools with the criteria established, we can verify that in the requirements definition process, the requirement is defined and utilizes the ISO/IEC 9126 or ISO/IEC 25010 standards to determine how well the modeller is addressing quality [40, 41].

Understanding how to measure the maturity of a system is a trait that must be modeled appropriately to understand the system's readiness. In engineering, the Technology Readiness Level

(TRL) is one such measurement tool that program managers utilize to assess the technology maturity [42]. The TRL rating is determined using subjective analysis from experts' analyses of how and whether criteria are fulfilled. The main issue in the non-MBSE analysis is that the experts' analysis is largely subjective. TRL metrics are often considered soft measures, which are qualitative, subjective, and based on subjective data. These metrics can be biased due to the reviewers' biases and interpretations of each TRL level. These maturity artifacts are identified and mapped to the system architectural element by identifying a set of DoDAF models suitable for maturity assessment [42]. The introduction of DoDAF and its fit-for-purpose (FFP) models helped solidify the use of MBSE metrics for decision-making and utilization of readiness assessments [42]. The use of a Conceptual Data Model (CDM) to define the higher-level data constructs is helpful in that it enables the decision-makers to understand the data included in the Architectural Descriptions [42]. By incorporating the CDM, the maturity elements that have been utilized have better characterization.

The use of MBSE tools in defining readiness levels provides a more structured documentation process. With the increased availability of data and transparency, the outcome is more informed and reliable decision making. However, this understanding for TRL fails to address the model quality or aspects of the model quality.

MBSE Modularity Addressing Quality

Complexity in systems engineering architectural development is problematic to manage for the systems engineering team [43]. The decomposition of system architecture into various buckets of data; however, can be accomplished through a modular approach. A modular approach is a means to divide the system into smaller chunks while maintaining their interdependencies [44]. Modularization of system elements into more manageable segments helps to reduce the complexity of the system and the DoDAF standard allows for this through view types [44]. The views for DoDAF provide a means to put elements and key relationships in patterned design diagrams with specific standardized ontology for DoDAF. Ontology is the structure and knowledge sharing between various aspects during design process [45]. Typically, in traditional systems engineering, quality for models is managed through processes or cycles of design, build, and review. The quality management processes mentioned in Section 1.2.2 focus on systems engineering meetings, team approvals, or SME determination for content to move forward into the design. In these processes, materials would be reviewed, feedback provided and comments adjudicated prior to design implementation. The cyclical approach to quality management processes uses various methods to provide analysis prior to entering the material for review. The various methods include functional, impact, or requirement analysis to analyze content as well as meta-data within elements. Modularity comes into play in the understanding of how granular or to what level decomposition has occurred including where lines of demarcation exist between lower levels of a system [44]. Specifically, modularity is a means to cluster system elements into a larger more manageable chunks to reduce complexity [44]. Typically, decomposition of requirement specification in to the appropriate architecture is very difficult and modularization can assist with complexity reduction [46]. Modularity can allow for ease of reconfiguration or assembly, improved field performance, or customization [47, 48]. The benefits of modularity are due to the ability to decouple elements of architecture and hide unnecessary information [49, 50]. Even with the bucketing of data into specific views within DoDAF architecture, considering modularization or understanding what level of granularity is needed is a difficult task in the representation of quality in the architecture [44].

While complexity exists in architectural development system design, standardization can assist as a starting point for addressing modularity. However, according to Chiriac and his team, understanding how and to what level modularization granularity occurs in the system architecture needs further research [44].

MBSE Quality Architecture

Recent case studies suggests that the non-functional quality of a system is of little use to the end-user and is more relevant to the design of the architecture [51]. Non-functional requirement types include licensing issues, availability of support, and organizational policies, whereas quality attributes include performance, usability, interoperability, etc [52]. In contrast to functional requirements derived from the customer, non-functional requirements are most often developed from the architect's perspective viewpoint. The implications of this alignment are profound. The ability to model the non-functional requirements from the customer's point of view is most important. Otherwise, the functional aspects of the model overrule the non-functional allocations [52]. Architects must find a balance between the functional and non-functional requirements that support end users' goals and demands but are also supportable from a financial perspective [52].

Within NASA's Safety and Mission Assurance (S&MA) group, MBSE tools are being evaluated in their application on how they relate to quality assurance, reliability, and maintainability, safety, and software assurance [53]. In the utilization of modeling languages, the ability to consolidate information for ease of use in decision-making has become an important factor in understanding the usefulness of MBSE tools [53]. Performed correctly, the requirements of the system and all applicable quality and –ility concerns can be stored in a centralized repository. The goal is to provide overlap between NASA's existing S&MA group and the MBSE community in the establishment of policies and standards that enable the totality of their goals [53]. Requirements definition, V&V, etc., can be represented in SysML, while other areas, such as Radiation Testing and Analysis, requires additional interface tools but can be modeled and captured in SysML [53]. After completing the process activity diagrams, it is apparent which actions have been completed, and metrics can be determined from thorough analysis [53]. Another process for consideration is that of non-conformance tracking [53]. Similar to quality assurance processes, metrics can be developed, and Boolean values can indicate the most updated information [53]. In the upcoming years, the NASA Model-Based Safety and Mission Assurance (MBMA) project will evaluate prototypes to implement S&MA use cases and provide the associated gate products.

From functional to non-functional requirements, the MBSE approaches to quality deal with the overall System of Systems (SoS) approach to quality of MBSE models focusing on the SysML and less on parts of defense aspects of the model quality [54]. One of these methods is Quality Attribute Balancing (QAb) by Nelson, Borky and Saga or quality characteristics design configurations [51, 55]. While the QAb method addresses the quality of the SoS architecture, it fails to address the DoDAF specific framework and instead focuses on the SysML stereotypes [51]. Another method evaluation of the SoS architecture for the trade study process is by Bankauskaite, Morkevicius, and Butleris [56]. Their research focuses primary on the Unified Architecture Framework (UAF) and trade study quality evaluation process [56]. UAF is a domain specific language used to represent an architecture for a system design [57]. While Bankauskaite, Morkevicius, and Butleris addresses trade study process, their methodology focuses less on defense and more on agnostic domains [58].

1.2.3 Literary Review Conclusion

Many topics associated with MBSE, DoDAF, and quality throughout industry and academia were addressed in the literary analysis Section 1.2.2. The topics covered show how quality across the modeling paradigm has been an issue in systems engineering from the very beginning. As technology has improved, model development has had a general improvement, helping system engineers inch closer to benefits for architecture development, but is still lacking in quality comprehension. The lack of quality metrics led industry and academia to formulate different standardizations with unique taxonomy and ontology to meet the growing need to improve quality. While standardization helped to address the deficiency of quality in a standardised architecture, engineering application of developed standards proved problematic for system designers. The insufficiency of the quality engineering knowledge basis for the application of developed standards resulted in introduction of subjectivity into how standards were applied in system development and the quality of architectures suffered. As the knowledge base increased, deficiencies in how to quantify quality began to emerge in industry and academia. The attempts to address metric definitions led to new concepts for data collection or modularity within model environments. The modularization of data provided a cleaner way to view or develop data in model architectures, but still lacks a true rigor in addressing aspects of quality. With modularizations of architectures, a new means to provide different views into data began to emerge with different frameworks focused less on defense applications and more towards general practice leaving defense to address topic of quality alone.

1.3 Problem Statement

Throughout the dynamic systems engineering industry, many questions surround the approach to architecture quality within MBSE, particularly with in the DoD. The DoD, as well as leading engineering companies, are quick to embrace the use of MBSE, with its standardized development of models, but run into problems as timelines grow. Most common questions focus on the quality surrounding the models being developed. Major defense programs have suffered from problems surrounding model quality leading to directly to increased costs and expanding schedules [18]. The Hawaii International Conference on System Sciences conducted an analysis of papers over a 15 year period and found some interesting information when it come directly to DoDAF architecture quality [3]. Table 1.2 show two of the critical findings from the 15 years of analysis.

Table 1.2: Critical Problems Facing Architecture [3]

Problem	**Description**
Modeling	Use of formal models and/or tools to describe and analyze the Architecture. Architectures must be modeled to present a clear, coherent, and concise picture of the baseline and target Architectures and to communicate this picture to the stakeholders. The Architecture must be good enough, but does not have to be perfect. Key sub-problems are: Business View Presence and Alignment, Modeling Tool Availability and **Quality**, Stakeholders Perspectives, Handling Dynamics
Managing	Use of practices and procedures – formal or otherwise – to develop the Architecture and manage the Architecture team. An Architecture framework, such as described in, TOGAF, **DoDAF**, etc., along with portfolio management processes, can guide the development. Key sub-problems are: Assessing Technical Architecture Maturity, Assessing Infrastructure Stress, The System Architect's Value Proposition, Virtual Enterprise, Scalability, **Architecture Metrics**, Best Practices
Challenge	Modeling Quality Attributes: Modeling systems, including languages, are required to facilitate assessment of Architectures according to **quality attributes**

One of the critical takeaways from the study was: "Modeling assessment encompasses two key areas: quality attributes and metrics. These subareas encompass both evaluation and measurement of methodological practice with its associated artifacts" [3]. The problems stem from the lack of quality knowledge in MBSE frameworks and evaluation means for the above quoted concepts. Additionally, some of the questions posed are:

- *"How do we know the model is complete?"*
- *"How do we know we have modelled sufficient detail in order to represent the system design accurately?"*
- *"How do we know what we have modelled can be clearly and unambiguously translated into a suitable design?"*

The responses to these questions are critical to programs and their understanding of what is trying to be accomplished. Many of these questions have been asked by DoD for programs as large as Acquisition Category (ACAT-1) level programs with Research, Development, Test, and Evaluation (RDT&T) budgets greater than $2.79 billion per Fiscal Year (FY) [59]. The implications of quality or completeness for MBSE models architectures are critical to avoid significant cost overruns or slips in the schedule. Industry-wide, the amount of rework or lack in quality of designs can lead to a yearly average of $15B in cost overruns across the U.S. DoD programs [60]. The average cost of rework for a project is around 2-20% of the total contract amount [60]. Systems engineering presents a suitable method for system design, but with the application of MBSE, many avenues exist that confuse or cloud what is a quality representation for the architecture of a system. By providing clear evaluation criteria at critical phases of a program, avoidance of rework and the ability to provide the best quality product can be accomplished for all stakeholders.

Regarding the first question, *"How do we know the model is complete?"*, this question reaches into the depth of what should be represented in the model. Should a production element be part of the system model? Should the link between the system and production be the schedule elements? Should we have a system model only and rely on document-based production understanding? Should the production model use the system model even when the system model does not know the production model exists? The research question associated with this development is addressed in (RQ1) in Section 1.2.1.

The next question, *"How do we know we have modelled sufficient detail in order to represent the system design accurately?"*,this question seeks to understand what is being represented in the model. The understanding of "need to know", with the appropriate level of detail, should show the system being designed. The framework referenced in evaluating the Quality of Design can be linked to a metrics development process. The methodology was presented and instantiated in the conference proceeding, "Digital Engineering Transformation of Requirements Analysis within Model-Based Systems Engineering" presented at 10th Annual World Conference of the Society For Industrial and Systems Engineering [5]. The research question associated with this development is addressed in (RQ2) in Section 1.2.1.

The final question, *"How do we know what we have modelled can be clearly and unambiguously translated into a suitable design?"*, this question speaks to the conceptual framework developed in addressing (RQ2) and applied to the quality of the models that already exist. The conceptual framework applied to the system being designed shows a trend analysis for the project in determining the quality of a model at a given time. Through case study evaluation, models that were developed by third parties were used to remove the bias and provide evaluation results using the developed conceptual framework. Metrics, based on the evaluation of the third party models, can represent an understanding and a graphical analysis to illustrate the quality of the model design. The research question associated with this development is addressed in (RQ3) in Section 1.2.1.

1.4 Purposed Solution

The proposed solutions means to address that no standard exists for the quality process development in systems engineering after the actions of of the Defense Acquisition Reform in 1990's [61, 62]. The egregious error by the Defense Acquisition Reform in the 1990's led to reinstatement of most processes for government acquisition, but only rolled a few aspects into already existing standards to address quality [63]. To address the methodological gap and research questions, the author introduces the theory of "Quality by Design" (QbD) in a re-contextualization mapping of terminology to the quality of CONOPs in an MBSE DoDAF architecture [64, 65]. Particular focus is given to the DoDAF architecture framework surrounding the CONOPs because of the prevalent use across the defense industry in both private and public sectors. Based on the experiential knowledge and literary review, the simple questions in Section 1.3 were derived to better understand quality in MBSE DoDAF architecture frameworks. The very broad questions were used to formulate research questions in Section 1.2.1 helping to narrow the scope to a more manageable means of quality in MBSE DoDAF architecture frameworks. In response to these questions, tasks were outlined as discussed in the research proposal presented to the advisory committee and approved prior to the development of this dissertation. The undertaking helped break new ground in the field of quality MBSE DoDAF architecture frameworks through a new procedural conceptual framework application approach. The research has yielded a promising approach to mapping QbD theory to the DoDAF architecture structure through the inclusion of definition of terms, quality metric definitions specific to DoDAF CONOPs, and practical application to case study DoDAF models.

The primary research methodology approach is blended between qualitative and quantitative analysis. By using the blended approach, an in-depth evaluation of the DoDAF CONOPs' content can be represented. The qualitative data involves comparing third-party applications of DoDAF and MBSE concepts to the case study models. The quantitative data analysis evaluates the application of framework analyzing model metrics for each of the case study models. The quantitative data includes definitions of terms associated with the DoDAF architecture of each of the case studies within that model concerning CONOPs. Data analysis provides statistical evaluation methods onto the values collected from each of the case study models to provide insight into quality meaning. The case study models used for research purposes come from current open-source models and are developed by the NASA and Dassault Systems. The use of third-party models removes bias of the conceptual framework application evaluation because the author's development can not be a factor in their interpretation.

The literary review methodology and analysis results show various methodological gaps that exist in the current state of quality perception within MBSE and DoDAF architecture framework. The literary review methodology in Section 1.2.1 helps to cover the breadth of data in industry and academia while providing a narrowed scoping on the available data for this dissertation. The overview of approach in Chapter 2 captures a generalization on MBSE relating to DoDAF. The generalization is important for allowing the contextual mapping of QbD to the DoDAF architecture in Section 2.2. The literary analysis shows that starting with a good technical as well as quality approach can provide substantial cost savings for programs and taxpayers by eliminating and/or lessening costly rework. Understanding the linkage between quality variables to architecture elements can be customized to the customers' satisfaction, but agreed upon use of standardization on the technical approach is critical. The metric definition provides a means for model quality to be quantified and presented. The literary review shows that metric definitions and a common understanding of the metric representations must be performed early in the model design process to ensure quality metric integrity. Establishment of processes and the use of conceptual framework helps to provide rigor to critical quality factors that are needed to address architecture quality. The research developments confirm that systems engineering quality has a considerable impact on system design and must have solid footing early in development of the model. Several novel developments were observed in the creation of the DoDAF Quality Conceptual Framework (DQCF) and its application to the case study models.

1.5 Chapter 1 Summary

The preceding sections represent the contents of Chapter 1. The chapter discusses the background associated with the MBSE and quality of the design. The chapter also presents a literary review surrounding the dissertation topic from both academia and industry. The literary review within the chapter includes a methodology approach, outlines research questions, provides an understanding of data source selection including the evaluation of material data sources, provides a data recording methodology, with analysis results. Following the literary review, a formulated problem statement helps to establish the relevant importance of this research. The problem statement provided early sets the stage for later chapters by helping to shape a potential solution that is presented in the dissertation.

The overall problem statement summarized in Chapter 1 helps to establish a better understanding for the following chapters for the dissertation topic; in Chapter 2, a discussion on the MBSE overview is provided with the focus on the DoDAF architecture including the design of a CONOPs. A detailed understanding of the DoDAF architecture framework is identified within Chapter 2. In Chapter 3, the developed framework is covered in great detail so that the application can be well documented. In Chapter 3, discussion on the development approach methodologies for each concept are discussed within the framework developed to analyze a DoDAF architectural model. Chapter 4 and Chapter 5 show how applications of the framework described in Chapter 3 can be applied to DoDAF architectural models. In each case study, discussion on the framework's application, the CONOPs associated with the particular model, key terms and application of the quality analysis framework, sampling understanding of elements from the model, and the overall analysis result are provided. The discussion in Chapters 4 and 5 contains a summary of the model and the application of the proposed framework solution. Fundamental principles to be considered and understanding of the strategies needed in the application for the proposed framework are also provided.

In Chapter 6, a summary of the results from both Chapter 4 and Chapter 5 is provided. Additionally, in Chapter 6, an overall conclusion of the dissertation is provided. The chapter also discusses the advantages provided by applying the new framework developed within this dissertation. A future work section discusses how the framework can provide additional information and provide an additional capability to be used in conjunction with other methods as MBSE technology progresses. Finally, disclaimers are included for the dissertation paper.

Chapter 2

Overview of Approach

Chapter 2 is outlined in a logical process flow of Sections to detail a methodical approach and provide means to evaluate analysis of each case study model. The outline of Chapter 2 includes Sections developed with context to assist with model analysis that will be applied to case studies in Chapters 4 and 5. Chapter 3 links all of content of Chapter 2 with additional data to evaluate the quality of modularity for case studies in Chapters 4 and 5. Chapter 2 includes development of systems engineering understandings, Model-Based Systems Engineering (MBSE) concept, DoDAF architectural framework, Logical model context, Quality By Design (QbD) mapping, metrics development, addressing subjectivity, assumptions for analysis, approach to analysis results, and statistical methods to provide insight into collected data for quality. Additionally, the Chapter conveys theoretical applications in detail to address the problem statement discussed in Section 1.3 of Chapter 1. To better understand the author's approach, key systems engineering disciplines were highlighted, including understandings for systems engineering, MBSE, and DoDAF. The methodology will be validated through the application of the resulting conceptual framework to DoDAF CONOP model architectures in case studies as direct analytical evaluation justifying the proposed solution.

The case study approach will be used to evaluate methods presented in this Chapter 2. Case studies methodology has a number of advantages, such as of allowing researchers to look at a phenomenon in its natural environment, rather than in a controlled laboratory or experimental setting, which is essential for gaining a deeper understanding of the developed framework application [66, 67]. Case studies present the author with a chance to get a comprehensive grasp of the research topic, and they may also aid in the description, comprehension, and explanation of a research problem or circumstance [68, 69]. The purposed logic that connects the theories in this Chapter to data in the case studies with the evaluation conclusions is derived to answer the original research questions in Chapter 1. For this purpose it is possible to think of Chapter 2 design in the context of an action plan execution of the DoDAF Quality Conceptual Framework (DQCF) for moving from the questions through methods to the conclusions [66]. A case study approach has been used in many research areas in many different disciplines, provided an individual with proper competencies conducted the evaluations, this is discussed further in Section 2.2.5 [70].

2.1 Systems Engineering, MBSE, and DoDAF Views

2.1.1 Systems Engineering

Many different prominent system life cycle models exist which include the DoD model or DoD 5000 [7] and Systems Engineering Life Cycle Model [8]. The DoD 5000 series of documents and the Systems Engineering Life Cycle Model will be discussed to highlight engineering process understandings. When applying the DoD Model, the formulation and validation of mission requirements are critical to the systems engineering process that guides the product development process [7]. The DoD 5000 acquisition or development model is segmented into four phases which require the systems engineering process through all phases and/or stages. The four phases of the DoD 5000 model are 1) Concept and Technology Development, 2) System Development and Demonstration, 3) Production and Deployment and 4) Operation and Support [7]. Figure 2.1 shows the DoD 5000 model.

The Systems Engineering Life Cycle Model has three stages, which are 1) Concept Development, 2) Engineering Development, and 3) Post Development. Specifically, the Production and Deployment phase and the Operation and Support phase are encompassed in the Post Development phase in the Systems Engineering Life Cycle model [8]. The system concept is definitized and formulated to meet a need in the Concept Development stage of the Systems Engineering Life Cycle model [8]. The level of effort in the Concept Development stage is less than in the subsequent stages but is of critical importance. The main objectives of this stage are validating: the item's need (requirements) and development risk for the new system, (ensuring that its development is feasible, both technically and economically), different system concepts to formulate system performance requirements, and then selecting the best system concept to meet the desired requirements

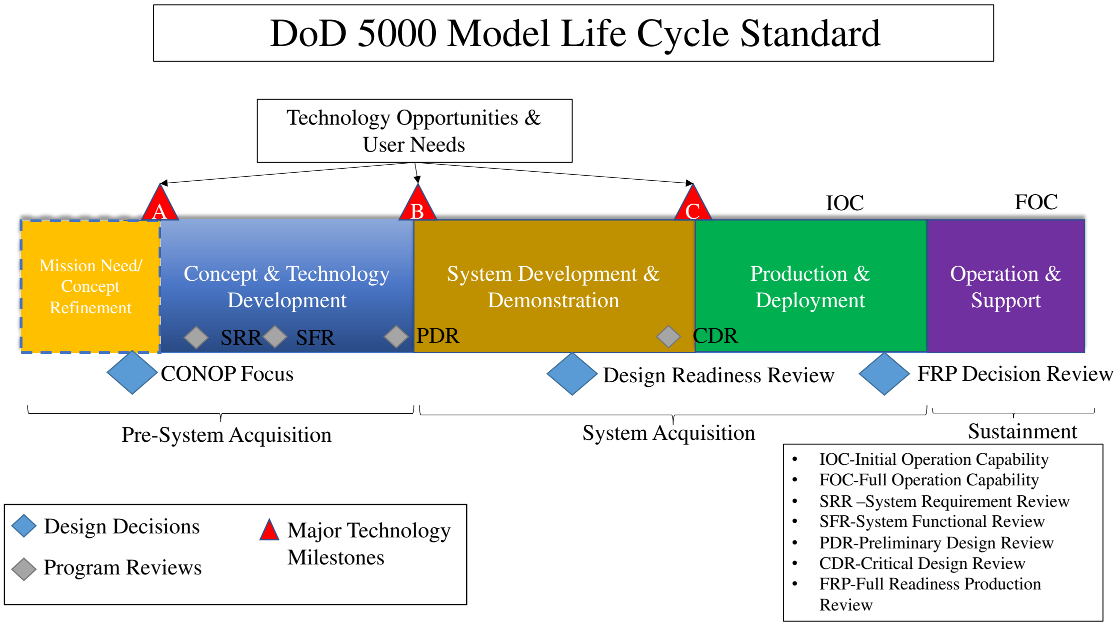

Figure 2.1: DoD 5000 Life-Cycle Model Development Standard [7]

and feasibility [8]. Requirements analysis conducted within the Concept Development stage include the formulation and validation of system performance requirements [8]. Figure 2.2 shows the Systems Engineering Life Cycle Model.

The NASA definition of Requirements Analysis is encompassed in the definition and refinement of the system, system elements, and associated functional and performance requirements analysis [71]. In the Concept Development stage, the functional performance or operational requirements analysis can be instantiate in an architecture and was demonstrated in the paper *"Digital Engineering Transformation of Requirements Analysis within Model-Based Systems Engineering"* [5]. Due to the importance of systems engineering in the Concept Development Stage, the author will focus on this stage and its quality of work to scope the area of analysis for the research questions in Section 1.2.1.

2.1.2 MBSE

Model-Based Systems Engineering (MBSE) can provide increased quality in the Concept Development Stage discussed in Section 2.1.1. MBSE also enables the use of data-centric modeling as

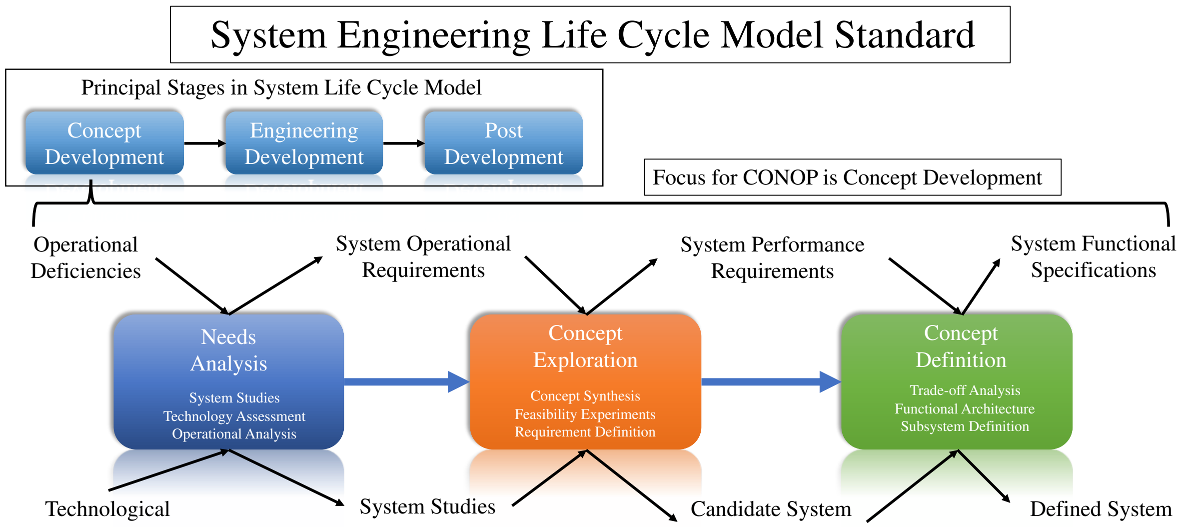

Figure 2.2: Systems Engineering Life-Cycle Model [8]

discussed in Section 2.1.3 [4]. MBSE meta-data allows for optimization providing a better opportunity to interrogate the system design much earlier in the Concept Development Stage as discussed in Section 2.1.1 [72]. MBSE also provides for unparalleled levels of system understanding and behavior through the integration of analytics linked to one or several model-centric baseline(s) [4]. As stated in Section 2.1.3, Unified Modeling Language (UML), and Systems Modeling Language (SysML), are the initial foundational base language(s) that are typically used to reflect the design of the system. MBSE graphical representations known as "diagrams" are data rich graphics combined with meta-data to enabled connections with elements and relationships [72, 73]. The following list are the SysML diagrams and are depicted on Figure 2.3.

- **Requirement diagram (REQ)**: A SysML Requirement diagram is a static structural diagram that shows the relationships among Requirement («requirement») constructs, model elements that Satisfy («satisfy» Dependency) them, and Test Cases that Verify («verify» Dependency) them [74].

- **Use Case diagram (UC)**: A Use Case diagram shows communications among system transactions (Use Cases) and external users (Actors) in the context of a system boundary (Subject; notation: rectangle). Actors may represent wetware (persons, organizations, facilities), software systems, or hardware systems. Defining relationships between the system Subject and the system Actors is an effective informal way to define system scope [74].

- **Block Definition Diagram (BDD)**: A Block Definition Diagram is a static structural diagram that shows system components, their contents (Properties, Behaviors, and Constraints), Interfaces, and relationships [74].

- **Internal Block Diagram (IBD)**: An Internal Block Diagram is a static structural diagram owned by a particular Block that shows its encapsulated structural contents: Parts, Properties, Connectors, Ports, and Interfaces. Stated otherwise, an IBD is a "white-box" perspective of an encapsulated ("black-box") Block [74].

- **Parametric diagram (PAR)**: An Parametric diagram is a specialization of an Internal Block Diagram (IBD) that enforces mathematical rules (Constraints) defined by Constraint Blocks across the internal Part Value Properties bound by the Constraint Block Parameters.

- **Activity diagram (ACT)**: An Activity diagram shows system dynamic behavior using a combined Control Flow and Object (data) Flow [74].

- **Sequence diagram (SD)**: A Sequence diagram is a dynamic behavioral diagram that shows interactions (collaborations) among distributed objects or services via sequences of messages exchanged, along with corresponding (optional) events model [74].

- **State Machine diagram (STM)**: An State Machine diagram is a dynamic behavioral diagram that shows the sequences of States that an object or an interaction go through during its lifetime in response to Events (a.k.a. "Triggers"), which may result in side-effects (Actions) [74].

- **Allocation Table**: An Allocation Table is a tabular (matrix) notation for Allocation relationships, but the SysML standard does not prescribe a particular format for these so they tend to be vendor specific [74].

UML and SysML consists of numerous different diagram types respectively and are divided within into two groups of diagrams structural or behavioral diagrams [73]. Structural diagrams show what the system consists of, or are the physical artifacts that make up a system while behavioral diagrams evaluate what the system does (system functions and interfaces) [73]. SysML supports the specifications (requirements) of system, analysis, design, Verification and Validation (V&V) while expanding upon both UML and SysML. Both UML and SysML allow for customized profiles and libraries to expand the capability of modeling languages to capture even further material needs with in a model [73]. MBSE tools provide the extensibility capability to the base UML and SysML structures into the customization realm for an industry areas or domains (i.e., business, aerospace, space & missiles, infrastructure, Information Technology, etc.) [5]. The extensible customization capability will be used later in this paper to develop a profile for use in the DQCF to capture criterion related to quality.

2.1.3 DoDAF Framework

MBSE has presented a completely new approach for systems engineering as a practice. Systems engineering has evolved to realize value from a graphical representation to interconnect related data within a digital environment. Typically, systems engineering is approached by being heavily document-based with disparate data connections that are difficult to find and understand [4]. The multitude of documents within systems engineering includes conceptions of a system's capabilities, interfaces, requirements, and many other features required for the development of a design. MBSE provides a means to connect these disparate data pools using computer environments and inter-connectivity of databases to provide a never-before-seen visualization capability for engineers as a system is developed [4, 75]. In the past, there have been significant issues with the document-based approach in developing a system. Documents referenced other documents and depending on an individual's access or knowledge of the system, consideration for all impacts to the design ended up causing shortfalls found later in development and verification process. Failure to identify issues such as redundant interfaces, untestable capabilities, or even irrational requirements could be missed and the program could be subsequently cancelled due to unforcasted cost growth or untenable risks. For example, in 2019, the lack of requirements definition led to the cancellation of the Redesigned Kill Vehicle (RKV) Program with a value in 2018 of nearly $800 million dollars [76]. Missing these critical data points created errors in the system design such that the proposed design solution failed in tests, evaluations, or customer expectations [60]. Failing to meet these critical points would lead to increased development and deployment risks for systems, increased system costs, lengthy development delays, or ultimately cancellation of the systems. As system modeling techniques and capabilities has progressed, MBSE has become more widespread in industry models used to control technical baselines for programs [4]. MBSE when applied correctly and with focus on quality can help ensure consistency across with crucial but disparate elements of the emerging system and there by significantly reduce risk of cost and schedule growth program development [60].

Typically, MBSE artifacts are organized are engineered using standardized methodologies that help clarify the data necessary for both program management and customers to make informed decisions [4]. One of these approaches is the Department of Defense Architecture Framework (DoDAF). The DoDAF framework approach provides a means to organize data and understand various Viewpoints needed to inspect data within a model [4]. The DoDAF models are typically based on two types of modeling languages, the first and the original is UML, the second which is based on UML is SysML as discussed earlier [4]. Figure 2.3 shows how the DoDAF diagrams map to the SysML diagrams. The red text in ovals show the identified DoDAF CONOPs diagrams discussed in DoDAF CONOP Design Process in Section 2.1.3. Not all diagrams map cleanly but this is a very close approximation.

The UML and SysML languages present the graphical representation for connections of data within diagrams throughout the model [73, 77]. From each language, a contextualization is applied to develop understandings of the interconnected relationships between these data elements [73]. The original purpose of these elements was to support the design of the software development, and introduce terminology presented to represent coding constructs [73]. Having these coded construct

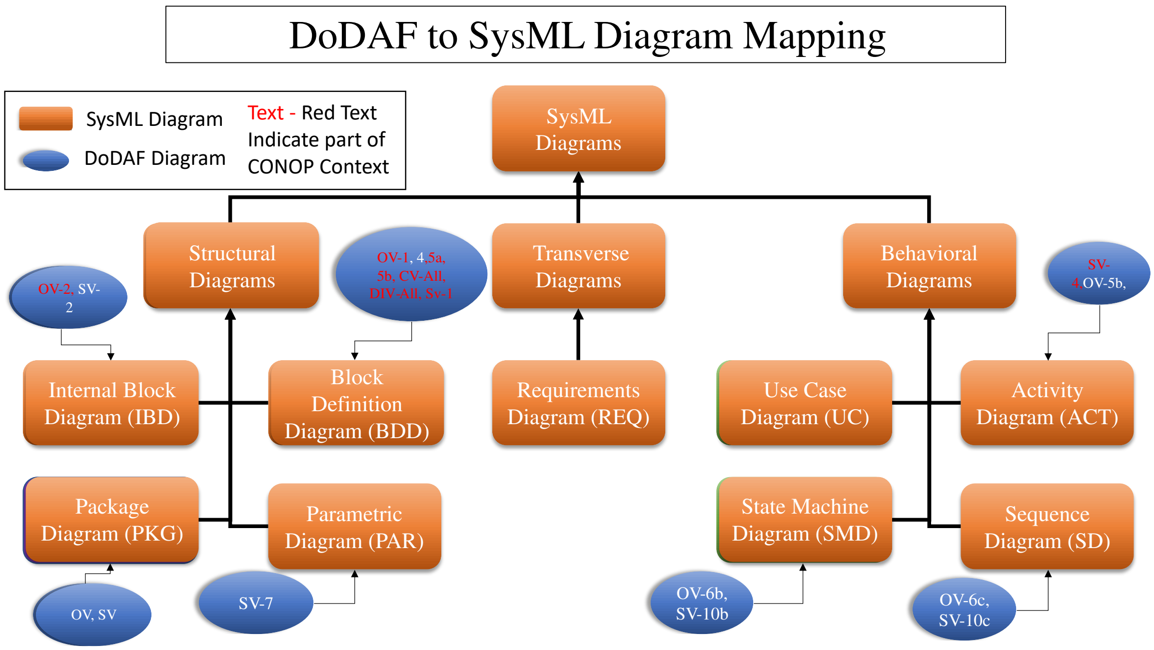

Figure 2.3: Systems Modeling Language (SysML) to Department of Defense Architecture Framework (DoDAF) Diagram Mapping

elements within a system model can easily be implemented for data extraction. The elements coupled with an Integrated Development Environment (IDE) can enable solutions that are modular and visible for ease of use in the engineering system designs process. Both UML and SysML modeling languages were used as a foundational part for developing an architecture framework by the DoD to meet the need for rapid visualization and understanding of development efforts within government contracts [4]. Figure 2.4 show the timeline of DoDAF standard development.

The original development that became DoDAF began in the mid-90s with a a directive from the Deputy Secretary of Defense [4] that evolved into the release of DoDAF 2.02 which was released in August 2010 [4]. The original DoDAF was called the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) architecture framework for a period of time from 1996 to 1998 when the government stood up the Architectural Coordination Council Memorandum [4]. The council composed of experts in industry and academia from the United States began development of the first official DoDAF version 1.0 [4]. DoDAF version 1.0 was released in August 2003 and was the first major accomplishment for the working group [4].

Subsequent DoDAF version 1.5 and DoDAF version 2.0 were released [4]. For the most part the Services within the DoD are expected to maximize the extensibility and use of the DoDAF architectural framework during their development programs. The DoD expects that most major weapons systems and information technology acquisitions should use the DoDAF framework to represent the Service's broad requirements that are to be presented by the Government to the supplier [4]. The DoDAF process allows and provides elements for inclusion of other DoD processes including Joint Capabilities Integration and Development System (JCIDS), Planning, Programming, Budgeting, and Execution (PPBE), Defense Acquisition System (DAS), systems engineering, operational planning, and agency capability portfolio management [4].

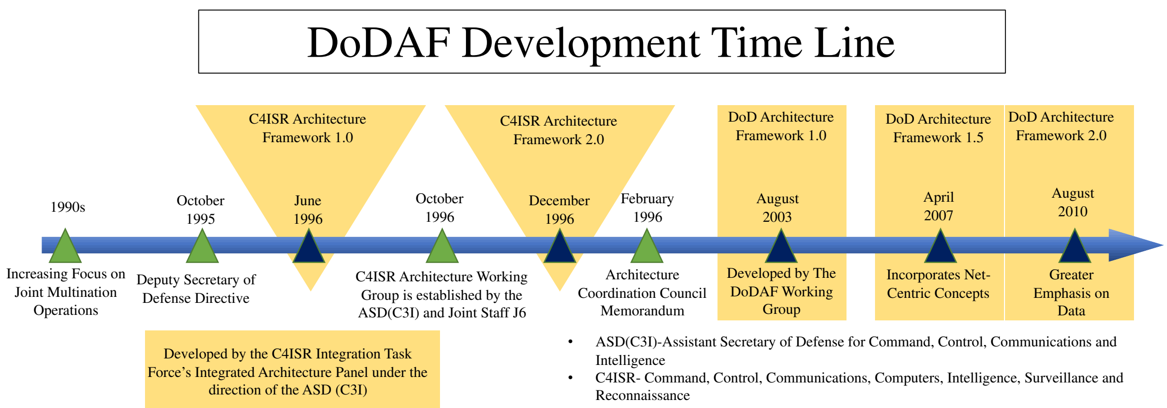

Figure 2.4: Department of Defense Architecture Framework (DoDAF) Development Timeline [4]

Ultimately, the architecture profile for DoDAF was developed jointly by the Object Management Group (OMG) and DoD [4]. The architecture profile development began around the 2005 time frame with the motivation to develop a specification dealing specifically with a DoD DoDAF implementation [4]. The first specification was called the UPDM DoDAF 1.0 and spanned through version DoDAF 1.5 [4]. The final profile that was developed by OMG and was released as version DoDAF 2.02 in August 2013 [4]. The formulation of this profile which became the Department of Defense Architecture Framework (DoDAF) was developed within a MBSE tool [4]]. The developed profile became the standard model ontology and taxonomy for the approach to DoDAF architecture for system acquisition by the U.S. government [4].

The purpose of DoDAF version 2.02 is to provide a comprehensive and conceptual modeling capability to develop architectures for the DoD [4]. The architectural framework was conceived in order to convey a mutual understanding across usually disparate parts of the DoD [4]. Additionally, the DoDAF architectural framework is used to assist DoD of government agencies make key technological decisions about the acquisition of systems for defense [4]. For the most part, DoDAF 2.02 furnishes a means of guiding principles of comprehension for the interconnected relationships between digital data [4]. The term Data-Centric is used rather than product-centric because the connections between the data actually represent the architectural description and are captured within a variety viewpoints or DoDAF views [4]. The DoDAF views provide a means to modularize data-centric information and scope UML and SysML stereotypes to a specific aspect for analysis of quality. Tags and restrictions are the other two forms of extension mechanisms available in the UML, with stereotypes being the third sort of extensibility mechanism [73, 78]. They enable designers to broaden the vocabulary of the UML in order to develop new model components that are derived from current ones but have specific attributes that are appropriate for a certain domain or other specialized application [73, 78].

DoDAF Viewpoints and Views

The DoDAF views are critical part of understanding the architecture standard. As stated in the Section 2.1.3, the views or viewpoints allow for data-centric elements to provide an ontology and taxonomy through an architecture profile to capture technical information for a system.

Table 2.1 shows a high level description of each viewpoint type and each viewpoint's specific views that contain specific data elements for each aspect of the architecture. Specific views will be identified in Section 2.1.3 relating to CONOPs development to scope analysis of case study models in Chapters 4 and 5. Key views will be described in further detail in the Section 2.1.3 that help to instantiate the DoDAF CONOP architecture in the model. The identified views will be critical

Table 2.1: DoDAF Views

Viewpoint Types	**Descriptions**
All or AV	The All Viewpoint provides data that is relevant to the entire architecture description [4]. The All Viewpoint is comprised of two views the AV-1 and AV-2.
Capability or CV	The Capability viewpoint captures any taxonomy or capability data as well as capability evolution data [4]. The Capability viewpoint is comprised of seven views CV-1, CV-2, CV-3, CV-4, CV-5, CV-6 and CV-7.
Data and Information or DIV	The Data and Information Viewpoint show operational and business information requirements or rules for system design [4]. The Data and Information Viewpoint consist of three views DIV-1, DIV-2, and DIV-3.
Operational or OV	The Operational Viewpoint describe tasks, activities, operational elements, and resource exchanges and is material independent [4]. The Operational Viewpoint has eight views OV-1, OV-2, OV-3, OV-4, OV-5a, OV-5b, OV-6a, OV-6b, and OV-6c.
Project or PV	The Project Viewpoint identifies how programs, projects, portfolios, or initiatives deliver capabilities, the organizations contributing to them, and dependencies between them [4]. The Project Viewpoint consists of three views PV-1, PV-2, and PV-3.
Service or SvcV	The Service Viewpoint shows services and their interconnections providing or supporting the program or project [4]. The Service Viewpoint consist of thirteen views SvcV-1, SvcV-2, SvcV-3a, SvcV-3b, SvcV-4, SvcV-5, SvcV-6, SvcV-7, SvcV-8, SvcV-9, SvcV-10a, SvcV-10b, and SvcV-10c.
Standards or StdV	The Standards Viewpoint maintains a set of rules governing the arrangement, interaction, and interdependence of parts or elements of the Architectural Description [4]. The Standards Viewpoint consists of two views StdV-1 and StdV-2.
System or SV	The System Viewpoint describes systems and interconnections providing for, or supporting, DoD functions [4]. The System Viewpoint consists of thirteen views SV-1, SV-2, SV-3, SV-4, SV-5a, SV-5b, SV-6, SV-7, SV-8, SV-9, SV-10a, SV-10b, and SV-10c.

in recognizing the elements to evaluate in the DoDAF CONOP architecture and understand their quality valuation.

DoDAF CONOP Design Process

As discussed in the previous Section 2.1.1, the Concept Development Stage often starts with the CONOP architecture development in conjunction with operational performance requirements and goes to an ever-increasing level of detail in identifying mission performance assumptions, constraints, deficiencies, and enhancements needed for the system operation to enable mission success [4, 79]. Operational requirements and CONOP architecture seeks to identify the missions, capabilities, and operations along with their associated explicit requirements, performance measures, and other metrics for best value using the systems engineering process [79]. Disciplined rigor is required to best address desired mission area deficiencies, threats, emerging technologies, and system improvements. Based on the literary analysis in Section 1.2, early phases of development are typically not very well-funded. Requirements and CONOP architecture that have been derived are often preliminary, incorrect, conflicted, inconsistent, and incomplete; therefore, there needs to be additional in depth analysis of the quality of CONOP architecture [5]. The process of CONOP architecture development includes the identification of stakeholders, requesting and deriving requirements, defining constraints, establishing critical and desired performance of the system from stakeholders' input [4]. The CONOP architecture consists of several viewpoints that specifically outline the system design. These specific viewpoints that the author has selected as key factors to analyze in the DoDAF CONOP architecture are the Operational, System, Capability, and Data and Information. The content covered with in the CONOP should include the following:

- The operational environment and its characteristics [79]
- Major system components and the interconnection among those components [79]
- Interfaces to external systems or procedures [79]
- Capabilities, functions, and features of the current system [79]

- Charts and accompanying descriptions depicting inputs, outputs, data flows, control flows, and manual and automated processes sufficient to understand the current system or situation from the users point of view [79]
- Cost of system operations [79]
- Operational risk factors [79]
- Performance characteristics, such as speed, throughput, volume, frequency [79]
- Quality attributes, such as: availability, correctness, efficiency, expandability, flexibility, interoperability, maintain-ability, portability, reliability, reusability, supportability, survivability, and usability (all relating to the system design) [4, 79]
- Provisions for safety, security, privacy, integrity, and continuity of operations in emergencies [4, 79]

The viewpoints contain the essential views critical to understanding a DoDAF CONOP architecture, in terms of key factors above. The views contained in Table 2.2 will outline the key terms and definitions used by the quality conceptual framework presented in this paper and specifically in Chapter 2 to guide understanding of lexicon from case studies CONOP architectures.

2.2 Conceptual Approach

The first step in establishing the DoDAF Quality Conceptual Framework (DQCF) was to understand the logic and context of Juran's QbD concept and then map that logic and context to the DoDAF CONOP architecture through a logical model. A context mapping was done to understand relating Juran's QbD ontology and taxonomy to the DoDAF CONOP architecture framework. The context mapping developed an understanding to scope characteristics for definitions of metrics for quality of architecture elements. A means to analysis was developed to establish the relationships between the elements for data extraction and how quality data would be collected from each case study model. A defined method for alternative application was established to make the DQCF

Table 2.2: Selected DoDAF Views for Analysis [4]

View Types	Descriptions
CV-1: Vision	Addresses the enterprise concerns associated with the overall vision for endeavors and thus defines the strategic context for a group of capabilities
CV-2: Capability Taxonomy	Captures capability taxonomies. The model presents a hierarchy of capabilities
DIV-1: Conceptual Data Model	The required high-level data concepts and their relationships
DIV-2: Logical Data Model	The documentation of the data requirements and or structural business process (activity) rules
OV-1: Operational Graphic	The high-level graphical/textual description of the operational concept
OV-2: Operational Resource Flow	A description of the Resource Flows exchanged between operational activities
OV-5a: Operational Activity Tree	The capabilities and activities (operational activities) organized in a hierarchical structure
OV-5b: Operational Activity Model	The context of capabilities and activities (operational activities) and their relationships among activities, inputs, and outputs; Additional data can show cost, performers or other pertinent information
SV-1: System Interface Description	The identification of systems, system items, and their interconnections
SV-4: Systems Functionality Description	A description of Resource Flows exchanged between systems

methods tool agnostic. A method for understanding the analysis results collected from the data was established such that quality interpretations could be projected.

2.2.1 Logical Model

In order to address the context of the research questions in Section 1.2.1 the author developed a logical model. A logical model is typically a graphical depiction that takes the addressed theory and puts that theory in terms of an explicit statement or statements for strategy formulation [80]. The logical model approach supports a means to outline the DQCF theory approach and application [80]. The logical model was developed originally from program theory but can be used for development efforts to identify intended or observed impacts [81]. Logical models have been used to improve development plans by identifying both theoretical and practical gaps while achieving the desired results [82]. The intent of this logical model is to provide clarity of ideas with certain aspects of overall approach to reach and end goal of the DQCF [80]. Figure 2.5 shows the logical model developed for this dissertation approach to interpret drivers for the development of the DQCF.

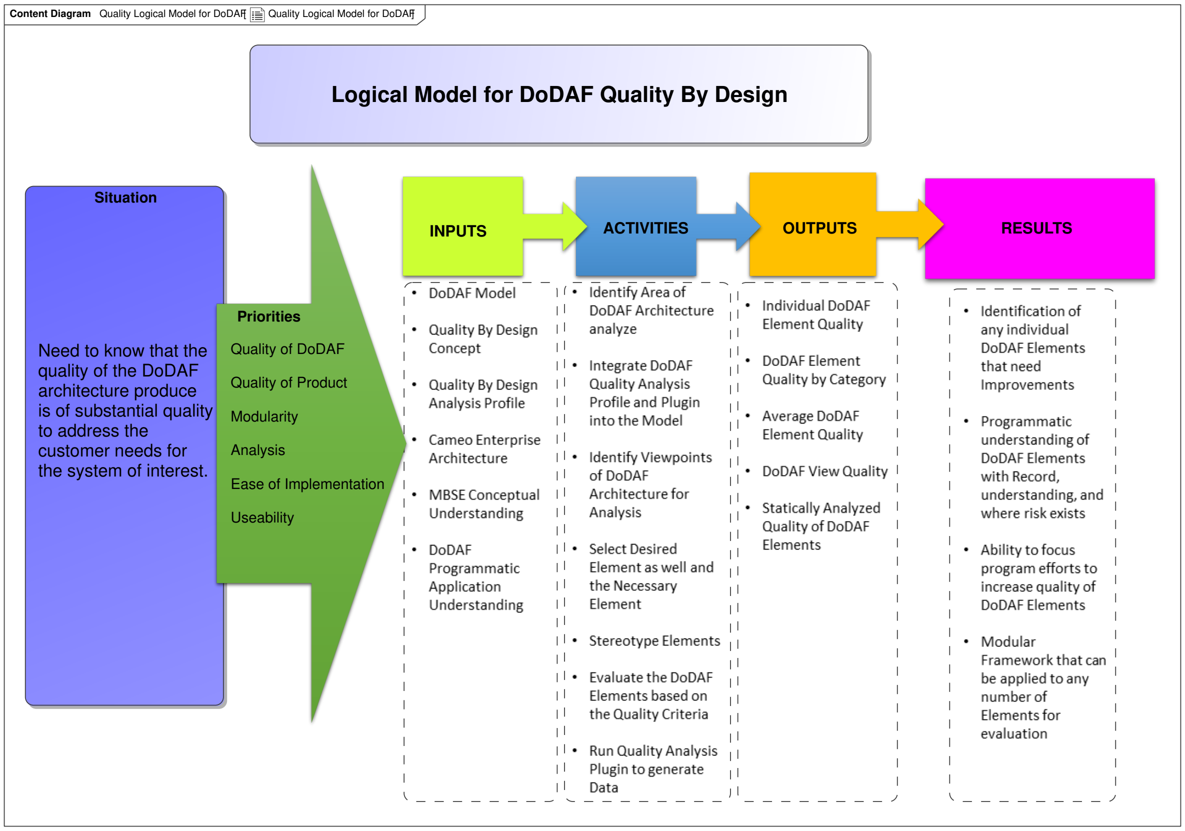

Figure 2.5: Logical Model for DoDAF Quality Conceptual Framework

First, the logical model development focused on the scenario for why the program change is needed by establishing a problem scenario or situation driven by research questions Section 1.2.1 and problem statement Section 1.3. The scenario or situation here states a *"Need to know that the quality of the DoDAF architecture produced is of substantial quality to address customer need for the system of interest."* and is indicated by the purple box. From the situation, we have a green arrow that highlights the priorities. The priorities identify high level needs addressed through the execution of the logical model. The priorities help to identify inputs that are the raw materials needed to formulate the design solution space to that situation. Inputs are critical in any logical model, specifically the Implementation Research Logic Model (IRLM) developed by Justin Smith states that the inputs or determinants part of the IRLM includes factors that prevent or enable implementation [80]. Including all inputs was considered because unforeseen problems that can impact execution later in development may be difficult to overcome later in execution. The inputs for this logical model help to scope the data to answer the research questions in Section 1.2.1 and problem statement in Section 1.3. The inputs are under the light green block and in no particular order include: 1) DoDAF Model, 2) Quality by Design Concept, 3) Quality by Design Analysis Profile, 4) MBSE Conceptual understanding, 5) DoDAF programmatic application understanding. The activities outline what was done with the inputs to formulate a desired output and results. The activities cover a breadth of actions performed to refine data and instantiate an approach solution. The activities under the blue block and in no particular order include: 1) Identify area of DoDAF architecture for analysis, 2) Integrate DoDAF Quality Analysis Profile and Plugin into Model, 3) Identify Viewpoints of DoDAF architecture for analysis, 4) Select Desired Elements as well as the Necessary elements, 5) Stereotype elements, 6) Evaluate DoDAF elements based on Quality Criteria, and 7) Run Quality Analysis plugin to generate data. The outputs are what the activities generate and present a solution to problem statement in Section 1.3. The outputs are located under the orange block and in no particular order include: 1) Individual DoDAF Element quality, 2) DoDAF Element Quality by Category, 3) Average DoDAF Element quality, 4) DoDAF View Quality, and 5) Statically Analyzed Quality of DoDAF Elements. The final results indicate the outcomes of taking the raw inputs, refining the inputs with activities, and collection of outputs that drive the answer to the situation and problem statement. The final results under the pink block in no particular order include: 1) Identification of any individual DoDAF elements that need improvement, 2) Programmatic understanding of DoDAF elements with understanding of where risk exists, 3) Ability to focus program efforts to increase quality of DoDAF elements, and 4) Modular Framework that can be applied to any number of element for evaluation. The developed logical model was used to analyze the research questions in detail and develop a conceptual approach to the theoretical and practical assessment resulting in a DQCF, which will be discussed further in Chapter 3.

2.2.2 Define Quality by Design for Framework

With a logical model developed for high level comprehension, a conceptual mapping was needed to relate the application of Juran's methodology to the DoDAF CONOP architecture. The idea for use of the concept map allowed the author not just to generate spontaneous associative elements but to outline key relationship between intentional terms from each area effectively completing the mapping re-contextualization of Juran's method [83]. Juran's taxonomy is indicated by blue boxes in the orange colored area of Figure 2.6. Concept mapping allowed the author to better understand relations between the Juran's methodology concept and DoDAF CONOP architecture concept bridging the association to the correct domains or translations between the five QbD phase areas [83]. The concept map provided a hierarchical structure with decomposition of ordinate parts relating each QbD phase areas to application of the understanding for DoDAF [83]. The utilization of a conceptual mapping for re-contextualization allowed for an approach of sufficient detail and rigor so as to establish and understanding of the DQCF being proposed [83].

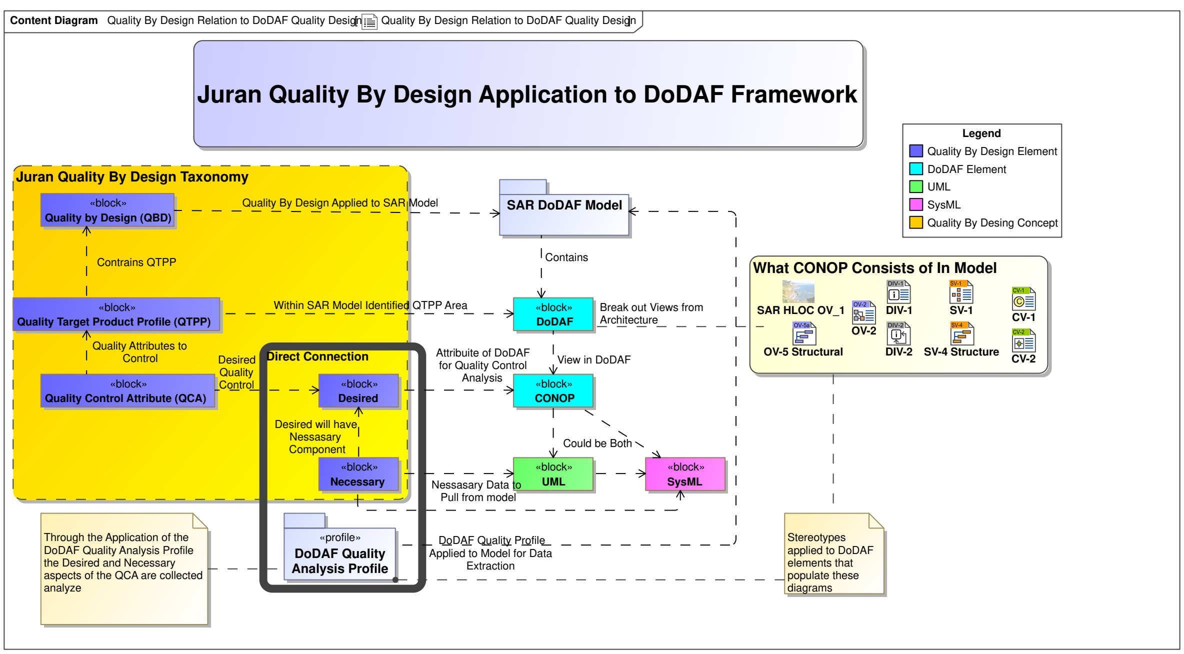

Figure 2.6: QbD Concept Mapping to DoDAF

The first step in creating the conceptual map was taking the decision to apply the Quality By Design (QbD) to a DoDAF model for analysis. Figure 2.6 shows how Juran's QbD methodology maps to the key DoDAF CONOP architecture including MBSE artifacts of SysML and UML base language elements. The decision would come down to the need or want to understand the gap in quality between what the stakeholders think is best and what exists in the model or architecture [1, 84]. The decisions typically would be driven from a cost or schedule perspective where overruns or general quality maturity understanding of the model are needed [1]. The processes for Juran's methodology application stems from five major area phases. The five phase areas of Juran's methodology include 1) *Define*, 2) *Discover*, 3) *Design*, 4) *Develop*, and 6) *Deliver* [1,85]. The process of doing this mapping would relate to the first area *Define* in Juran's method where the stakeholder's understanding the product are identified as where quality need should be addressed [1]. The translation process for the concept map uses the arrow between the QbD and the DoDAF model to address the quality of the DoDAF architecture, which is desired. Following the identified *Define* phase of Juran's methods, the *Discover* phase is a specific aspect that must be measured [1]. The application understanding of the QbD to the DoDAF CONOPs architecture framework drives the identification of what needs to be analyzed or what needs to be extracted from architecture for the *Discover* phase [1]. Figure 2.6 shows as QbD is applied to the DoDAF model the Quality Target Product Profile (QTPP) arrow illustrates a relationship to the DoDAF architecture and drives more specificity to the CONOPs defined views from Section 2.1.3. The QTPP profile content was tailored through the *Discover* phase to extract the DoDAF CONOP architecture. Now that the QTPP has selected the DoDAF CONOP architecture with specific views additional refinement can be applied to get the specific quality attribute or Quality Control Attribute (QCA) [1, 86]. The QCA breaks down into what is *desired* and *necessary* [1, 86]. The *desired* and *necessary* aspect of the QCA directly correlate to the elements of UML and SysML as the base for modeling languages. Throughout the identification process of the *desired* and *necessary* QCA, the author has shown the relationship to the *Design* phase of Juran's method [1]. In Chapter 3, a deeper explanation of the DoDAF Quality Analysis Profile (DQAP) will highlight a stereotypes that is used to extract UML, SysML, and DoDAF elements are indicated in the purple folder at bottom in Figure 2.6. The *desired* and *necessary* QCA elements are broken down into key characteristics of the model elements that were evaluated through a metric definition and quality characteristics rating scale reaching the *Develop* phase of Juran's method [1]. The *desired* and *necessary* QCA elements are indicated in the thick black lined area coupled with the DoDAF Quality Analysis Profile (DQAP) which will be discussed further in Chapter 3. The metric definitions will be discussed further in Metrics Development and Definition in Section 2.2.3. The rating scale will be discussed further in Statistical Analysis Methods in Section 2.2.7. By establishing the QCA data the control space gives teams an insight that ensures product quality. The approach can help maintain the production development of the DoDAF CONOP architectures on large multifaceted programs [87]. The advantages of MBSE tools can be exploited at this point through the development and collection of metrics from the model. The collection of the *desired* and *necessary* QCA elements in use of the DQAP would bridge to the final step in Juran's method; *Deliver* would be met when metrics would be delivered from the data collected from the model for quality analysis and a verified quality assessment of the DoDAF CONOP architecture established.

2.2.3 Metrics Development and Definition

Metrics traditionally help with systems engineering to understand performance or other different aspects of a system, model, or framework [88]. As MBSE has matured, models have taken a key role in the collection of digital data information and tracking progress or maturity [38]. MBSE, through UML and SysML, uses a descriptive language based in a software environment and provides unprecedented unique capability to collect metric data from models [38]. The metric definition process must effectively deliver the desired information to inform decision makers to adjust execution or effectively understand quality of processes or models [89]. Metrics that were developed provide quantifiable measures of the DQAP framework the author has outlined for collection of data from the case study models in Chapter 4 and 5. The QCAs have been identified in the previous Section 2.2.2 as *desired* and *necessary* elements of UML and SysML in a DoDAF

CONOP architecture model to collect. The metrics were defined to understand the data for each corresponding views selected from Section DoDAF CONOP Design Process 2.1.3.

Most of the data elements deal with the operational aspects of the DoDAF CONOP architecture. The process of evaluating each element will provide a measure of quality through the exercise of each evaluation [90]. The exercise of evaluating elements will include interrogation of attributes and their interrelations that exist in the model [90]. Examples are based on a previous outline methodology presented in “Digital Engineering Transformation of Requirements Analysis within Model-Based Systems Engineering” at 10th Annual World Conference of the Society For Industrial and Systems Engineering [5]. Table 3.1 shows what elements are created and are identified by *«text»* modeling language stereotype. For the complete list of various aspect that are collected please see the Quality Characteristic Categories (QCC) in Appendix A. The author used the criterion to evaluate each element contained in the selected DoDAF CONOP architecture views in previous DoDAF CONOP Design Process Section 2.1.3. The metrics definitions trend to operation analysis because of the nature of the development of the CONOP to instantiate the DoDAF CONOP architecture [5]. The metrics in Appendix A constitute variables that will be collected for statistical analysis. Aspects for each of the variables address application of the DoDAF standard, UML/SysML standards, and requirement instantiation. In total, six aspects for the DoDAF standard are collected; five aspects for UML/SysML standards are collected; and six for requirement instantiation are collected, for 17 aspects to address quality. The variables are discussed further in Statistical Analysis Methods Section 2.2.7 of this chapter.

2.2.4 Addressing Subjectivity of Approach to Analysis

During analysis, subjectivity is always difficult to capture and quantify, typically because not many standardized methods exists for addressing subjectivity [91]. For the most part, subjectivity deals with decision making, so when introducing human factors, to making a multi-attributed choice, such as for the Likert scale evaluation of the QCC variables, introducing bias in to the analysis is almost a certainty [92, 93]. With multi-attributed categories, it is important to note they can be deterministic when evaluating for quality [93]. The use of ordinal or Likert scale approach is more acceptable because when using strictly mathematical methods for analysis, the mathematical method is more prone to audit and scrutiny to determine implications of use on a analysis [36]. Any type of decision making can rarely be regarded as independent or purely objective and is likely to be influenced from outside factors [93]. In truth, basic scoring techniques have increased in favor primarily because they are linear, traceable, transparent, and straightforward to utilize [94]. Using subjective attributes such as the QCC which is essentially a Likert scale can assist in both developing and testing substantive theories thereby mitigating as much subjectivity as possible [95]. By using a Likert scale to survey a sample of model elements, system models, elements, and content can be evaluated through the application of numerical ratings, providing a promising approach for quantifying deterministic values of quality [96–98]. Additionally, a Likert scale format may effectively reduce *Acquiescence Bias* without lowering *Psychometric* quality of the data produced from the evaluation to determine the quality [99–101]. The Likert scale will be discussed further in Statistical Analysis Methods of Section 2.2.7 in this chapter.

2.2.5 Assumptions for Performing Analysis

To better understand the approach that is laid out throughout Chapter 2, a few key assumptions need to be expressed to bound the problem space for the case study analysis data collection. The assumptions were arrived at based on an understanding of what is needed to perform an effective evaluation of the case study DoDAF CONOP architectures. As outlined in the literary review in Chapter 1 Section 1.2, understanding the role of quality engineer is key to effectively assessing the quality of model architectures. Research has provides evidence that human architect or SME, with consideration for the competencies provided below, is best to conduct evaluations of architectures [70]. A SME is considered to have between an estimated 10,000 to 20,000 to hours of time or work in any particular area [102]. The 10,000 hours, if using the standard federal contracting hours for a year of 2,088 hours, translate to approximately 4.8 years experience at a minimum [103]. The explanation for this is because even when using an automated or standardized technique, the architect's subject skills and experience are still essential when describing a problem or analyzing an assessment [70]. Figure 2.7 shows the minimum necessary competencies needed to fully execute effective Quality Management assessment of model architectures. The competencies in red boxes, in the figure, are an amalgamation of the several different frameworks discussed in Chapter 1 in Section 1.2.2 MBSE Quality Role in DoDAF Application. The frameworks included for this collection of competencies are the INCOSE Systems Engineering Competency Framework [33], NASA Systems Engineering Competencies [34], and the MITRE Company Systems Engineering Competency Model [32, 35]. While other competency lists or frameworks exist that outline the expected or necessary competencies for system engineers these were the main one the author considered for this research.

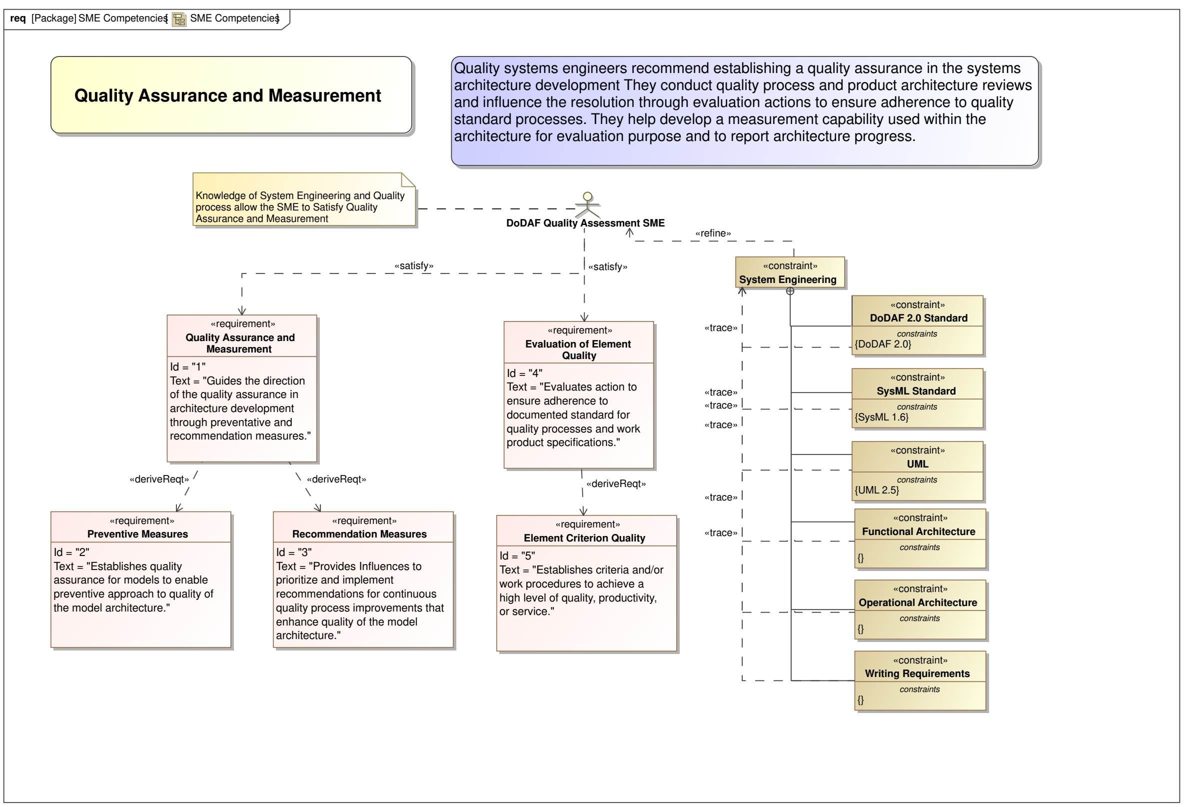

Figure 2.7: DoDAF Quality Assessment SME Model

For the majority of the competencies listed in the figure, they are very similar in knowledge areas, information processing understanding, and recommendations, the basic quality concepts are broken down into three areas [104]. The three basic areas are preventive measures, recommendation measures, and quality assurance/measurement [104]. The preventive and recommendation measure help to get put in place mitigation strategies for engineering efforts to minimize impact or recommend action plans to address quality. The preventive and recommendation roll up to the means to drive Quality Assurance and Measure impacts to quality. Understanding of the constraints shown in the constraint blocks to the right of Figure 2.7 bound the quality problem space knowledge areas that are needed by a SME when considering skills and experience. The constraints consist of: 1) DoDAF Standard, 2) SysML Standard, 3) UML Standard, 4) Operational Architecture, 5) Functional Architecture, and 6) Writing Requirements. All of these constraints fall under the main systems engineering base knowledge and *«refine»* the knowledge of the DoDAF Quality Assessment SME. The competencies mold the quality engineering SME role to enable the best product through understanding of 1) normative, 2) rational, 3) participatory, and 4) heuristic traits when assessing aspects of the architecture [105]. The meaning of these aspects of architecture include 1) being the codes and standards to follow, 2) system analysis and engineering, 3) concurrent engineering and brainstorming, and 4) simplify and scope [105]. The assumption is that a SME or quality engineer could recommend the DQCF to address quality and evaluate for continued improvement in the architecture. Additionally, the following enumerated items in conjunction with the assumed competencies are key assumptions for collection of data and interpretation of analysis:

1. The person performing the evaluation of the DoDAF CONOP architectures is familiar with DoDAF Quality Assessment SME engineering role and exhibits the competencies described in this Section.

2. Operational Functional Performance requirements may or may not exist and but will provide more robust analysis of the DoDAF CONOP architecture.

   (a) This may not be applicable if Government Acquisition process such as JCIDS is followed [106].

3. The DQCF Likert scale was used as evaluation criterion for each DoDAF elements with in the CONOP architecture as shown in Appendix A.

4. For each case study model only the DoDAF CONOP architecture view elements contained within specific mission threads were analyzed as described in Section DoDAF CONOP Design Process 2.1.3.

5. The approach to data collection from each case study model is established in Section Approach to Analysis Results 2.2.6.

6. For both case studies, model analysis was conducted using the automation or primary path of execution integrating the Cameo tool through Application Programming Interface (API) and data was interrogated with IBM SPSS covered Section 2.2.6 Approach to Analysis Results .

   (a) An alternative path of execution is described in in the Section 2.2.6 Approach to Analysis Results but the analysis can be conducted using any other spreadsheet type tool.

   (b) The author did use IBM SPSS version 26 to conduct statistical analysis but any other statistical software could be used that performs the same functions as described in Section 2.2.7 Statistical Analysis Methods.

   (c) Case study one focused on the SMD mission thread to bound the amount of elements to analyze in the Joint Polar Satellite System (JPSS) DoDAF CONOP model.

   (d) Case study two focused on the Command and Control signaling mission thread to bound the amount of elements to analyze in the Search and Rescue (SAR) DoDAF CONOP model.

7. Tools and Software

   (a) The architecture framework standard used is DoDAF 2.02 standard.

   (b) Both Case study model are contained in Cameo Enterprise Architecture 19.0 Service Pack 3 Model-Based Systems Engineering (MBSE) tool.

(c) The tool for automation is Cameo Enterprise Architecture 19.0 Service Pack 3 with Unified Profile for DoDAF/MODAF (UPDM) DoDAF profile [58].

(d) The Java based plugin is designed specifically to work with Cameo Enterprise Architecture 19.0 Service Pack 3 [107].

(e) The Java base library for API calls is the jdk1.8.0_231 (64x) version.

(f) Intellij IDEA idealC-2021.2.3 is the Java Integrated Development Environment (IDE) for automated data extraction.

(g) Microsoft Office Excel 2013 or later is used for the template of data collection.

(h) IBM SPSS Version 26 for IDE data interrogation and development of plots.

2.2.6 Approach to Analysis Results

With the supporting theories outlined, a logical model defined, QbD concept map for key terms established, and with metric definitions established, the next step is to illustrate a means to obtain analyze data or how that data is extracted from the case study models for use in the data analysis process. Figure 2.8 illustrates how data is extracted and stereotype *«DoDAF Quality View»* applied to the case study model elements for evaluation purposes. First, an MBSE model with DoDAF architecture has been established or provided for evaluation. From the DoDAF model architecture, the CONOP views prescribed in DoDAF CONOP Design Process Section 2.1.3 are identified and abstracted out of the main model for analysis. The identified views are indicated in the yellow box and are dependent on the DoDAF architecture model.

While the views can be addressed individually, the overall context of what the CONOP provides in context maybe lost by evaluating the views this way; however, depending on what the analysis is trying to determine this could differ for one user to another user when using the DQCF. Each of the views contains elements on the diagrams with attributes and inter-relations that consist of UML,SysML, and DoDAF standard stereotypes. These stereotypes related directly to the *desired* and *necessary* aspect of the QCA discussed in the Define Quality by Design for Framework Section 2.2.2 of this Chapter. Each element on a diagram will have an additional stereotype added which

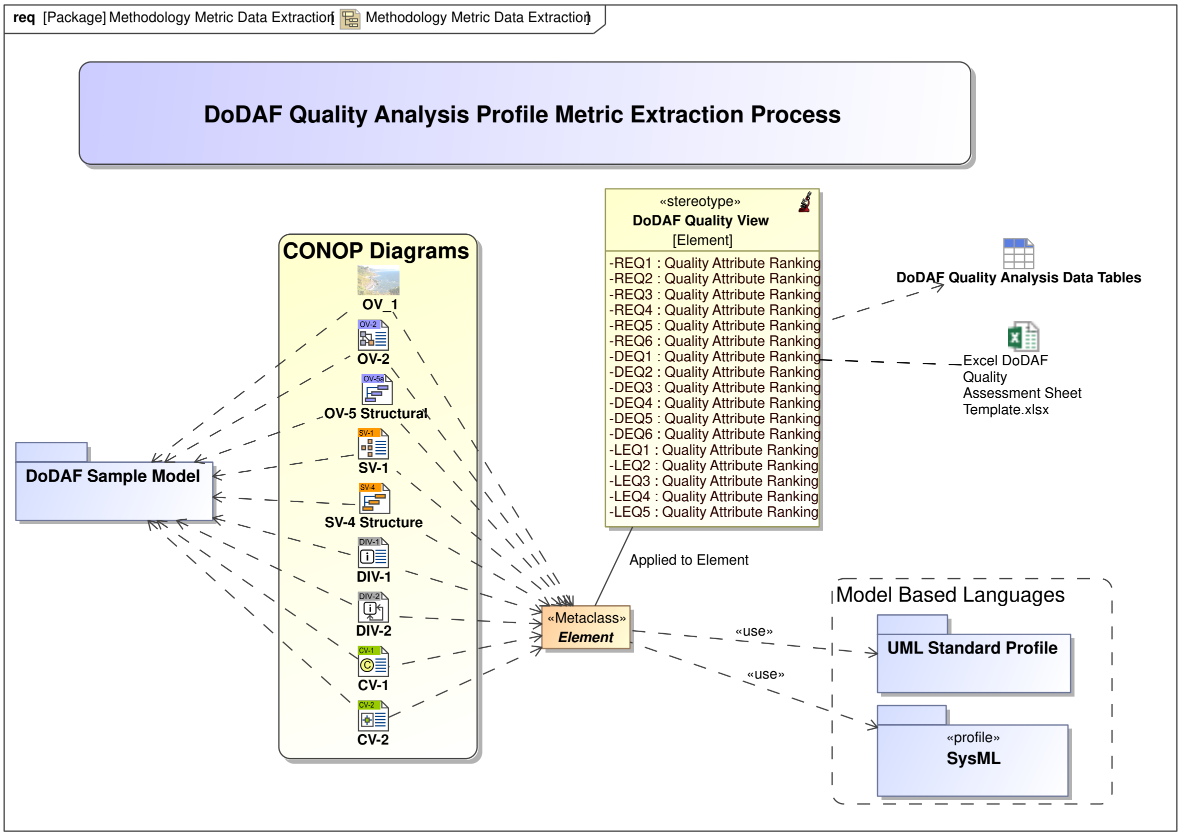

Figure 2.8: Methodology Metric Data Extraction

is the *«DoDAF Quality View»* or DQV stereotype. The *«DoDAF Quality View»* contains the QCC *«definitionTags»* related to the Likert rating scale for quantitative data collection for each element to which the stereotype is applied. The developed plugin automated capability within the DQCF or standardized method through a dataframe tool like Microsoft Excel can be used to collect the data values from the model.

In order to understand the approach to data collection from the case study models, Figure 2.9 illustrates a simplified possible execution activity of the developed framework. Parts of the process can be automated through the application of developed plugins to collect data or collect data using spreadsheet based tool. The plug-in tool for Cameo and the Microsoft Excel Template are available upon request. Initially, a key decision will be made to use the DoDAF Quality Conceptual Framework (DQCF) including some of the assumptions made in Section 2.2.5. One key question includes *"Start with Requirements or Not"* as seen in Figure 2.9. The implications of this decision drive critical understanding as the foundational part of systems engineering and provide context for how the architecture was instantiated. The author acknowledges this not always the case to have the requirements available but is preferred. The requirement driven instantiation of the architecture was addressed in *"Digital Engineering Transformation of Requirements Analysis within Model-Based Systems Engineering"* and has shown how functional performance requirement can drive architecture development [5]. Factors from the DQCF that contribute to this portion of the activity include Figure 2.2.1 Logical Model and Figure 2.7 SME Quality Assessment knowledge areas. The next step in the execution would be that a quality SME would tailor or select the QCA identification as defined in the Section 2.2.2 that are in need of evaluation in the model. The the QCA identification allows the SME to focus quality understanding on critical areas of DoDAF architecture model. The DoDAF Quality Analysis Profile (DQAP) stereotype *«DoDAF Quality View»* could then be applied to elements of the model. After the application of the profile stereotype the evaluation of elements could occur with in the model or exterior with in a spreadsheet type tool to collect data. The data collection would provide a quantitative means to assess the quality of each element in the model then help to assess the overall quality of the model content. The selected element would be evaluated along the Quality Characteristic Categories (QCC) provided in Appendix A for the Likert scale questions.

The automation can be done at this point where data is extracted from the model and analyzed with a tool that provide statistical methods described in Section 2.2.7. Additionally, the spreadsheet tool could be populated manually and used as an alternative means to collect data from the model. By providing an alternative means to collect data from the model, the application of the proposed framework is both modular and tool agnostic. The statistical techniques will be discussed further in Statistical Analysis Methods of Section 2.2.7. The final step in the activity execution is to statistically interpret the data to understand the quality of the DoDAF model. A feedback loop exists in the activity to reapply data to assess different areas of model content or increase the sample of model elements evaluated. If an increase in model elements for evaluation is necessary

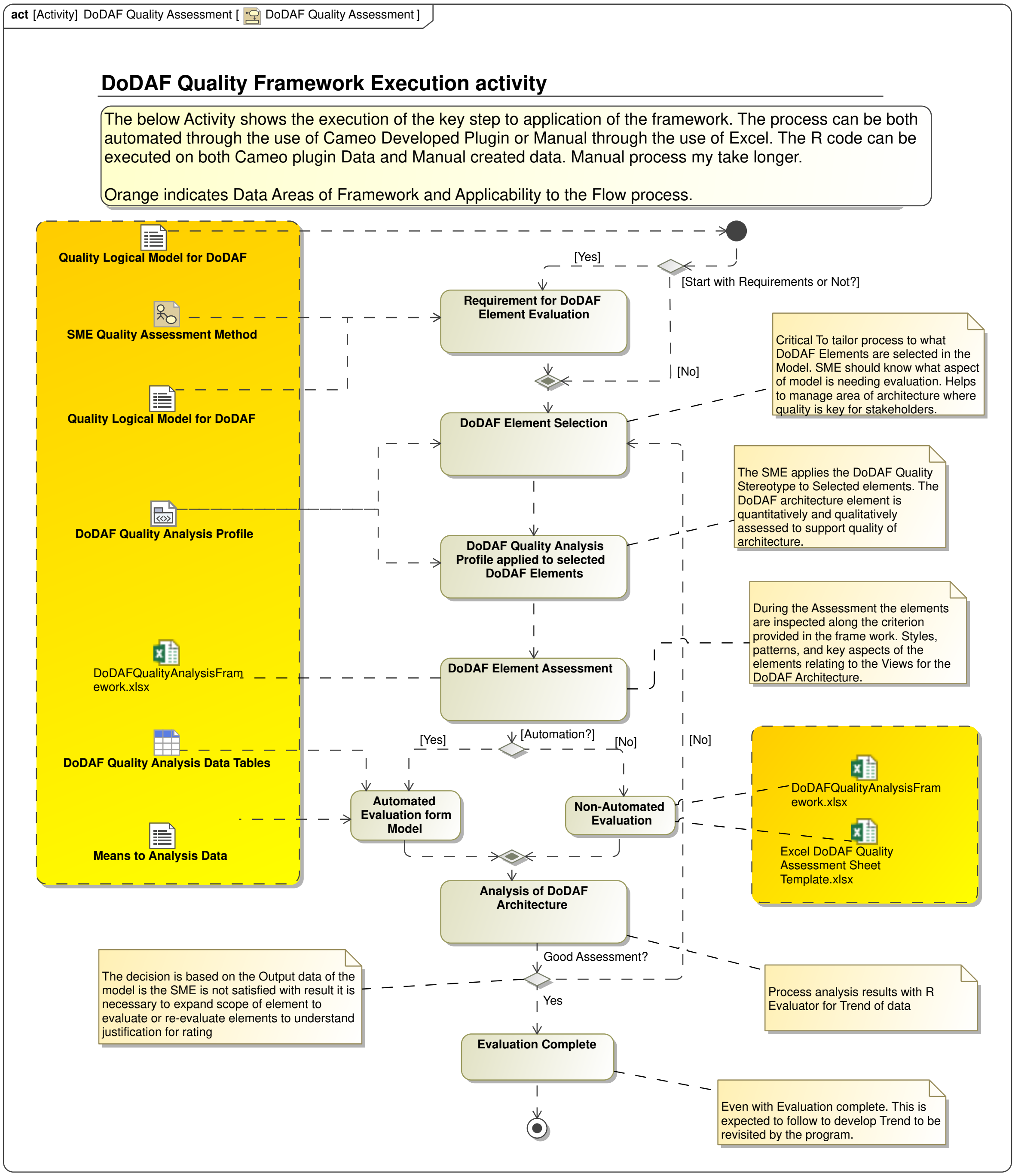

Figure 2.9: Simple DoDAF Quality Assessment Activity Flow

that will be reflected in the Kaizer-Meyer-Olkin (KMO) test measure of sampling adequacy which is discussed further in Section 2.2.7.

2.2.7 Statistical Analysis Methods

The DoDAF Quality Analysis Profile (DQAP) stereotype *«DoDAF Quality View»* was used to collect data from the case study models through both automated or manual collection. Statistical techniques were used to analyze the data and provide insight to the data with respect to quality for each of the case studies. The data is collected based on the questions for each factors defined in Appendix A. The questions or statements are presented as a Likert scale questionnaire to collect data on each DoDAF model element. The Likert scale was invented by Rensis Likert in 1932, and used to determine degrees of agreement or of disagreement based on criteria applied when assessing a particular topic area [108]. The Likert scale was used for each question based on an agree or disagree common construct used to help generate greater detail about the evaluation of each case study model quality [109]. Typically, the data generated from the Likert scale is ordinal in nature and reports the ranking/ordering of the data without actually establishing the degree of variation [110]. Medical education research techniques have shown that parametric tests may be utilized to examine ordinal data in medical education research [109, 111]. Additionally, when examining ordinal data, such as that which is found in Likert scales, parametric tests are often more resilient than nonparametric tests even when statistical assumptions such as the normal distribution of data are broken [109, 111]. The reliability of the seven point Likert scale has been shown empirically to be approximately ~90% reliable and approximately ~89% valid [112]. While these are not a 100%, the author considers this acceptable for analysis purposes. For the purpose of the analysis a seven point Likert scale will be used and is shown below.

1. *"= Strongly Disagree"*

2. *"= Disagree"*

3. *"= Somewhat Disagree"*

4. *"= Neutral"*

5. *"= Somewhat Agree"*

6. *“= Agree”*

7. *“= Strongly Agree”*

The seven point Likert scale provides adjacent options that are most commonly used in the scale design construct [113, 114]. The step wise spectrum offers independence to an element component factor evaluation for a participant to select the best choice for the evaluation [114]. In many cases, the element component factors’ questions are rolled up into metric variables that were defined below Section 2.2.7. Additionally, the seven point Likert scale data provides a more reliable result for analysis [115]. Typically, variables are unimportant or correlated with one another, leaving it difficult to construct a proper mathematical model [116]. When it comes to data collection from each case study model, the author is well aware that although conceived variables may be inconsequential or associated to one another, some of the statistical rigor in this part will offer meaning and insight into data received from each case study models.

Dependent and Independent Variables

Now that understanding for the Quality By Design (QbD) has been mapped to the DoDAF framework including where data needs to be collected from within case study models, the following will help to capture and quantify the data needed for interpretation of quality for the developed architecture. To create a quality architecture includes three key aspects which are the DoDAF standard application, the UML/SysML standard application, and the requirement instantiation within the architecture. The following formulated variables represent the Likert scale questions compressed for easier understanding and statistical analysis method application:

- *DoDAF Element Quality = DEQ*
- *Language Element Quality = LEQ*
- *Requirement Element Quality = REQ*

The first aspect of DoDAF Element Quality *DEQ* variable takes into account the DoDAF standard aspects of element quality as defined in Appendix A and functions as the dependent variable for analysis purposes for PCA and OLR. The second aspect of Language Element Quality *LEQ* variable was used to address quality aspects related to the UML/SysML. The *LEQ* variable is also used as a independent variable for analysis purposes. The final aspect of Requirement Element Quality *REQ* variable takes into account the systems engineering methods of the DoDAF CONOP architecture and relates the element evaluation to requirement instantiation of the architecture in the model [5]. Additionally, the *REQ* variable looks to establish system contextual meaning for an element in the architecture to understand developed requirements or outline requirement development support for an early stage architecture. The *REQ* variable was used as an independent variable for the purpose of this analysis. Figure 2.10 shows the construct for the variables. The *DEQ* variable indicated in yellow is the DoDAF Element Quality. The *LEQ* Language Element Quality and *REQ* Requirement Element Quality variables are indicated in red and are causal factors that will influence the *DEQ* value. The Single Element Quality or *SEQ* has three aspects that can be shown for that element but is not a variable or calculated value just represents variable aspects of a single element that are collected. The green box indicates the the QCC questions from Appendix A. The additivity of the variables characterizes the understanding for a single element aspect taking into account DoDAF CONOP quality, requirement and design quality, and UML/SysML language quality [117]. All variables were used to answer the research questions in the research question Section 1.2.1 of Chapter 1. Figure 2.10 shows the construct for the variables. Within each block of the tables a single value for Likert scale rating will be entered, values larger than seven or smaller than zero will be ignored.

The factors that determine whether a element from the case studies contributes to analysis or does not is based on the element being included on the corresponding DoDAF CONOPs view diagrams which can be quantitatively evaluated by the QCC scale. The mean and median values will be compared to one another in the analysis for each case study. The reasoning stems from the example presented in Section 2.2.7 of this Chapter. Once the determination between mean and median is made, one or the other will be use to assist in the Ordinal Logistic Regression (OLR) analysis for each of the case study models in Chapter 4 and 5. The values of mean or median for

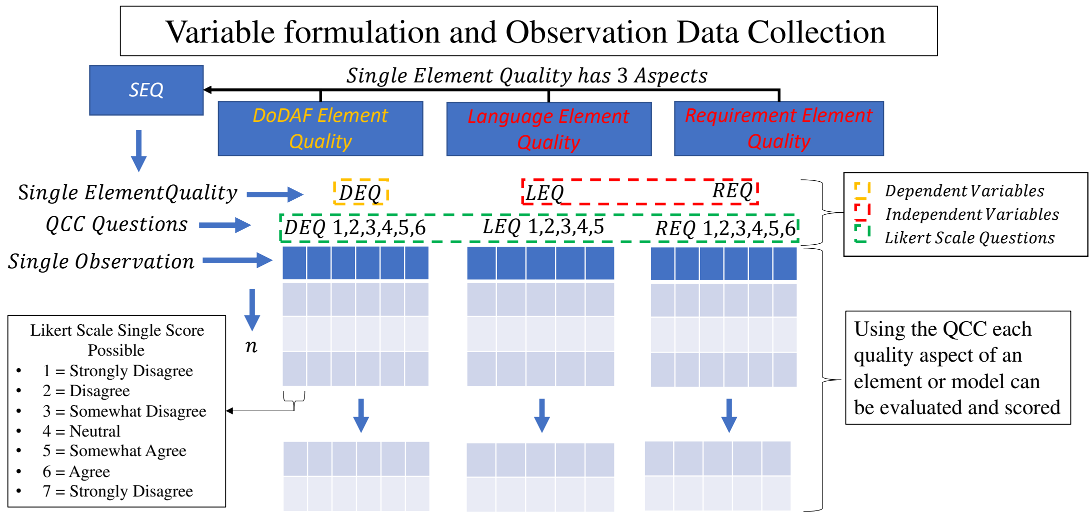

Figure 2.10: Dependent and Independent Variables for Analysis

DEQ, *LEQ*, and *REQ* will be used to assist in interpretation and analysis for each case study. The descriptives calculated for each variable will include: *mean, median, variance, standard deviation, minimum, maximum, range, standard error, skewness and kurtosis*. While models can be relatively small and may not provide large sample sizes of historical size for data analysis, techniques exist to generate defensible, quantified metrics within uncertainty bounds from small sample sizes or based on subjective expert judgment [36]. The methods include: Bayesian Statistics methods, generalization table with percentage errors, and many others [118]. If an increase in model elements for evaluation is necessary that will be reflected in the Kaizer-Meyer-Olkin (KMO) test measure of sampling adequacy which is discussed further in Section 2.2.7.

Mean vs Median

With the variables formulation completed using the *median* vs the *mean* values for analysis purpose must be determined [119]. The *median* use is justified on occasion because the data is ordinal in nature and not normally distributed [119]. Consider the following answers as an example to demonstrate the reasoning for use of the median: Sample: 1,2,2,5,5. The rating scale is as follows: 1) Disagree, 2) Somewhat Disagree, 3) Neutral, 4) Somewhat Agree, and 5) Agree. The *mean* for the Sample is 3 and the *median* is 2. What would the interpretation for a *mean* of 3 mean for the observation with in the framework when the representation is neutral? By checking frequencies for the example, two five values which are "agree" ratings, and the remaining three basic ratings are "disagree". The frequencies show that the example only has a 40% agreement, and a 60% disagreement. The frequencies show that the observation is not neutral as the *mean* of 3 would indicate, but is in disagreement. Justification for the use of the median over the mean is a critical assumption to ensure the appropriate perspective is indicated for each question asked in the Likert scale data. The comparison will include descriptive statistics and plots for normality checks such as Q-Q Plot and Frequency plots to make determination on *mean* vs *median*.

Normality Testing

Once the data sets were collected, normality tests were conducted in order to conduct some of the statistical methods to affirm the assumptions of ordinal, discrete, and limited range for parts of the analysis to be conducted. The first check on the data set was the skewness and kurtosis of the data set to determine normality [120]. The skewness statistic provides information about whether a distribution is symmetric or skewed to either side on a frequency plot [121]. The skewness can be both positive and negative in nature [120]. If the data is normally distributed, the expectation of a low value, near 0, for skewness and a flatter peakedness value is expected [120]. The formula for skewness is equation 2.1. $\widetilde{\mu}_3$ represents the value for skewness [120]. n is the number of variables in the distribution [120]. X_i is any random variables [120]. $\overline{X}$ is the mean of the distribution [120] σ is the standard deviation [120].

$$\widetilde{\mu}_3 = \frac{\sum_i^n \left(X_i - \overline{X}\right)^3}{(n-1) \cdot \sigma^3} \tag{2.1}$$

The next check will be the kurtosis check for the data or the degree of peakedness of the data distribution [121]. The formula for kurtosis is equation 2.2. X_i is the ith variable of the distribution [120]. $\overline{X}$ is the mean of the distribution [120]. The N is the number of variables in the distribution [120].

$$K = \frac{\sum_i^n \left(X_i - \overline{X}\right)^4}{n \cdot \sigma^4} \tag{2.2}$$

In cases where samples are small $n < 50$, when the absolute z-scores for either skewness or kurtosis are larger than 1.96, then the distribution is non-normal [122]. In cases for small samples where $n > 50$ but $n < 300$, and the absolute z-scores over 3.29, then the distribution is non-normal [122]. For sample sizes greater than 300, one should factor in the frequencies and the absolute values of skewness and kurtosis. [122]. Either an absolute skew value larger than 2 or an absolute kurtosis larger than 7 may determine a substantial non-normality or ordinal data set [122].

Additionally, tests that deal with normality of a data set are Kolmogorov-Smirnov and Shapiro-Wilk. The Kolmogorov-Smirnov tests for normality can be used for a uni-variable ordinal data set [123]. The Kolmogorov-Smirnov is considered non-parametric when used in this fashion [123]. The Kolmogorov-Smirnov test can be considered if the sample size of n is greater than 100. The Kolmogorov-Smirnov test will provide a significance value associated with each of the variables ***DEQ***, ***REQ***, and ***LEQ***. The Kolmogorov-Smirnov test equation 2.3. The F_o values are the Observed cumulative frequency distribution of a random sample of n observations [120]. The F_r values are the theoretical frequency distribution [120].

$$D = Maximum \left| F_o\left(X\right) - F_r\left(X\right) \right| \tag{2.3}$$

The expectation for the Kolmogorov-Smirnov test is that if the significance (p) of each of the variables ***DEQ***, ***REQ***, and ***LEQ*** is less that 0.05, then variables are considered significant and not normally distributed [123]. The Shapiro-Wilk test deals with normality of a data set, if the sample size of n is less than 100 [124, 125]. The Shapiro-Wilk test will provide significance of value associated with each of the variables ***DEQ***, ***REQ***, and ***LEQ***. The expectation for the Shapiro-Wilk test is that the significance (p) of each of the variables ***DEQ***, ***REQ***, and ***LEQ*** is less that 0.05, then variables are considered significant and not normally distributed [124, 125]. The Shapiro-Wilk test equation 2.4. The X_i values are the ordered random sample values [125]. The a_i values are constants generated from the covariances, variances and means of the sample size n [125].

$$W = \frac{\left(\sum_{i=1}^{n} a_i X_i\right)^2}{\sum_{i=1}^{n} \left(X_i - \overline{X}\right)^2} \tag{2.4}$$

If the resultant from both tests are questionable then the *log* of values will be calculated and retested for normality. If the result still shows significance $p < 0.05$, then the data set can be considered as not normally distributed. Checking to confirm if non-normality exists is a critical assumption for conducting ordinal regression between the dependent and independent variables [126]. Additionally, using the output of a normal Q-Q Plot, we may visually assess the normality of a given distribution [127]. If the data is regularly distributed, the data points will be clustered along the diagonal line, indicating that the data is normal [127]. Normally distributed data are not normally distributed if the data points deviate significantly off the line in an evident non-linear pattern [127].

Multicollinearity

The term multicollinearity refers to high intercorrelations among two or more independent variables in a regression model [128]. When dealing with Multicollinearity, the independent variables could produce less reliable probabilities that effect the mathematical model resultant and data interpretation for the case study models [128]. Multicollinearity needs to be addressed because the standard errors of the coefficients for variables could cause false indicators and become non-significant or significant [129]. The best way to test for multicollinearity is to run a linear regression equation 2.5 analysis and look at the Variance Inflation Factors (VIF) values for each factor [129]. The equation for linear regression is equation 2.5. Y_i is the dependent variable or in this case the mean or median value for *DEQ* [129]. β_0 is the constant or intercept [129]. β_i is the slope coefficient [129]. X_i is the independent variable or *LEQ* and *REQ* [129]. ϵ_i is the random error term [129].

$$Y_i = \beta_0 + \beta_1 X_i + \epsilon_i \tag{2.5}$$

The equation for VIF is 2.6. R_i^2 represents the unadjusted coefficient of determination for regressing the ith independent variable on the remaining ones [129]. In checking the multicollinearity between variables VIF to determine the relation, it is desired to obtain a value below 0.8. If the value is greater, this means multicollinearity exists between the variables [129].

$$VIF_i = \frac{1}{1 - R_i^2} \tag{2.6}$$

Additionally, Spearman's ρ is a non-parametric measure of rank correlation for ordinal data and tells how well the relationship between the two variables is [130]. The non-parametric measure of rank correlation coefficients higher ρ coefficients denote a stronger magnitude of relationship between variables and Smaller rho coefficients denote weaker relationships [130]. ρ is Spearman's rank correlation coefficient [120]. d_i^2 is the difference between the two ranks of each observation [120]. The n is the number of observations [120]. The goal for the ordinal data is to have a weak or almost non-existent correlation for the coefficients for each of the variables indicated in the matrix [120]. Spearman's ρ can both be positive and negative, with the goal is to have a value between 0.1 and -0.1 [120]. The equation for Spearman's ρ is 2.7.

$$\rho = 1 - \frac{6 \sum d_i^2}{n\left(n^2 - 1\right)} \tag{2.7}$$

Checking to confirm no multicollinearity exists is a critical assumption for conducting OLR between the dependent and independent variables [120]. Dimensionality could be an issue considering the number of questions asked through the Likert scale questionnaire for element component factor evaluation [131]. Conducting Test of Proportional Odds tests the proportional odds assumption that the slop of coefficients in the model are the same across the response categories.

Proportional Odds tests needs to be cautioned in that if the significance $p > 0.05$, it will violate this assumption [120]. The author wants to stress it is vital to remember that statistical significance does not always imply the strength of Spearman's correlation between variables [132]. Statistical significance testing of the Spearman correlation does not, give any information regarding the strength of the link between variables [132]. Just because the value result ρ = 0.001 does not imply that the association is stronger than it would be if you had achieved the result ρ = 0.04 instead [132]. This is mostly due to the fact that the significance test is looking to see whether you can reject or fail to reject the null hypothesis throughout the investigation [132]. Assuming that the null hypothesis is correct and if you get a statistically significant Spearman correlation, this indicates that there is less than a 5% chance that the strength of the association discovered occurred by coincidence [132].

Principal Components Analysis

Principal Components Analysis (PCA) for categorical variables is a method performed on the data in order to test the theoretical model of latent factors which cause the observed variables to change [133–135]. Ordinal variables are converted to quantify their underlying equivalents with the goal of increasing the amount of variance explained by a small number of main components taken from the data set. The approach becomes explicitly goal driven rather than theory driven, and for the purpose of analysis, critical to reach maximum of two primary components with acceptable percentage to with 50% to 60% [136]. The author recognizes this is considered a parametric test, but is often more resilient than nonparametric tests and is considered acceptable practice via available research [109, 111]. The author understands and acknowledges that using PCA for analysis of ordinal data is highly debated both in the positive and negative, but considered acceptable to perform analysis as long as the Kaizer-Meyer-Olkin (KMO) and Bartlett's test are passed as described. PCA will also assist the analysis by preventing "over fitting" due to the use of many factors for quality evaluation [137]. PCA is also used for dimensional reduction of component factor for the analysis, and will be used as such for the purpose of this analysis [138].

$$\sigma_{jk} = \frac{1}{n} - \sum_{i=1}^{n} \left(X_{ij} - \overline{X}_j\right)\left(X_{ik} - \overline{X}_k\right) \tag{2.8}$$

By using PCA for dimensional reduction to conduct OLR, if collinerarity still exist after reduction but the VIF values were small for all remaining factors then PCA is still acceptable and analysis can continue [139]. While PCA should be analyzed on a continuous basis, the approach can be used on ordinal data to provide unique insight into the relations of variables and explain findings from case study models [138, 140]. PCA can be used to provide insight into multicollinearity and dimensionality, as well as establish linear combinations of the element component factors [140]. The first step in the analysis provides the descriptive statistics on each of the observations or elements with the Likert scale. The covariance matrix contains all element combination pairs for each variable [120]. The equation 2.8 is used to calculate the covariance between two attributes [139]. The matrix breakdown equation for covariance matrix is equation 2.9.

$$[X_1, X_2, ..., X_n] = \begin{bmatrix} X_1(t_1) & X_1(t_1) & ... & X_n(t_1) \\ X_1(t_2) & X_2(t_2) & ... & X_n(t_2) \\ \vdots & \vdots & \ddots & \vdots \\ X_1(t_m) & X_2(t_m) & ... & X_n(t_m) \end{bmatrix} \tag{2.9}$$

The covariance between variables can be both positive and negative with clusters closer together or separated moving apart [120]. Additionally, the KMO test can be conducted which will return a measure of sampling adequacy [141]. The equation for KMO test is equation 2.10. r_{ij} is the correlation matrix [141]. u_{ij} is the partial covariance matrix [141].

$$KMO_j = \frac{\sum_{i \neq j} r_{ij}^2}{\sum_{i \neq j} r_{ij}^2 + \sum_{i \neq j} u_{ij}} \tag{2.10}$$

The KMO addresses partial correlation between the variables [141]. The expectation is that the test should return values closer to 1.0 to 0.5 meaning the sample is adequate, less than 0.5 is considered problematic requiring further investigation [120,141]. The Bartlett's Test is a statistical method to test the correlation matrix as a true identity matrix [120,142]. The equation for Bartlett's Test is equation 2.11. s_i^2 is the variance of the ith group [142]. n is the total sample size [142]. n_i is the sample size of the ith group [142]. k is the number of groups [142]. s_p^2 is the pooled variance [142]. The Bartlett's test will return a value of significance if the value is less than ($p < 0.05$), the matrix is not an identity matrix and the variables are unrelated and difficult for factor analysis [142].

$$T = \frac{(n-k)\ln s_p^2 - \sum_{i=1}^{k}(n_i -)\ln s_i^2}{1 + \left(\frac{1}{3(k-1)}\right)\left(\sum_{i=1}^{k}\frac{1}{n_i - 1}\right) - \frac{1}{(n-k)}} \tag{2.11}$$

The next step would to analyze the total variance for each variable [120]. The variance of the total variables will tell what variables provide the most important impact for the data set [142]. The correlations component matrix can show the correlations between variables which can show linear relations between variables showing a change in one that directly changes another through a linear equation [120]. The eigenvalues of 1 or greater will determine what factors remain for continued analysis [142].

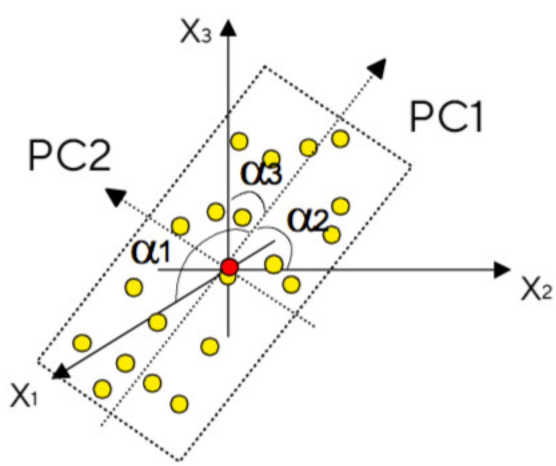

Figure 2.11: PCA Loading Plot Example [9]

Figure 2.11 illustrates a PCA loading plot. Whenever the numerical value of one variable changes, the numerical value of the other variable has a strong propensity to change in the same manner [9]. When variables are negatively (or inversely) linked, they are plotted on the opposing sides of the plot origin, in diagonally opposed quadrants, as seen in the figure [9]. Furthermore, the distance from the point of origin transmits information as well. The farther the distance a variable is from the plot's origin, the greater the influence that variable has on the model's outcome [9]. Geometrically, the principle component loadings represent the orientation of the model plane in the K-dimensional variable space, and this is expressed by the principal component loadings [9, 142]. It can be determined which way PC1 is moving in regard to the initial variables by taking the sine of the angles a_1, a_2, and a_3 [9, 142]. These numbers demonstrate how the original variables x_1, x_2, and x_3 "load" (that is, contribute to) PC1 when they are multiplied together. As a result, they are referred to as loadings [9, 142]. The ultimate goal is to look at the loading plots generated for the PCA analysis and understand the components relations to the variables.

Ordinal Logistic Regression

Ordinal Logistic Regression (OLR) analysis has three particular approaches which include feature extraction, forecasting of an effect on the DoDAF model quality and trend forecasting [120, 143]. OLR analysis assumes a dependence or causal relationship between one or more independent and one dependent variable [120]. Primarily, OLR can be used to identify the strength of the effects that the independent variables have on a dependent variable [120]. OLR is more likely to be the correct approach, although it is less well-known and more difficult to grasp than formal logistic regression [144]. It is much more difficult to grasp MLR since it is a highly complicated model with a large number of parameters to estimate [144]. Collapsing the variables through MLR will only be accurate in a very small number of cases [144]. OLR can be used to forecast effects and to understand how much the dependent variable changes when the independent variables are changed [120]. Additionally, Multinomial Logistic Regression (MLR) can be used for ordinal data for statistical analysis; however, it is preferred to use Ordinal Logistic Regression [144]. Only when the proportional odds assumption is violated will MLR be used over OLR. The proportional odds assumption has a constant relationship between the independent variable and dependent variables [144]. The equation for Ordinal Regression is 2.12.

$$\text{logit}\left[\gamma_j\right] = \log\frac{P\left(Y \leq j|x\right)}{1 - P\left(Y \leq j|x\right)} = \log\frac{\pi_1\left(x\right) + \cdots + \pi_j\left(x\right)}{\pi_{j+1}\left(x\right) + \cdots + \pi_J\left(x\right)}, j = 1, \ldots, J-1 \tag{2.12}$$

The $\pi_j(x)$ is the probability that score j is rated through subjective human analysis [145]. The logit$[\gamma_j]$ models the logit that users score less or equal to score j [145]. J specifies the total number of response categories 7, based on the design of the Likert scale used for each question [145]. A number of $J-1$ logit's are established since $P(Y \leq J|x)$ is always 1 [145]. Additionally, checks will be made on the data set prior to conducting the OLR analysis. The Pearson and Deviance test are conducted to understand the observed distribution of the data expected in the independent calculated mean of abstracted variables [146]. Equation 2.13 shows the Pearson test equation. X^2 is Chi-squared obtained. y_i is observed value. $\widehat{\mu}_i$ is the expected number of observed values.

$$X^2 = \sum_{i=1}^{c}\left[\frac{y_i - \widehat{\mu}_i}{\sqrt{\widehat{\mu}_i}}\right]^2 \tag{2.13}$$

Equation 2.14 shows the Deviance test equation. L^2 is Chi-squared obtained. y_i is observed value. $\widehat{\mu}_i$ is the expected number of observed values.

$$L^2 = 2\sum_{i=1}^{c} y_i \log\left[\frac{y_i}{\widehat{\mu}_i}\right] \tag{2.14}$$

The Pearson and Deviance test were conducted to understand the observed distribution of the data expected in the independent calculated mean of abstracted variables [146]. The indication for the tests on the evaluation data is that the values are non significant, meaning a $p > 0.05$ [147]. If the significance level was low, meaning $p < 0.05$, the predicted model would deviate from the observed model presenting a problem with the data set requiring further investigation [148]. The next test values calculated are the Pseudo R-Square values including the Cox and Snell, Nagelkerke, and McFadden tests. The values are treated as rough analogues to the R-Squared values in ordinal least squares method for estimating the unknown parameters in an OLR analysis [149]. Equation 2.15 shows the Cox and Snell test. n is number of observed values [149]. $L_{intercept}$ is the intercept value [149].

$$R_{cs}^2 = 1.0 - \exp\left(\frac{2\ln L_{Full} - 2\ln L_{intercept}}{n}\right) \tag{2.15}$$

As the $-2\ln L$ value for the model intercept refers to the intercept-only model increases, the Cox and Snell R-squared result will approach one [149]. Since the result can never actually reach one, the Nagelkerke R-Squared is also shown; this descriptor takes Cox and Snell value and divides by the result with the model $-2\ln L$ set to zero [149]. Equation 2.16 shows the Nagelkerke test.

$$R_{Nag}^2 = \frac{R_{CS}^2}{1.0 - \exp\left(\frac{-2\ln L_{Intercept}}{n}\right)} \tag{2.16}$$

Equation 2.17 shows the McFadden test. L_0 are the likelihood for the model being fitted [149]. The consensus is that the values when calculated for equations 2.15, 2.16, and 2.17, must not be statistically significant or a problem may exist with the data set [149, 150].

$$R_{McF}^2 = -\frac{n}{2} \cdot \frac{\ln\left(1 - R_{CS}^2\right)}{\ln L_0} \tag{2.17}$$

Furthermore, a Wald Chi-Squared test will be used to determine whether or not explanatory variables in a model are significant [151]. Significant signifies that the variables contribute something to the model; variables that contribute nothing may be removed from the model without influencing it in any significant manner [151]. Equation 2.18 shows the Wald test. $\widehat{\theta}$ is the maximum likelihood estimator [151]. $I_N\left(\widehat{\theta}\right)$ is how much information about an unknown parameter we can get from a sample or the Fisher information [152].

$$W_T = I_N\left(\widehat{\theta}\right)\left[\widehat{\theta} - \theta_0\right]^2 \tag{2.18}$$

A one-unit change in an independent variable has a constant influence on the probability, however this is not achievable because of the non-linearity of the model [144]. Instead, the projected probabilities need the inclusion of the other variables in the model in order to be accurate [144]. The final aim is to evaluate the variables in terms of their likelihood of occurring and preform interpretations of quality.

Summation

The statistical techniques describes will help to interpret the Likert scale data for the quality of each of the case study models. The methods used through the Likert scale questions and evaluations can illustrate key factors influencing quality of DoDAF CONOPs for each model. Plots of data as well as interpretations will provide a unique approach and story board for quality of each case study model.

Chapter 3

Conceptual Framework and Overview

3.1 Framework Development Methodology

The ultimate goal of this dissertation is to provide a means through a New DoDAF Quality Conceptual Framework (DQCF) to evaluate quality of MBSE DoDAF architecture models. The scope for the framework will focus primarily on DoDAF CONOP architecture element evaluations to achieve an overall quality understanding for the system CONOP mission threads defined in the case studies. The Quality By Design (QbD) application through the DoDAF Quality Analysis Profile (DQAP) addresses selected aspects for quality analysis to evaluate elements within a model. While many methods exist for quality assessment of model architectures, most focus primarily on the UML/SysML base languages, which in truth are only part of the equation for quality. Considerations for the system design with respect to quality as well as the DoDAF standard application need to be included for the total quality assessment. Statistical methods are needed to provide meaningful insight into the data collection evaluations, instead of arbitrary meaningless counts of elements.

The goal of this conceptual framework is to describe various concepts that can map relations of the methodology into execution [153]. Typically frameworks consist of five major functional areas including: 1) building a foundation, 2) methodology capture, 3) conceptualization framework formation, 4) application and data collection, and 5) interpretation of findings [154]. The purpose of this section is to provide the conceptual framework connections to the ideas described in Chapters 1 and 2 to the data collected from case studies in order to offer empirical evidence of how the DQCF can interpret quality of DoDAF CONOP architectural quality [153]. Most of the details discussed for the framework are designed using the Cameo Enterprise Architecture tool suite as discussed under Chapter 2 Section 2.2.5 Assumptions for Performing Analysis. The methods and the framework itself are tool agnostic and can be used to address the QbD of any DoDAF architecture construct within a model. The primary examples and images for profiles were taken from the Cameo Enterprise Architecture tool suite version 19.0 service pack 3. The profile is exportable to Extensible Markup Language (XML) 1.0 and can be imported to other tools making the profile useable in many other tools. Cameo Enterprise Architecture Tool Suite was selected as the primary tool for illustration purposes it is the primary tool used for Object Management Group (OMG) when building Domain Specific Language (DSL) extensions for new release of UML/SysML. For readability, Stereotypes will be indicated by having «» symbols around them.

3.2 Framework Design for Modularity Evaluation

The conceptual framework described in this chapter provides insight into modularity including both the Quality Characteristic Categories (QCC) and the end model product that is developed. The degree of modularity assessment is used in order to grasp functional reusability understanding of architecture aspects for development of system design. The developed product for purpose of modularity evaluation will be the DoDAF CONOP architecture specified mission threads in the case studies [155–157]. In the architectural design, a mission thread is a sequence of end-to-end actions and events that are presented as a series of stages and that are used to execute the execution of one or more capabilities that are supported by the architectural design [158]. Although listing the steps and explaining them are important, they do not reveal all of the important concerns associated with cooperation among the systems in order to complete the mission; understanding the architectural and engineering considerations associated with each mission thread is also necessary [158]. As stated from the Literary Review in Section 1.2 of Chapter 1, problems have always existed with document based approaches to systems engineering [159]. While data integration can suffer from inconsistencies, continuity in data is primarily where the modularization suffers during the architecture development [157]. Understanding or measuring to what degree the aspects of cross integration and data continuity create the complex network structure of an architecture, ultimately reflecting the degree of modularity of a model [157, 160]. The flow of information between, or created by, these model elements is critical to the understanding for modularization [161, 162].

The DoDAF CONOP data interactions and how they are evaluated will be critical to the system design quality as well as model quality. To address the interactions or relations between elements, it is best to look at how they are defined dimensionally [44]. The first dimension is the structural interactions and the second dimension is the weight of the relationship, whether it is a positive or negative interaction [44] The third dimension is the element detail and will be where this conceptual framework stresses the evaluation by a Subject Matter Expert (SME) [44]. This third dimension constitutes the architecture abstract subsystems, major components, and individual parts which reside on DoDAF views of a system design [44]. The third dimension and corresponding DoDAF views in the quality evaluation of elements is where conceptual framework addresses the degree of modularity.

Modularization for the conceptual framework constitutes the interconnected dependencies relationships to the created system design data that instantiates the architecture for the system [163–165]. A good example of the created system design data can be seen in the textual Requirement grammatical patters that translate to the instantiation of an architecture [5, 166]. The segmentation of text from the grammatical patterns helps to bring in modularity by driving element creation on specific DoDAF views in the model architecture [50]. The following bulleted list illustrates different structural requirement patterns developed by Carson and others that present how system design data is created [167]. The first bullet is from Carson's pattern method for functional performance requirements' structured requirement [167–169]. The second bullet is from IEEE 29148 standard for requirements writing [168]. The third is from INCOSE Guide for Writing Requirements [169]. The textual patterns can relate requirements' text directly to the quality of architecture elements as they are developed [167]. Instantiation of architecture elements through requirement text was shown in Miller's *Digital engineering transformation of requirements analysis within model-based systems engineering* [5]. Table 3.1 show steps and elements created from each step in Miller's purposed method.

- Functional/Performance - The AGENT shall FUNCTION in accordance with INTERFACE-OUTPUT with PERFORMANCE [and TIMING upon EVENT TRIGGER in accordance with INTERFACE-INPUT] while in CONDITION [167].

- When signal x is received [Condition], the system [Subject] shall set [Action] the signal x-received bit [Object] within 2 seconds [Constraint] [168].

- The <subject clause> shall <action verb clause> <object clause> <optional qualifying clause>, when <condition clause> [169].

The textual pattern for the functional performance requirement shown in the first bullet was used as a reference to construct the evaluation criteria for Quality Characteristic Categories (QCC) from Appendix A. The operational functional performance requirement should drive the development of a CONOP architecture for a system design as stated in Section 2.1.3 DoDAF CONOP Design Process in Chapter 2 [4, 79]. The QCC variable that represents the requirement development is the *Requirement Element Quality* or *REQ* from Section 2.2.7 of Chapter 2 The *REQ* variable attempts addresses the impact of requirements' quality to the system design and architecture for each DoDAF element created.

The criticality of requirements' to systems engineering quality is why the *REQ* plays a vital role for the DoDAF CONOPs element quality evaluation. All of the *REQ* present a key aspect for QCC that bring the analysis system design data into the degree of modularity. The DoDAF element relations, through created relationships driven from the system design data to other elements of the architecture, introduce modularization relating system requirements while instantiating model elements for the DoDAF CONOP architecture [5, 163–165]. By visualizing the relationships of system design data via the Quality Characteristic Categories (QCC), the Quality Characteristic Categories (QCC) establishes the Quality Control Attribute (QCA) from the Quality By Design (QbD) theory aspect into the applied desired DoDAF CONOP architecture shown in Figure 3.1.

Module formation is shown through the views to establish the CONOP architecture views via the complex stage network structure or interconnected relations with the help of a network dia-

Table 3.1: Elements and Relations Created for Miller's Method [5]

Method Step	Element Stereotype Created	Relations Created
1	«requirement»	
2	«functionalRequirement»	«deriveReq»
2.a	«System»	
2.a.1		«allocate»
2.b	«function»	
2.b.1		«refine»
2.c	«MeasurementSet» «ActualMeasurementSet»	
2.c.1		«refine»
2.c.2	«Standard»	
2.d	«OperationalAction» «OperationalActivity»	
2.d.1		«refine»
2.e.1		«dependency»
2.e.2	«OperationalStateDescription»	«refine»
2.e.3	«OperationalConstraint»	
3	«Capability»	
3.a		«trace»
4	Complete	Complete

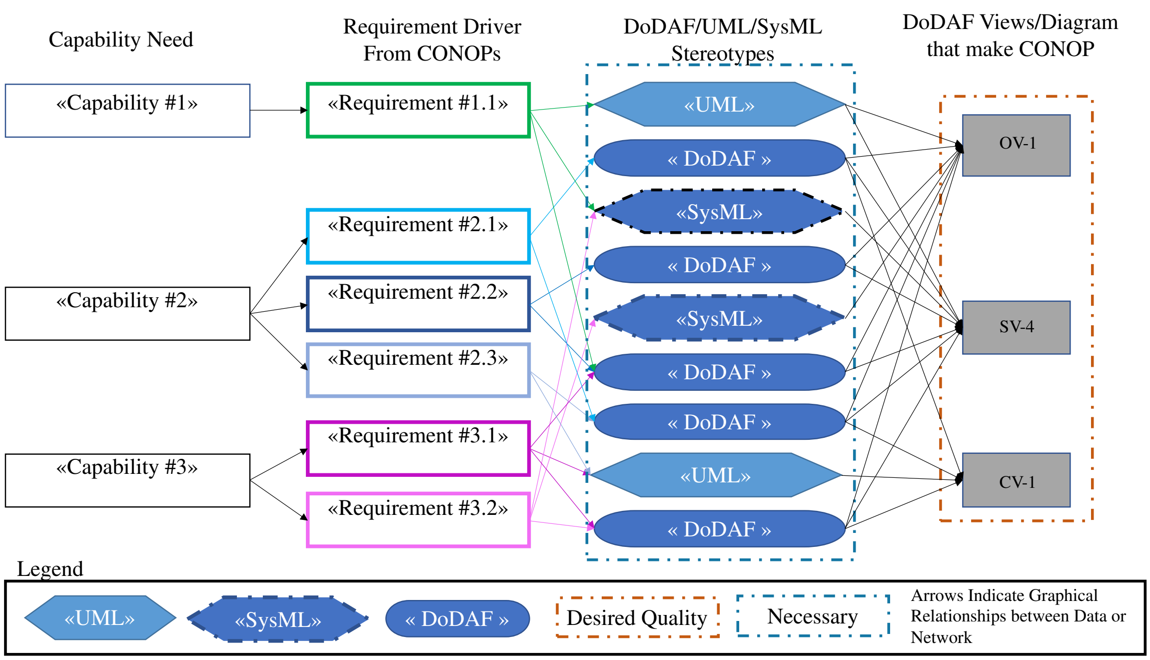

Figure 3.1: Network Diagram Understanding for DoDAF Example

gram [157, 170]. The important aspect is that the more modular a designed system is, the easier it is to upgrade, replace, or reuse design aspects [156, 171]. Figure 3.2 shows the groupings of elements as defined in Miller's method. The red dashed line indicates DoDAF element stereotypes created from functional performance requirement statement using Miller's method [5]. The yellow dashed line indicates the relationships that are created using Miller's method [5]. The blue solid boxes indicate customer or supplier provided material. The yellow solid box indicates the derived requirement statement which decomposes in the the created DoDAF CONOP elements to create the architecture. The framework evaluation criteria establishes two factors for evaluation addressing modularity for quality aspects and can be extracted to understand the modularity quality for the DoDAF CONOP architecture. Additionally, the textual pattern introduces modularity in the integration for consistencies and continuity in data where modularization traditionally suffers in architecture development and is reflected in the QCC through the *DoDAF Element Quality* or *(DEQ)* [157]. The first factor is *DEQ2* networked relationships between the graphical elements [157, 160]. The second factor is *DEQ6* which provide understanding of consistency and continuity of system design data [157]. By taking this multiple factor approach through *DEQ* and *REQ* to integrate understanding for quality of modularity within the evaluation criteria of the DoDAF elements, a more manageable segmented approach can be applied to reduce the complexity while quality of modularity can be achieved [44, 172].

Additionally, assessing modularity cannot be complete without addressing complexity of the system design [173]. While several equations exist for modularity and are documented in several different papers, many of the equations rely on generated architectures which is them ideal for application to case study model to determine a degree of modularity [171]. Holtta-Otto's team paper evaluated several of the equations, the teams analysis found that for the factors for that study that YuTian's equation for Minimum Description Length (MDL) was most useful for describing the degree of modularity [171, 174]. The author based on the Holtta-Otto's team paper will use an adapted version of YuTian's equation for MDL in an attempt to quantify modularity for case study models. Typically, all of the approaches to modularity equations use a Design Structure Matrix (DSM) to understand the relationship between elements in a model [171, 173]. The Hölttä-Otto paper outlines the best performance modular equation to use in order to detect modularity

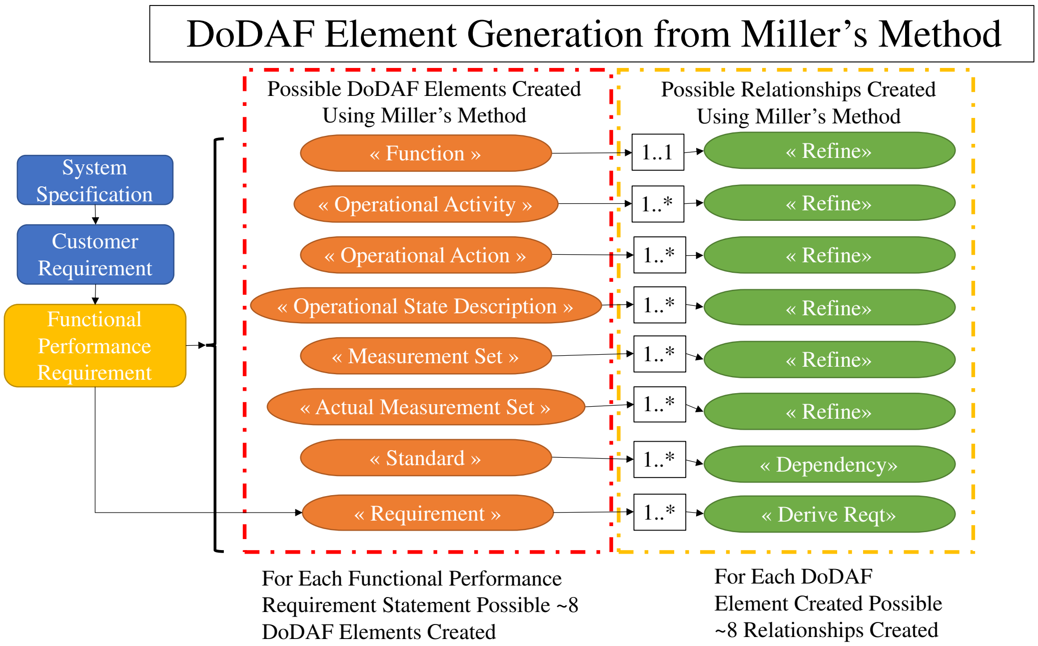

Figure 3.2: Requirement Transformation Analysis of Elements and Relations

which based on the data would suggest the best approach when DoDAF architecture structure views are considered as individual modules [171]. The paper *An information theoretic method for developing modular architectures using genetic algorithms* details promising approaches with DSM and equations to support addition for the DQCF to address modularity [174].

$$MDL = \frac{1}{3}\left(n_c \log(n_n) + \log(n_n)\sum_{i=1}^{n_c} cl_i w\right) + \frac{1}{3}S_1 + \frac{1}{3}S_2 \tag{3.1}$$

The variables in Equation 3.1 represent n_c number of modules, n_n number of rows in DSM, cl_i size of module, w weight of view importance, S_1 is number of cells in a module in DSM, and S_2 is the number of cells in between modules in DSM [174]. YuTian and his team's approach uses a logistic transformation making the data more manageable to calculate [175,176]. While no bounds exist for the value that is calculated from the equation 3.1, a more modular architecture will result in a smaller value for description length. The type I mismatch should be substantially larger in value than type II mismatch [171]. For the purpose of this analysis the author will look at each of the MDL calculated for the overall model to make a determination on degree of modularity.

Table 3.2: Weighted Ranking Structure to Determine

Score	Definitions
10	Highest possible order of affirmation for the Model and DoDAF View is much more important than the other
8	Strongly Important and is absolutely more important that other DoDAF Views
6	The DoDAF View is more important that another DoDAF View
4	The DoDAF View is slightly more important than another DoDAF View
2	The DoDAF View is not practically important
9,7,5,3,1	Intermediate values between two adjacent judgments

Furthermore, the author will use pairwise weighting for each DoDAF view importance, meaning analyst should compare each DoDAF view with the rest of the group and give a preferential level to the DoDAF view [177, 178]. The preference level would be one if the DoDAF view in question is equally significant to that of the second DoDAF view. If the preference level were much more significant, its preference level would be 10. After all of the comparisons have been completed and the favored levels have been determined, the data will be combined together and normalized. The weights for each DoDAF view are derived from the findings and shown in Table 3.3. If you're comparing one DoDAF view with another, you may use Table 3.2 as a reference to determine which DoDAF view deserves a preferable level score. The weights of each DoDAF view were utilized to determine the relevance of each of the associated clusters of relationships in the data set under consideration. This was advocated by the YuTian team as a method of adjusting the modularity measure within the limits of the MDS. The weights were applied to each cluster in order to understand how each cluster was weighted during the summing of all clusters for modularity calculation in Chapters 4 and 5. As a result of the fact that certain DoDAF views include more significant information than other views, this method was adopted.

Based on Figure 3.1, which would be in alignment with the Minimum Description Length (MDL), each case study will be used as a means to quantify degree of modularity for architectures. DSMs are easy to build within MBSE tools for the selected analysis methods and are often referred to as relationship matrix or dependency matrix [179]. Figure 3.4 shows an illustrated example of what Modularity DSM evaluation template exists in the conceptual framework. The example shows two containers or packages of elements in DoDAF CONOP *viewpoints* and the interconnected relationships between the DoDAF elements. A *viewpoint* in this context is an arbitrary

Table 3.3: DoDAF View Weights of Importance

DoDAF Views Weight Table												
		OV-1	**CV-2**	**OV-2**	**SV-1**	**DIV-1**	**OV-5**	**SV-4**	**DIV-2**	**CV-1**	**Total**	**Weights**
DoDAF Views	**OV-1**	1.00	0.25	0.13	0.17	0.25	0.13	0.14	0.20	0.50	2.76	0.014
	CV-2	4.00	1.00	0.13	0.20	6.00	7.00	7.00	1.00	2.00	28.33	0.148
	OV-2	8.00	8.00	1.00	3.00	8.00	7.00	6.00	4.00	2.00	47.01	0.246
	SV-1	6.00	5.00	0.33	1.00	2.00	4.00	1.00	5.00	4.00	28.33	0.148
	DIV-1	4.00	0.17	0.13	0.50	1.00	0.25	0.20	0.33	2.00	8.58	0.045
	OV-5	8.00	0.14	0.14	0.25	4.00	1.00	3.00	6.00	8.00	30.54	0.160
	SV-4	7.00	0.14	0.17	1.00	5.00	0.33	1.00	4.00	7.00	25.64	0.134
	DIV-2	5.00	1.00	0.25	0.20	3.00	0.17	0.25	1.00	4.00	14.87	0.078
	CV-1	2.00	0.50	0.50	0.25	0.50	0.13	0.14	0.25	1.00	5.27	0.028
										Total	191.31	

collection point for elements within a model for ease of data organizational management [4, 180]. *Views* are the contextual technical view of system design data presented under DoDAF CONOPs specific areas of the architecture such as OV-1, SV-4, or CV-5 and are discussed in Section 2.1.3 DoDAF Viewpoints and Views of Chapter 2 [4].

It is the next step to organize the related data into clustering sites in order to better understand how data is included inside model modules using the MDS. An example of how this was done is on a dependency matrix is shown in Figure 3.3.

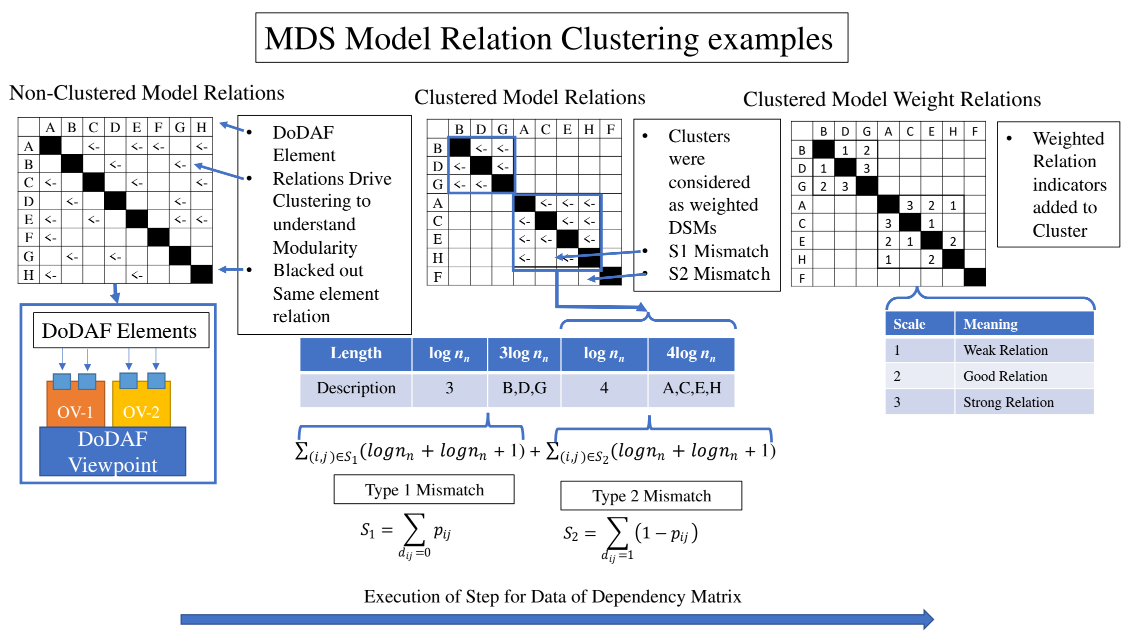

Figure 3.3: DoDAF CONOP Modularity Clustering Approach

The first grid in Figure 3.3, shows what a general dependency matrix in the Cameo and is random and non-clustered. In the concept of DoDAF views, the modules or the individual letters communicate data elements independent of element type. The box in the lower left corner shows the viewpoint with views as the orange and yellow boxes, the little blue boxes are the individual elements on that view. The "$\nearrow$" in the grid indicates a relation between the elements from column to row. The black squares indicate an element in a relation with itself and are not counted or addressed. In the second grid in Figure 3.3, shows the relations clustered in groups with blue squares around the identified clusters. The clusters dictate the table just below the second grid and show how these values will map into the equation shown just below the table. Equation 3.2 just below the table is the description length for mismatch type I and II.

$$MismatchDescriptionLength = \sum_{(i,j)\in S_1} (\log n_n + \log n_n + 1) + \sum_{(i,j)\in S_2} (\log n_n + \log n_n + 1) \tag{3.2}$$

The S_1 and S_2 variables are the type I and type II mismatch errors. Type I mismatch is for blanks inside of a cluster and Type II mismatch is for blanks outside of a cluster [174]. In the last gird in Figure 3.3, shows the weight of strength of relations between elements in the gird. One concern is that viewpoints are not interconnected and considered separate modules [181].

Another concern with this aspect of quantifying modularity, based on Miller's approach for the functional performance requirements, is the requirement statement volatility. Requirement uncertainty in the development phase of a program can have a huge impact on design [182]. Requirement volatility is where requirement statements change causing flux in the system design process [183]. Volatility in the functional architecture design for the system is critical for aligning the problem space with solution [10]. Mauricio et al. found that research has shown a dependency between the number of system functions and the number of requirements for the system [184, 185]. Specifically, dynamic requirements that are ever changing, would have an impact on how the architecture is instantiated using Miller's method [185]. The National Defense Industrial Association

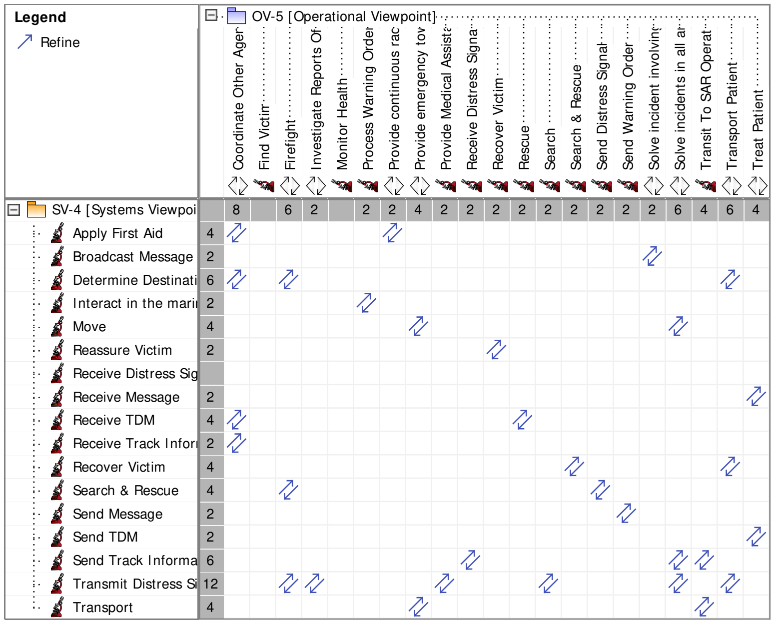

Figure 3.4: Modularity Design Structure Matrix Example

(NDIA) in conjunction with INCOSE and industry leaders developed metrics to address requirement volatility in architectures. The *Functional Architecture Completeness and Volatility* metric is one of the first industry standards that addresses the stabilisation for the functional architecture which is directly impacts the performance requirements statements [10].

Figure 3.5 shows how functional performance requirement volatility plotted over the system life cycle of a system design [10]. System life cycle processes were discussed in Chapter 2 Section 2.1.1 Systems Engineering. The comparison of these standards can be shown in Figure 3.6. The gray diamonds indicate where the major programmatic milestones occur such as SRR, SFR, Preliminary Design Review (PDR), and Critical Design Review (CDR) [7, 8, 21]. The red bracket and dashed line indicate where the CONOPs development and requirements analysis development are conducted [7, 8, 21]. The standards are discussed further in Section 1.2.2 Literary Review analysis in Chapter 1. The indicated blue block shows where volatility change is of most concern for the requirements statement. The illustration points out that the blue line indicates that volatility is not zero at the points of System Requirements Review (SRR) and System Functional Review (SFR).

Even with the understanding of initial customer requirements, some material could change throughout the system design. Completed means, for the purpose of the volatility metric, that the

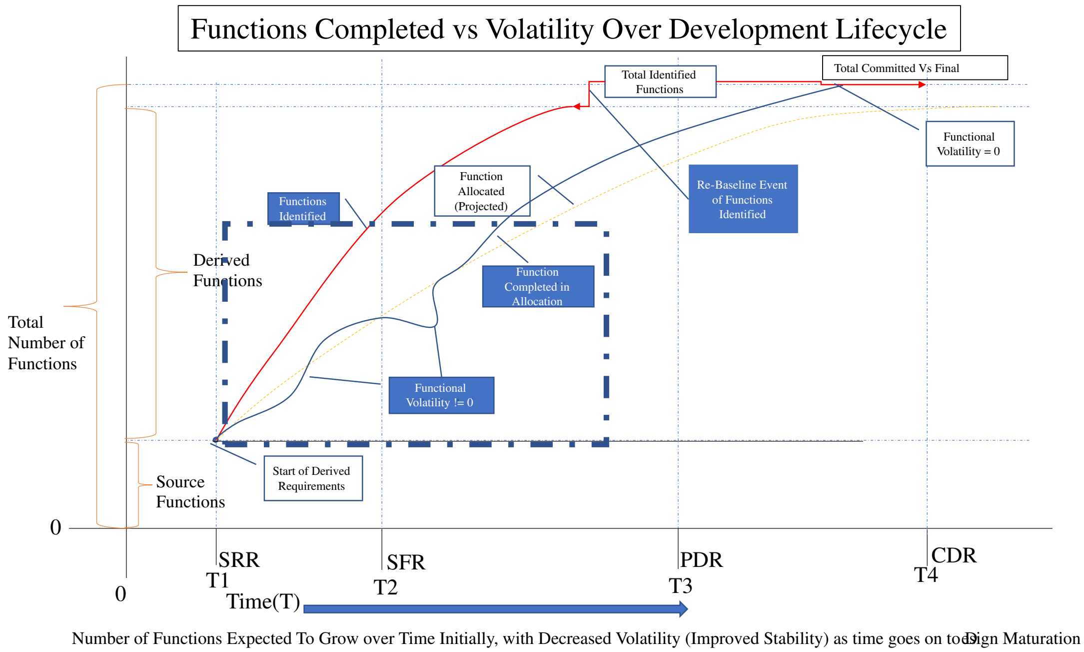

Figure 3.5: Functional Requirement Volatility Over Life-cycle [10]

requirement statement is allocated to a system block, but is stable in what the statement is for functional performance for the system [10]. The fluctuations across the allocation, the orange line, means that DoDAF CONOP element creation would be in flux which would directly effect the modularity of the design as well as growth of the model content.

The author believes that through the QCC factors of *DEQ* and *REQ* for interpretation coupled with degree of modularity calculation, modularity for the DQCF will have sufficient rigor to address the topic.

3.3 Framework Defined Profile

The structure of MBSE uses UML and SysML, which allows for easier management of system data in a data-rich environment and both languages are extendable for additional support [73, 186]. Examples of these profiles and libraries are Unified Profile for DoDAF and MoDAF (UPDM), Business Process Modeling Notation (BPMN), and The Open Group Architecture Framework (TOGAF) [75]. The DoDAF Quality Conceptual Framework (DQCF) contains the DoDAF Quality Analysis Profile (DQAP) and was built using a built-in profiling capability that enabled the

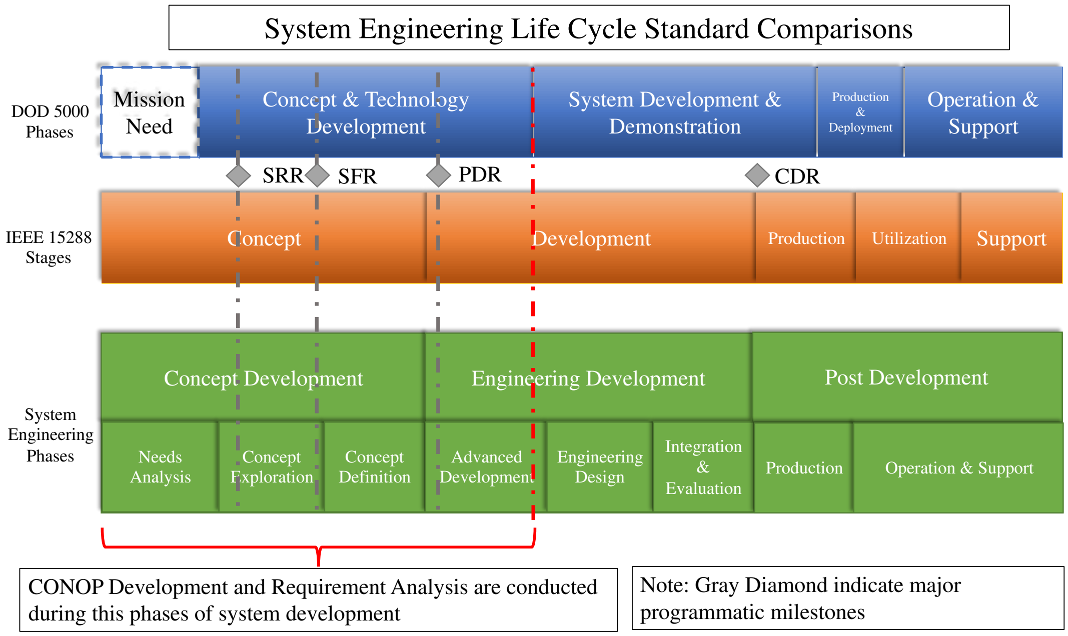

Figure 3.6: Systems Engineering Life-Cycle Standard Comparisons

author to collect and analyze data concepts of the DoDAF elements that were specified in case study models. The use of built in tool capability is a classical modeling language design approach to identifying key concepts to be determined with model based environment [187, 188]. Figure 3.7 shows how the UML and SysML standards relate to the development of the DQAP within the DQCF. The arrows indicate the relations to the components profiles and standards that govern the DQAP profile and the relation to an MBSE tool.

UML is the modeling language that can specify artifacts and is one of the main languages used for describing software intensive systems [58, 186]. The use of UML falls under two approaches to development with profiles according to OMG [58]. The first is based on Domain Specific Language (DSL) which is how a complete new language is developed for use in a model that would be as extensive as UML or SysML [11, 58]. The second is based on particularization of a UML specializing elements or stereotypes with tag definitions with respect to the UML base language [11].

The DoDAF Quality Analysis Profile (DQAP) was built using the second approach and extending the metaclass *«Element»* of uml to create a new characterization to contain tag definitions for the newly developed *«DoDAF Quality View»* stereotype. Figure 3.8 illustrates the DQAP in detail

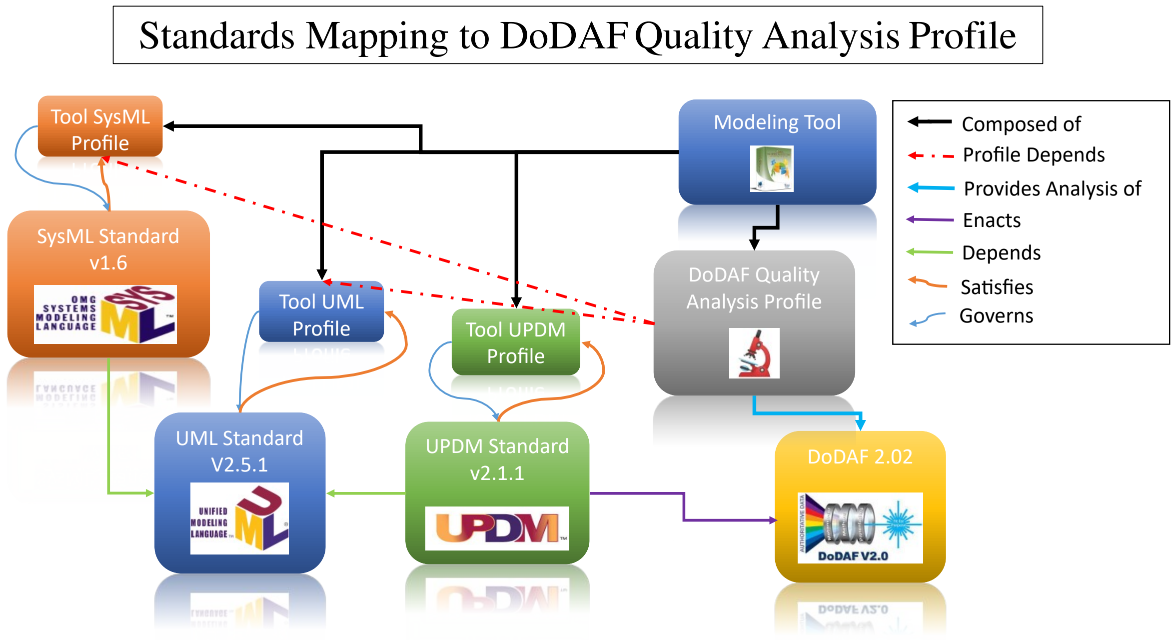

Figure 3.7: DoDAF Quality Analysis Profile Relation to Standard

for the conceptual framework. The *«DoDAF Quality View»* stereotype section shows the *«DoDAF Quality View»* which contains the *«tag definitions»* stereotype properties for the QCC that are defined in Appendix A. The *«DoDAF Quality View»* has a *«generalize»* relation to the metaclass of *«Element»*. As opposed to traditional object models, metaclasses explain the structure and behavior of classes in such a manner that messages may be delivered to classes in the same way that messages are given to individual objects [189]. Metaclass-supporting systems enable data to be organized into an architecture with several abstraction layers by using metaclasses [189]. The metaclass of *«Element»* was selected as the prime candidate for UML metaclass extension due to the fact that the general nature of the metaclass allows it to be applied to any DoDAF architecture element. The *«Element»* metaclass makes the application easy to select elements in the model and apply the stereotype. The *«DoDAF Quality View»* contains a image icon as well for SME recognition so that one can tell the element is under evaluation. The *«Quality Attribute Ranking»* is an *«enumeration»* that allows the *«tag definitions»* stereotype properties to be typed in the DoDAF model architecture. The *«enumeration»* literals directly link the Likert Scale rating approach discussed in Section 2.2.7 of Chapter 2 to the *«tag definitions»* stereotype properties. Once an DoDAF

CONOP architecture element is selected for evaluation, the SME only needs to apply the stereotype to the element. The DoDAF Quality Analysis Data Collection Table is configured and scoped according to the selected *«DoDAF Quality View»* stereotype. The DoDAF Quality Analysis Data Collection Table also collects relative important data from the a selected element. The additional data collected is the Name of the element, the element ID, DoDAF view, DoDAF viewpoint, primary UML metaclass type, and the qualified path to where the element is located in the model. The additional data allows for rapid understanding of what the element is and where the element is located. The *Modularity Design Structure Matrix* can do a large scale comparison of of the various views selected to generate module understanding with relations within the model. Based on the criterion from *Modularity Design Structure Matrix* equation 3.1 can be calculated. Additional details can be extracted from the model based on the data that is collected. The profile design upon application to elements can be extracted through various means. The automated extraction process uses a means of extensible programming language to extract the evaluation data from the model. The data is placed into a more convenient application so that it can be scrubbed and prepared for analysis. The next section will cover the plugin and model integration.

3.4 Framework Plugin and Model Integration

One method of increasing productivity and efficiencies of using MBSE tooling is through development of Extensible Programming Languages (EPL) or Application Programming Interface (API)s to increase integration. EPL or APIs are a means for data to be passed between written programs of the same or different languages [190]. Most often the case for the use of an API, is connecting external libraries, graphical toolkits, database access or operating system calls from another program [190]. Most MBSE tools have purpose built APIs that allow interaction for development or data extraction purposes.

The main MBSE tool that was used for development of the API tools for automation was the Cameo Enterprise Architect tool. The tool selected was based on OMG using the same tool for primary development of all MBSE standards as stated at the beginning of this chapter. While the

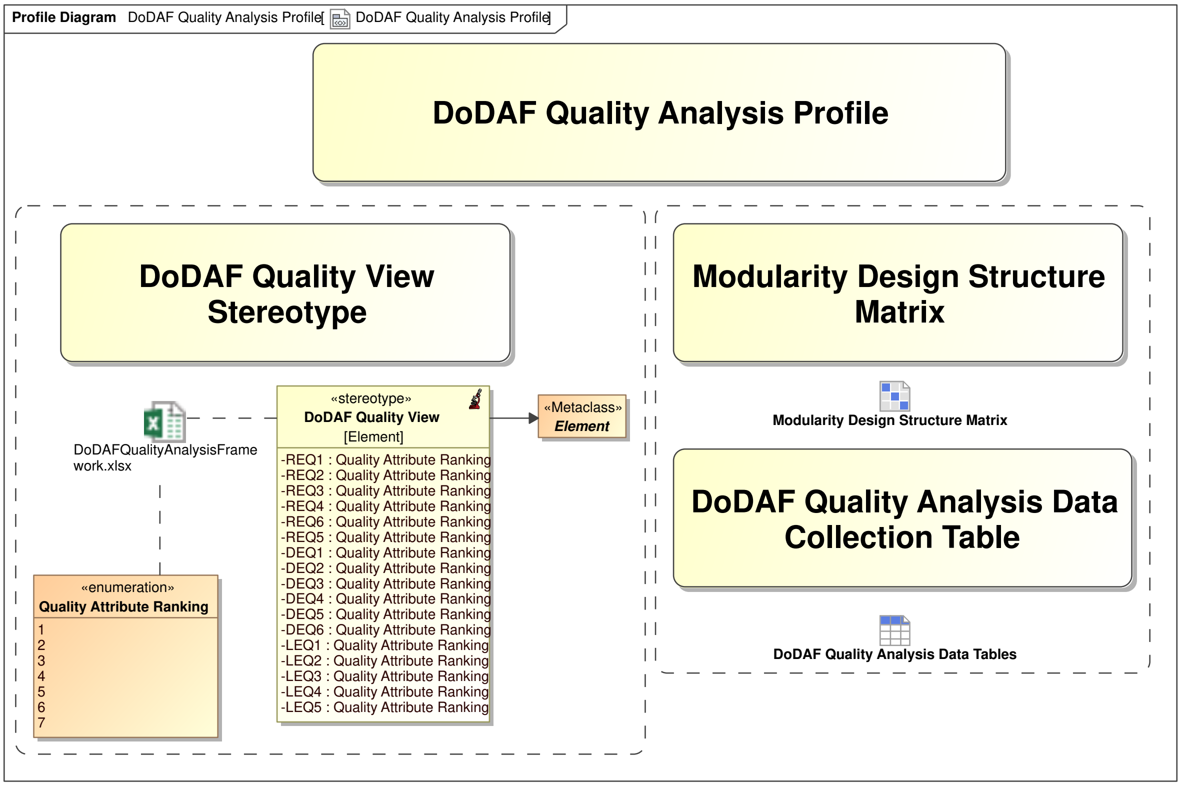

Figure 3.8: Conceptual Framework DoDAF Quality Analysis Profile

tool does allow for internal scripting through multiple various languages such as, m-script, Jython, Maple, Matlab, JavaScript, etc., the author determined it was better for the framework to be able to conduct analysis outside of the primary modeling tool, so internal scripting was abandoned. By conducting analysis outside of the primary modeling tool, processing power and memory are saved on the analysis computer because MBSE tools can be process intensive. Furthermore, extracted analysis data can be sent to another station to conduct analysis without needing the primary tool installed on the analysis computer. The approach also makes the analysis software deployable to multiple systems without relying on additional costly purchase of software.

Plugins developed in the Cameo tool typically follow as particular execution method for enabling new functionality in the MBSE toolset. Figure 3.9 shows the basic plugin execution activity diagram. First, the Cameo tool checks the directory to ensure java library codes exists to enable content. Next, the Cameo tool reads java descriptor files to enable menu updates and checks Graphical User Interface additions. Next, the Cameo tool checks required material for enabling

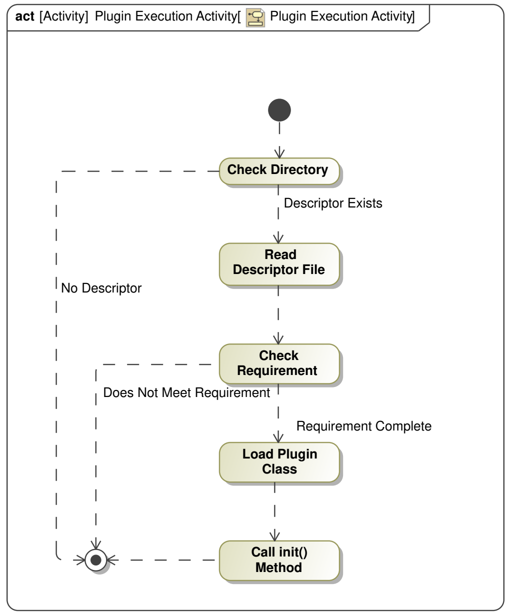

Figure 3.9: Plugin Execution Activity Diagram [11]

the plugin for creation of material. The check could include validation that the correct profile is installed or XML development files are in place for content creation. Next, the Cameo tool loads additional java classes and material areas of development execution for creation of the content. Finally, java methods are called to API content to ensure proper actions are executed when a user attempts to use the plugin menu action buttons. The plugin is available for public use upon the author receiving request for use.

3.5 Framework Application

In Chapter 2, the author discussed theories behind systems engineering that are applicable to the development of DoDAF Quality Conceptual Framework (DQCF). Section 3.5 Framework Application serves as a mean to show the full application of the framework calling specific aspects of the approach from other chapters into a step by step execution. In Chapter 2, the author discussed systems engineering, MBSE, DoDAF views, DoDAF CONOP, and statistical methods. In Chapter 3, the author discussed development method, modularity evaluation, defined profile, and plugin integration. These Chapters and Sections gives foundational theory on the comprehension needed to establish the DQCF. The steps outlined can be executed through the activity automation within the Cameo Enterprise Architecture tool. Figure 3.10 is a capture of that DQCF activity execution. The following outlines the steps in the DQCF application:

1. Use the Logical Model from Section 2.2.1 from Chapter 2 to establish approach to quality aspect.

2. Collect DoDAF CONOP views from the architectural model.

    - For the purpose of this work, the elements selected will be in accordance with the following ten DoDAF CONOPs architecture views: OV-1, OV-2, OV-5a, OV-5b, CV-1, CV-2, DIV-1, DIV-2, SV-1, and SV-4.

3. Collect relevant term and definitions from the architecture model for understand of mission threads.

4. Relate QbD methodology to the DoDAF CONOP architecture to show what material is to be extracted from the model.

    - See Figure 2.6 for the context mapping to extract relative material from model for evaluation.

5. Integrate the DQAP into the architecture model as follows:

    - DQAP plug-in is extracted and installed in the tool's plug-in directory.
    - For an element that needs to be evaluated, apply the the stereotype *«DoDAF Quality View»*
    - Create a generic table as a collection point for the data analysis.
    - Ensure that Table Element type is set to the *«DoDAF Quality View»* stereotype.
    - Ensure that columns for the *«tag definitions»* are set as columns in table.
    - Ensure that scope of the table is set to appropriate *«package»* area.

- Figure 3.11 shows an element with a *«OperationalActivity»* in purple. The stereotypes that are applied to the element are indicated at the top of the purple box. The *«DoDAF Quality View»* icon appears in the right upper corner of the element indicating application.

6. Determine how data will be extracted from the model and collected for analysis.

   - What tools are selected?
     - MBSE tool used for architecture model (e.g., Sparx Enterprise Architecture, Cameo, IBM Rational Rhapsody, SPSS, Excel)
   - What methods are used for inspection?
     - This might include a visual inspection, automated inspection with code base, or spreadsheet tracking
   - Why does the need exist for quality analysis?
     - This includes understanding the customer concerns with model quality, the engineering team's concern for completeness, and the progression of model development.

7. Establish metrics associated with data collection from the model to include the three important aspects from Appendix A: *DEQ*, *LEQ*, and *REQ*.

8. Establish criteria that removes ambiguity from the analysis process as well as identification of a DoDAF Quality Assessment Subject Matter Expert (SME) qualified in SE competencies.

   - Indicate what elements are counted and not counted for evaluation, example would be only elements with GUIDs or only elements in specific area.
   - Figure 3.11 gives and notional example of what the DoDAF Quality Analysis Profile (DQAP) *«DoDAF Quality View»* stereotype looks like when applied to an element in a model. The Specification window displayed to the right of the figure, shows the applied

stereotype section of data. The section indicates that the element is an *«OperationalActivity»* with the *«DoDAF Quality View»* applied for evaluation. The window to the left in the figure shows the *«tag definition»* area of the element and is populated with the *«DoDAF Quality View»* Likert scale data for evaluation of the element.

9. Establish assumptions to explain why data was omitted or included as well as the approach to this analysis.

10. Establish what approach is used to collect data for analysis (i.e., is automation going to be used or an external data collection method).

    - Consider DoDAF Standard application to model elements, UML and SysML appropriately applied for created elements, and requirements justification to instantiate element for the system design.

    - The table in Figure 3.11 indicates that the element is collected into DoDAF Quality Analysis Data Table. The first column in the table is the Element ID or Globally Unique Identifier (GUID) for the element generated once the element is created in the model. The GUID is critical because it ensures the model element is unique to the architecture, and no other element within the same architecture can have the same one. The GUID would most likely be the best means for identification of model information that reduces the risk of data manipulation [191]. This concept is different within different tools (Cameo Enterprise Architecture calls it the Element ID, and Sparx Enterprise Architecture calls it the Universally Unique Identifier). The second column in the table is the Name of the element. The last columns are the QCC for the element in the model. If all of these criteria in the table are present for an element, the element is considered to be under evaluation for quality.

    - The score data using the seven-point Likert scale is applied through the *«tag Definitions»* for each element that is evaluated.

- The data object is generated and in each consecutive element evaluation, the table is populated with data shown at the bottom of Figure 3.11.

11. Describe element sampling approach the architecture model to determine what elements are included in the subsequent analyses.

    - Include percentage of total elements evaluated from the model or break down by number of elements per DoDAF View

12. Establish that the selected statistical approaches are appropriate for use on the collected data. The analysis in this work was conducted using IBM Statistical Package for the Social Sciences (SPSS) Version 26. SPSS was used as a supplement material to ensure calculation and resultants were correct. Additional statistical analysis tools that might be used include R, SPSS, Matlab, or Excel. (i.e., perform checks to ensure the validity of the statistical methods). The analysis is conducted on the data object table using the following statistical methods:

    - Determine Mean vs Median and descriptives
    - Determine Skewness and Kurtosis check
    - Determine Kolmogorov-Smirnov or Shapiro-Wilk Test
    - Multicollinearity
      - Determine Linear Regression
      - Determine Variance Inflation Factor (VIF)
      - Spearman's ρ
    - Principle Component Analysis
      - Covariance matrix
      - Determine Kaizer-Meyer-Olkin (KMO) test for sample adequacy
      - Determine Bartlett's Test

- Determine Ordinal Logistical Regression for factor examination

13. Perform a preliminary check of statistical results.

14. Establish Design Structure Matrix (DSM) of modular data aspects to determine degree of modularity.

    - Determine weight of importance of views, a pairwise comparison can be done for this and weight injected during the summation cluster cl_i calculation.
    - Create the DSM data object for use in the modularity calculation.
        - Ensure that Matrix Element types for rows are set to the *«DoDAF Quality View»* Stereotype.
        - Ensure that columns for the DoDAF element types by DoDAF viewpoint.
        - Ensure that scope of the matrix is set to appropriate *«package»* area.
        - Ensure that the relationship type is set to the correct type.
        - The matrix will be responsible for populating the data variables needed.
    - MDL is calculated using an adapted version of YuTian's equation for MDL to quantify modularity in an architecture model see Equation 3.1. While no bounds exist for MDL, a "more modular" architecture will result in a smaller value. Typically, approaches to modularity equations use a Design Structure Matrix (DSM) to understand the relationship between elements in a model [171, 173]. The Hölttä-Otto paper outlines the best performance modular equation to use in order to detect modularity which based on the data would suggest the best approach when DoDAF architecture structure views are considered as individual modules [171].
    - Assess the degree of modularity based on these results—is the system considered more modular/less integrated or less modular/more integrated?

- Note: The degree of modularity assessment is used in order to grasp functional reusability and complexity understanding of architecture aspects for development of system design.

15. Interpret the statistical data, determine degree of modularity, and make final quality determination

    - The final step to include analysis of the statistical methods and MDL for interpretation of the model content. The final step in the analysis will be to transform the final mean values for *DEQ*, *LEQ*, and *REQ* in to an overall rating for quality of the model. The quality rating scale is as follows:
      - *1 = "Very Poor"*
      - *2 = "Poor"*
      - *3 = "Acceptable"*
      - *4 = "Good"*
      - *5 = "Very Good"*

      A simple linear transformation is used to transform the seven-point scale in Appendix A to this five-point scale. Each mean value for the factors will be transformed and given an individual score rating for each category, the average of the three scores will be used as the overall model quality score.

Figure 3.11 gives and notional example of what the DQAP *«DoDAF Quality View»* Stereotype looks like when applied to an element in a model. The element is an *«OperationalActivity»* in purple. The stereotypes that are applied to the element are indicated at the top of the purple box. The *«DoDAF Quality View»* icon appears a the right upper corner of the element indicating application. The Specification window displayed to the right of the figure, shows the applied stereotype section of data. The section indicates that the element is an *«OperationalActivity»* with the *«DoDAF Quality View»* applied for evaluation. The window to the left in the figure shows the

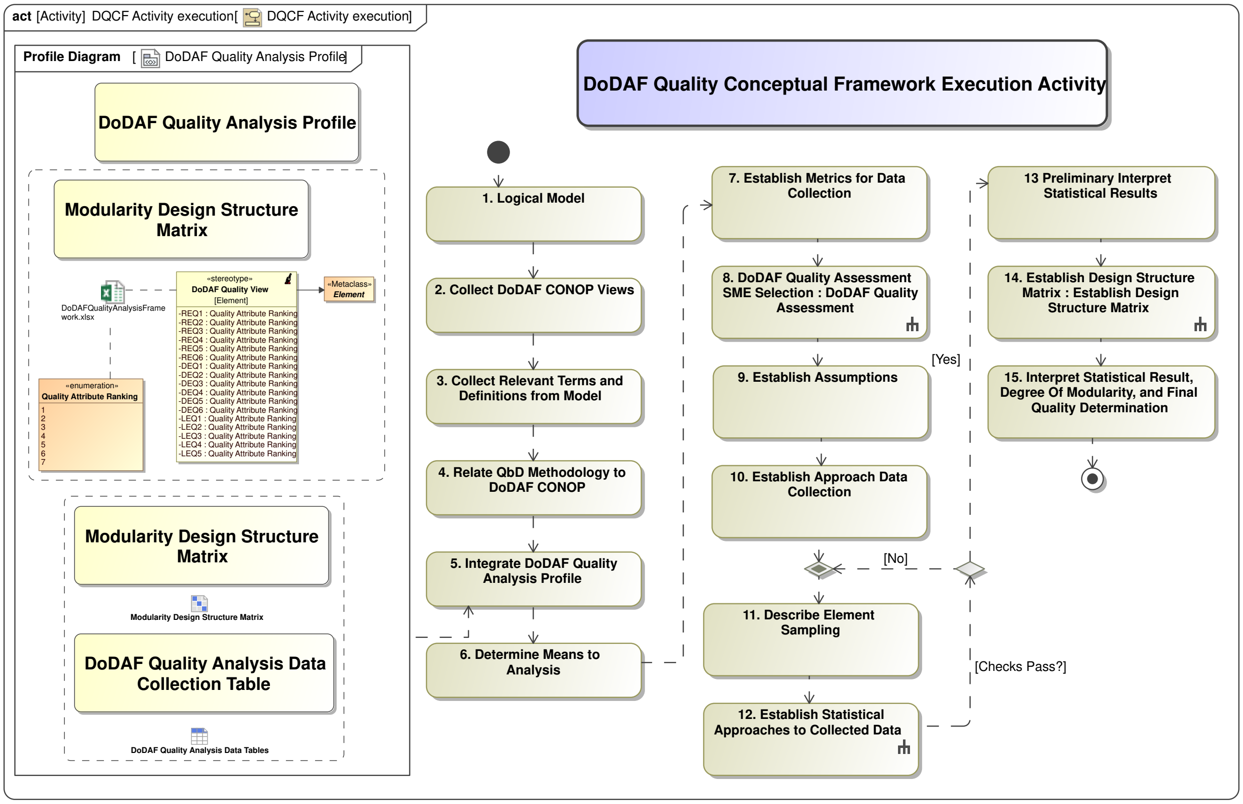

Figure 3.10: DoDAF Quality Conceptual Framework (DQCF) Activity Outline

«tag definition» area of the element and is populated with the *«DoDAF Quality View»* Likert scale data for evaluation of the element.

The table at the bottom for the figure indicates that the element is collected into the DoDAF Quality Analysis Data Table in the model. The first column in the table is the Element ID or Globally Unique Identifier (GUID) for the element that is generated once the element is created in the model. The element ID or GUID is critical in the fact the ensures the model element is unique to the architecture and not other element within the same architecture can have the same one. Within different tools is refereed to as different things, within Cameo Enterprise Architecture is called the Element ID and Sparx Enterprise Architecture is called the Universally Unique Identifier (UUID). The UUID would most likely be the best means for identification of model information that should be transferred to research systems and reduces risk of data manipulation [191]. The second column in the table is the Name of the element. The third column in the table is Qualified Name of the element. The Qualified Name is simply a path within the containment tree used to

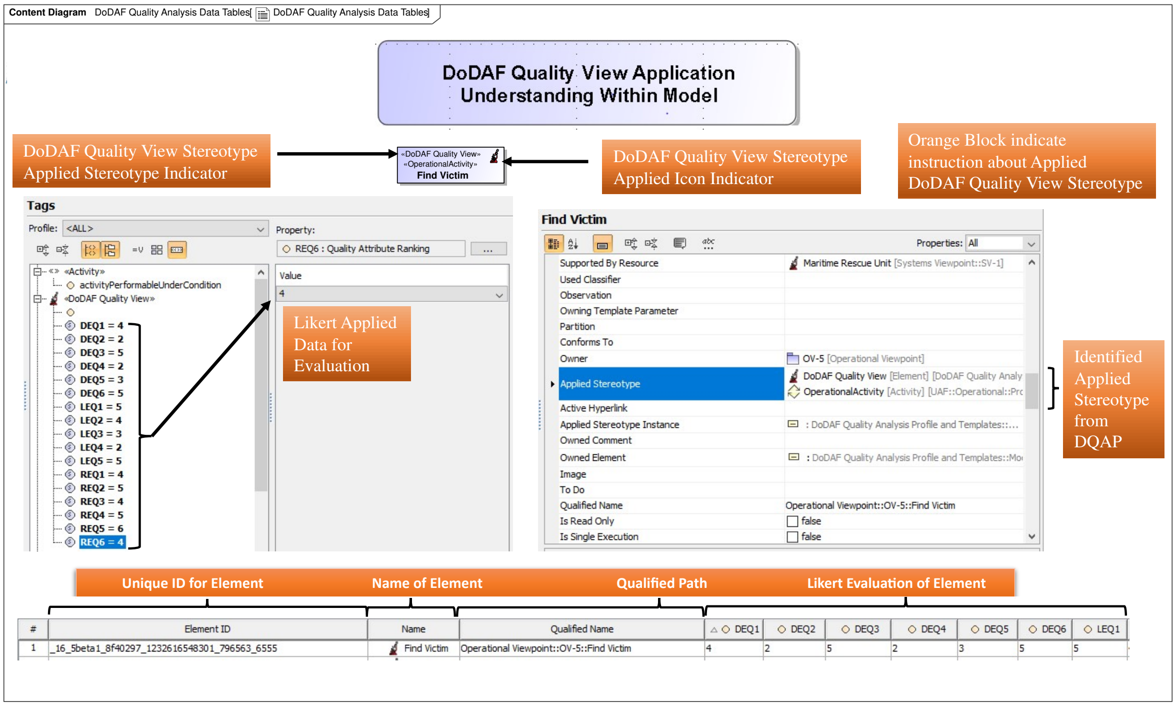

Figure 3.11: DoDAF Quality Analysis Profile Applied Example

locate the element in the model. The last columns are the Quality Characteristic Categories (QCC) for the element in the model. If all of these criteria in the table are present for an element, the element is considered to be under evaluation for quality.

3.6 Framework Complete Roll-up

The theory discussed in this Chapter lays the foundational information to understand the application of the DQCF. The consolidation of a methodical approach to the content provides a demonstrated advancement to evaluation capability to determine the quality of a DoDAF CONOP architecture. The conceptualization of all factors that would effect the understanding of the quality of a model are captured and provided as evaluation criterion QCC for each element in the DoDAF CONOP architecture. The design of the plug-in for data extraction, ingestion into IBM SPSS, and selected statistical methods, outlined in Chapter 2 applied to analyze the data to provide meaningful results constitutes the instrumentation design of the DQCF. Finally, The application of the

DQCF to case study models in Chapter 4 and 5 will provide real world empirical resultant data for the DQCF.

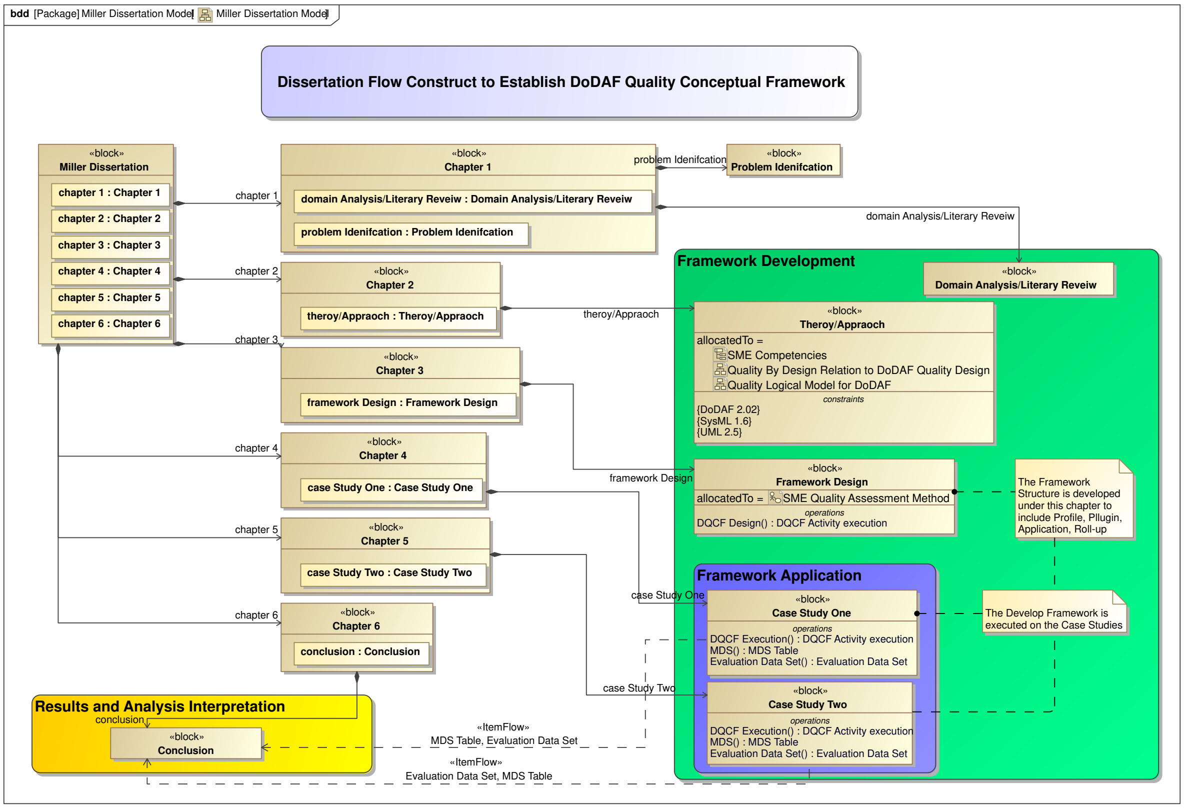

Figure 3.12: Dissertation Outline to Formulate DoDAF Quality Conceptual Framework Development

Through the various concepts and methodical approaches described above, the execution of the DQCF approach to the QbD analysis of a DoDAF CONOP architecture meets the basis of Tonnette's and Merriam definition for a conceptual framework [153, 154]. Figure 3.12 shows the Chapters design to establish DQCF. The green area represents the development of the DQCF framework. The blue area represents the application phase of the DQCF for generation of results. The orange area is the conclusion analysis were the interpretation will occur for the case studies analysis. The *«ItemFlow»*s coming into the conclusion are the data *«object»* from the executed *«operation»* generated by the DQCF *«activity»* in the case study *«block»*. The *«activity»* execution in Figure 3.10 becomes the *«operation»* within the *«block»*s for each case study or what the framework must "do".

The final step in the analysis is to transform the final mean values for *DEQ*, *LEQ*, and *REQ* in to an overall rating for quality of the model. The execution of doing this step will quantify the overall ratings of each variable providing insight of the coherent design of the system model as well as application of standards. Specifically, the variable's rating can provide insight into sensitivities of the system design that could be used to identify risks to the system design. In general, programs will aim to reduce compliance risks, mitigate hazard risks, manage control risks, and seize opportunity's risks as much as they possibly can [192]. It is crucial to highlight; however, there is no 'correct' or 'wrong' way to divide risks into categories [192]. It is likely more typical to see risks categorized into two categories: pure and speculative. Whatever the theoretical debates, the most essential thing is that an organization choose the risk categorization system that is most appropriate for its particular set of circumstances. It is possible that some risk occurrences will only have negative consequences. These risks are classified as hazard risks or pure risks, and they may be classified as either operational risks or insurable risks. In general, programs will have a tolerance for hazard risks, and these risks must be controlled within the limits of what the program or project is willing to accept as acceptable. Aside from these risks, there are additional factors that contribute to uncertainty regarding the outcome of a scenario [192]. These are referred to as control risks, and they are commonly encountered in the context of project management. Uncertainties may be linked with the advantages that the project delivers, as well as with the project's ability to be completed on time, within budget, and according to specifications [192]. It is common for the management of control risks to be implemented in order to guarantee that the result of business operations fits within a specified range [192]. Ultimately, the goal is to identify and address the sensitivity through possible mitigations presented with the variable quantifications. The author will base the overall quality rating on a five point scale system, five being Very Good to one being Very Poor. The rating scale is as follows:

1. *"= Very Poor"*

2. *"= Poor"*

3. *"= Acceptable"*

4. *“= Good”*

5. *“= Very Good”*

Equation 3.3 is used to do the transformation of the average calculated from the mean values from the seven point scale to five point scale. Each mean value will be transformed and and given an individual score rating for each category, the average of the three scores will be used as the overall model quality score.

$$Y_5 = (X_7 - 1)\left(\frac{4}{6}\right) + 1 \tag{3.3}$$

In Chapter 4 and 5, the DQCF application will generate results for detailed interpretation. The resultant interpretation will meet the goals of addressing problems discussed in Chapter 1 advancing knowledge about QbD into DoDAF CONOP architecture quality.

Chapter 4

Joint Polar Satellite System Case Study

The first case study is the National Oceanic and Atmospheric Administration (NOAA)/ National Aeronautics and Space Administration (NASA) Joint Polar Satellite System (JPSS) DoDAF CONOP architecture with focus on the Stored Mission Data (SMD) mission thread. The most current open source versions of Joint Polar Satellite System (JPSS) DoDAF architectural model and JPSS documentation were used to assist the author in context capture, DoDAF Quality Conceptual Framework (DQCF) application, illustration, and analysis for the case study. The JPSS is a next-generation earth observation program that collects and communicates global environmental data via polar-orbiting satellites [193]. The primary mission of the JPSS system is to understand/predict changes in weather, climate, oceans, coasts, and space environment [193]. The first satellite Suomi National Polar-orbiting Partnership (S-NPP) was launched in October 2011 with the additional launch of JPSS-1 in 2017 [193]. JPSS-2 was delayed in 2021 to a future unknown date [194]. Additional missions are planned for JPSS-3 and JPSS-4 to extend the life-cycle of the JPSS system out to 2038 [193]. The DoDAF, UML, and SysML stereotypes will be presented with guillemets «» to indicate a model element specific language.

4.1 CONOP for JPSS

The JPSS DoDAF CONOP purpose is to communicate system functional and operational information that will accomplish the system mission under normal operating conditions [193]. The model-based JPSS system deign not only covers planned operations but include many cases that directly identify the requirements for the system as well as core components [193].

Figure 4.1 shows the high level OV-1 for the JPSS System. Several acronyms are present in the diagram specific for the JPSS system. For further context, details on the definitions of these acronyms, see Appendix B, the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Acronyms List. Figure 4.1 provides a description for the DoDAF Operational View

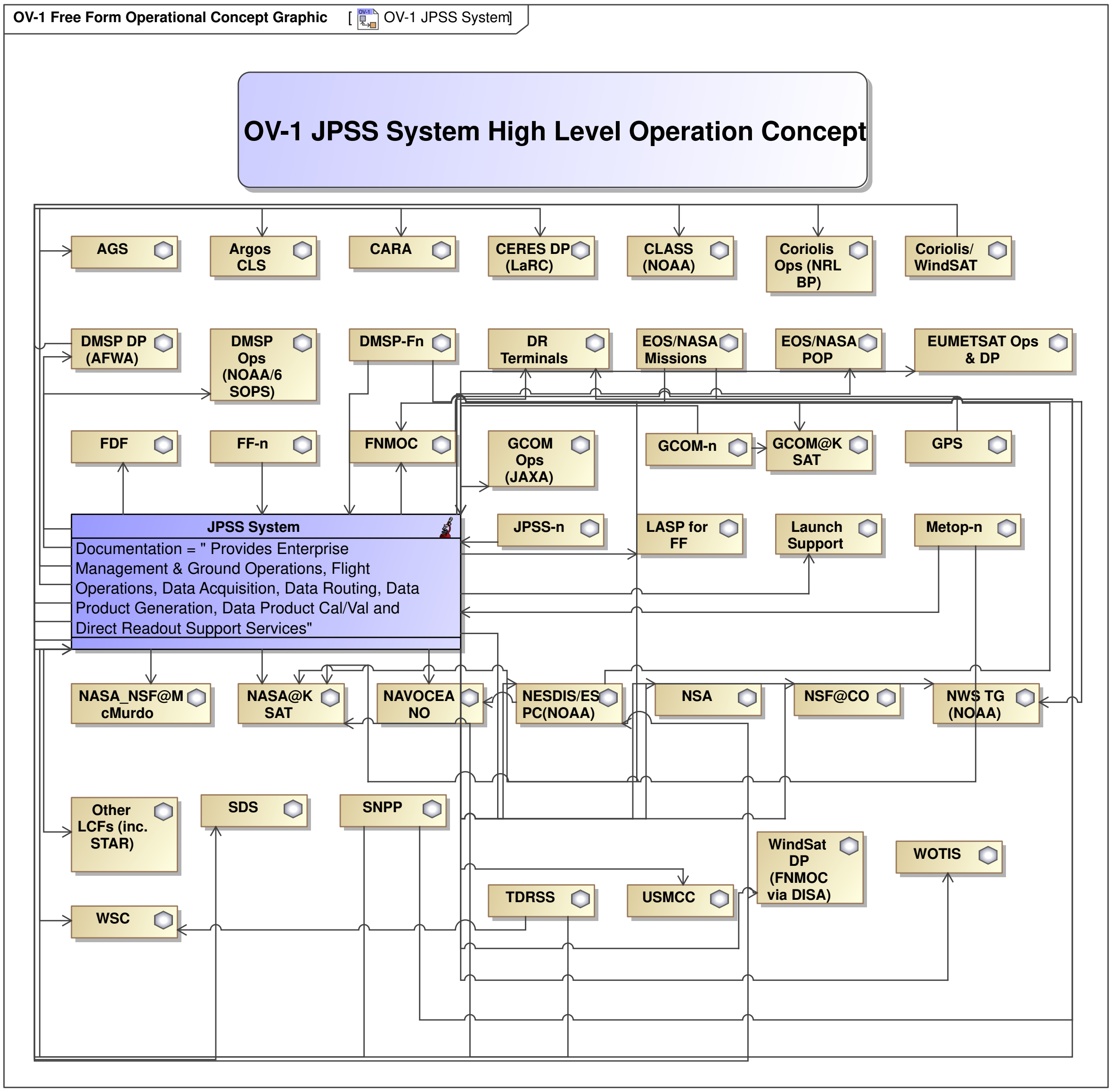

Figure 4.1: Joint Polar Satellite System (JPSS) DoDAF Operational View OV-1

OV-1 for the operational concept of the JPSS. Figure 4.1 shows images of the corresponding missions, activities, organizations, and high-level operations of the JPSS system [195]. The legend at the bottom of the image includes details about the relations between architecture aspects or *«OperationalPerformers»* and what data is being transmitted [196]. Note that the image reflects the space operational environment and some characteristics under which the JPSS will conduct its functionality [197]. The orange circle in the middle represents the JPSS with interfaces to external systems and data exchanges [198]. The OV-1 presents information that provides links from *«Operational-*

Resources» on the Operational Resource Flow OV-2 diagram to the *«OperationalPerformers»* for the JPSS system architecture.

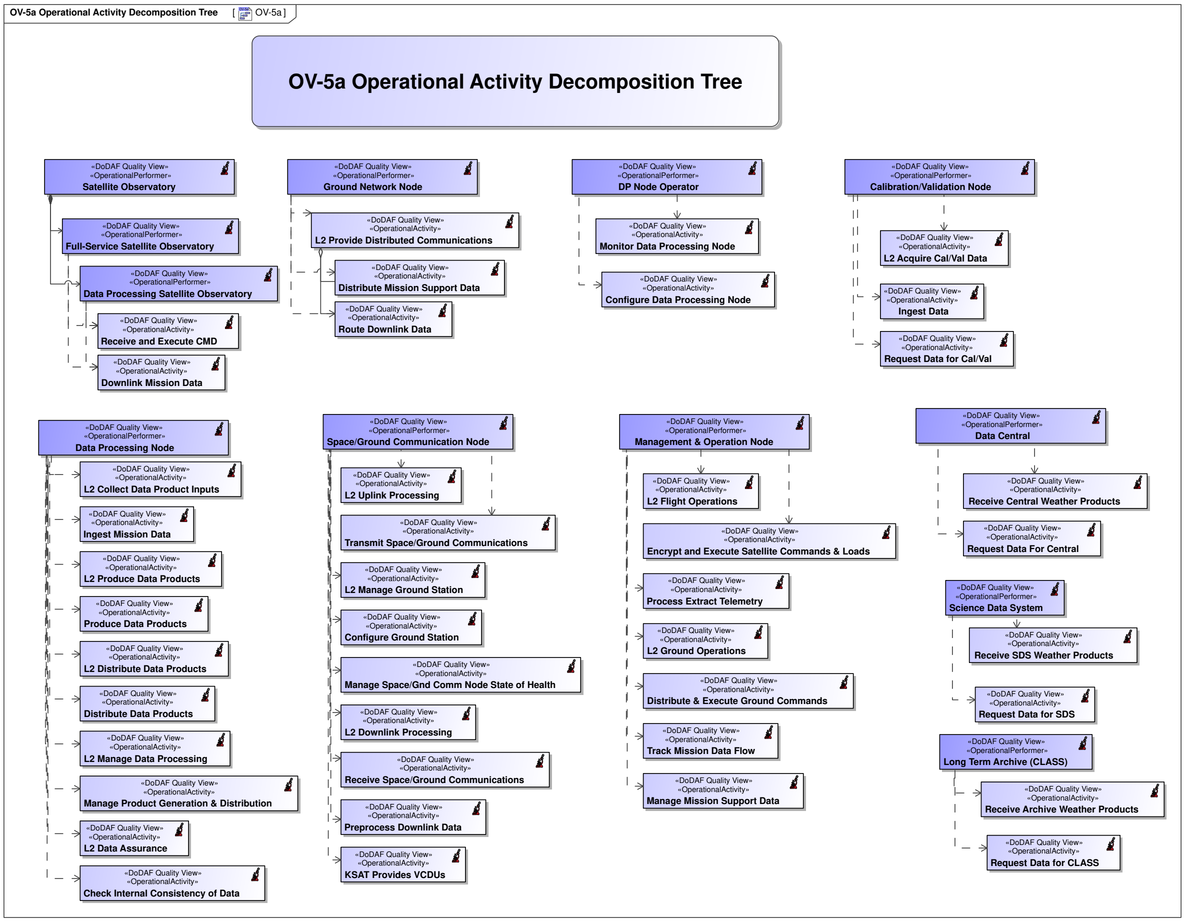

Figure 4.2: Joint Polar Satellite System (JPSS) DoDAF Operational View OV-2/OV-5a Combined

Figure 4.2 shows the *«OperationalPerformers»* as well a the hierarchy of the relations between each of the *«OperationalPerformers»*. The critical aspect of the OV-2 is to describe "who or what" will be *«OperationalPerformers»* in the JPSS system design [4]. The Operational Activity Decomposition Tree or OV-5a shows a structured aspect to the *«OperationalActivities»* and gives a representational hierarchy to the developed *«OperationalActivities»* addressing the *«Capabilities»* the system must perform with general aspects at the top of diagram and more specific as the tiers are descended on the diagram [4]. Furthermore, *«OperationalActivities»* can provide logical interaction information of actions between *«OperationalPerformers»* [4]. The *«OperationalActivities»* exchanges within an Operational Activity model or OV-5b and can be seen in Appendix B JPSS OV-5b Operational View SMD Figure B.1.

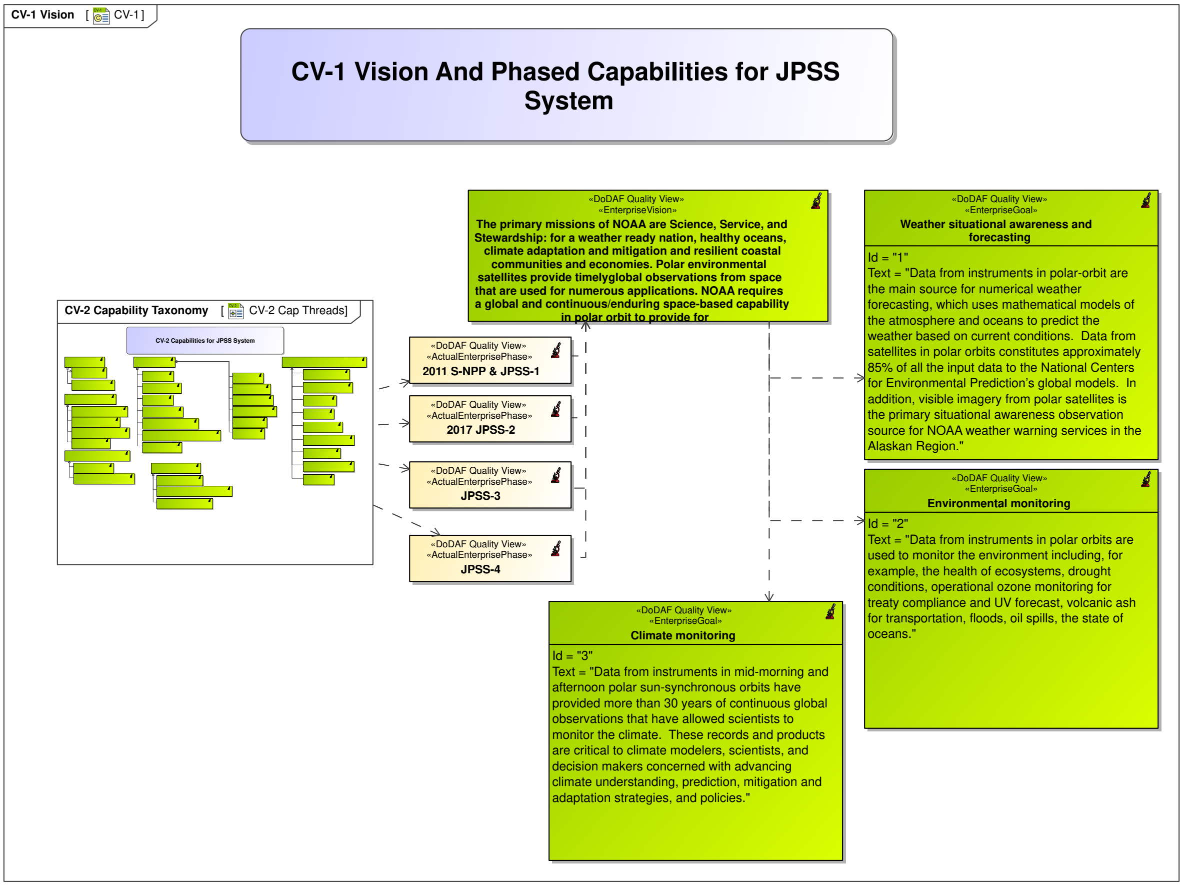

Figure 4.3: Joint Polar Satellite System (JPSS) DoDAF Capability View CV-1

The textual data present on the diagram helps to describe what data is being conveyed between elements in order to accomplished the JPSS system mission [4]. The OV-1 textual context linkage to accomplish the mission is described through the JPSS DoDAF Capability View CV-1 shown in Figure 4.3. The CV-1 documents the *«EnterpriseVision»* or mission statement for the JPSS system with high level *«EnterpriseGoals»* the system must accomplished [199]. Illustrated in Figure 4.3, is the phased implementation of the JPSS system *«capabilities»* and a timeline to which satellites will come online for the system. The CV-1 gives strategic context for a group of *«capabilities»* for the architecture by capturing the vision through bounded period of time or *«Ac-*

tualEnterprisePhase» [4]. The CV-1 tells planners when *«capabilities»* can be expected to be met for system lifecycle as well as showing future transformation and new *«capabilities»* of the system. The phased implementation of *«ActualEnterprisePhase»* linkage to the JPSS DoDAF Capability Taxonomy or CV-2, gives timing to phased *«capabilities»* for the system allowing for all aspects system lifecycle planning to occur [4]. Figure 4.4 shows the *«capabilities»* of the JPSS system at an abstract level. The abstract level of the CV-2 is designed to drive needs for the *«capabilities»* without prescribing a solution to the provided the *«capabilities»* [4]. Figure 4.4 shows a structured aspect to the CV-2 giving a hierarchy to the developed *«capabilities»* with general aspects at the top of the diagram and more specific as the tiers are descended on the diagram. The *«capabilities»* will be referenced in the *«OperationalActivities»* or Systems Functional Flow, bringing the system behavior to address the *«capabilities»* needed as well as interconnections of data for the JPSS system [4]. The interconnection of data leads to the capture of the JPSS System Interface Description or SV-1. Figure 4.5 shows the JPSS system SV-1 diagram.

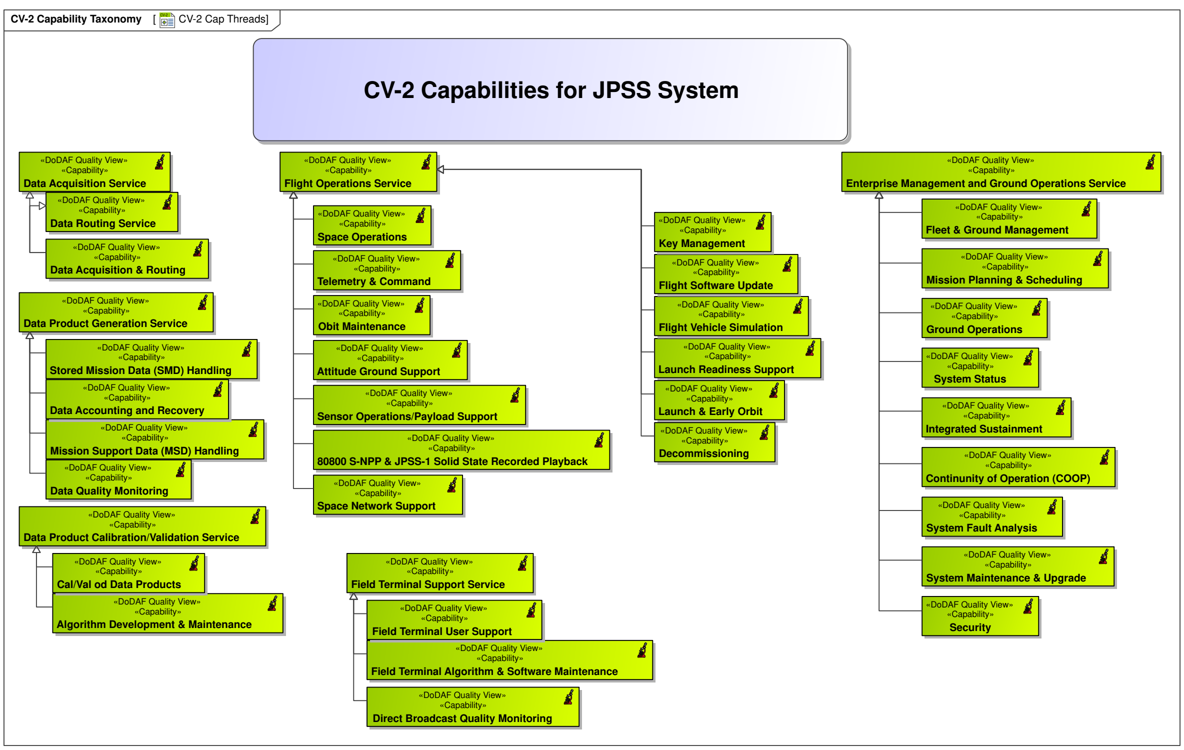

Figure 4.4: Joint Polar Satellite System (JPSS) DoDAF Capability Taxonomy View CV-2

The figure shows the interactions between internal and external *«System»* blocks with directional *«AssociationProperties»* interfacing with data exchanges [4]. The *«flowSpecification»* governs the format and represent the Interface Control Documents (ICD) that prescribe how the *«System»* blocks or actual system will communicate [4]. The represented *«Post»* shows human interface component to the JPSS system and what information is passed to the representative displays a human user would see when the JPSS system is in operation. The interactions described in the SV-1 bring the operational and system architecture to specify the logical architecture from the OV-2 [4]. When designing a system, the logical architecture outlines functional groups, selects particular logical components to implement functional architectures, and reflects the connection linkages and data interface links between logical components [200]. The logical architecture also describes how the logical scheme of the system, including logical non-redundant architecture and logical redundant architecture, is formed using BDDs and IBDs. It shows how the mapped relationship between functional architecture and logical architecture without redundancy, as well as between logical architecture with redundancy and functional architecture with redundancy, is established [200]. The grouping of elements in the SV-1 bring the *«capabilities»* and *«OperationalPerformers»* to meet a specific capability. The figure shows both hardware and understanding for software combined to address human interfaces for the JPSS system [4]. The complimentary representation with the actual *«Function»* exchanges within an System Functionality Description model or SV-4 and can be seen in Appendix B JPSS SV-4 System View SMD Figures B.2.

The final view of the JPSS DoDAF CONOP views is the Conceptual Data Model or DIV-1. Figure 4.6 shows the conceptual data which shows information for requirements and rules that manage or constrain the JPSS system design [201]. The Conceptual Data Model or DIV-1 provides factual grounding for concepts, associations, and attributes that are used to govern the design process from business to technical standards [4]. The items captured here are part of the data model. These tie data of technical nature to the architecture concept [4]. The DIV-1 bridges the gap to bring the logical and physical data together [4]. The DIV-2 relates information in an

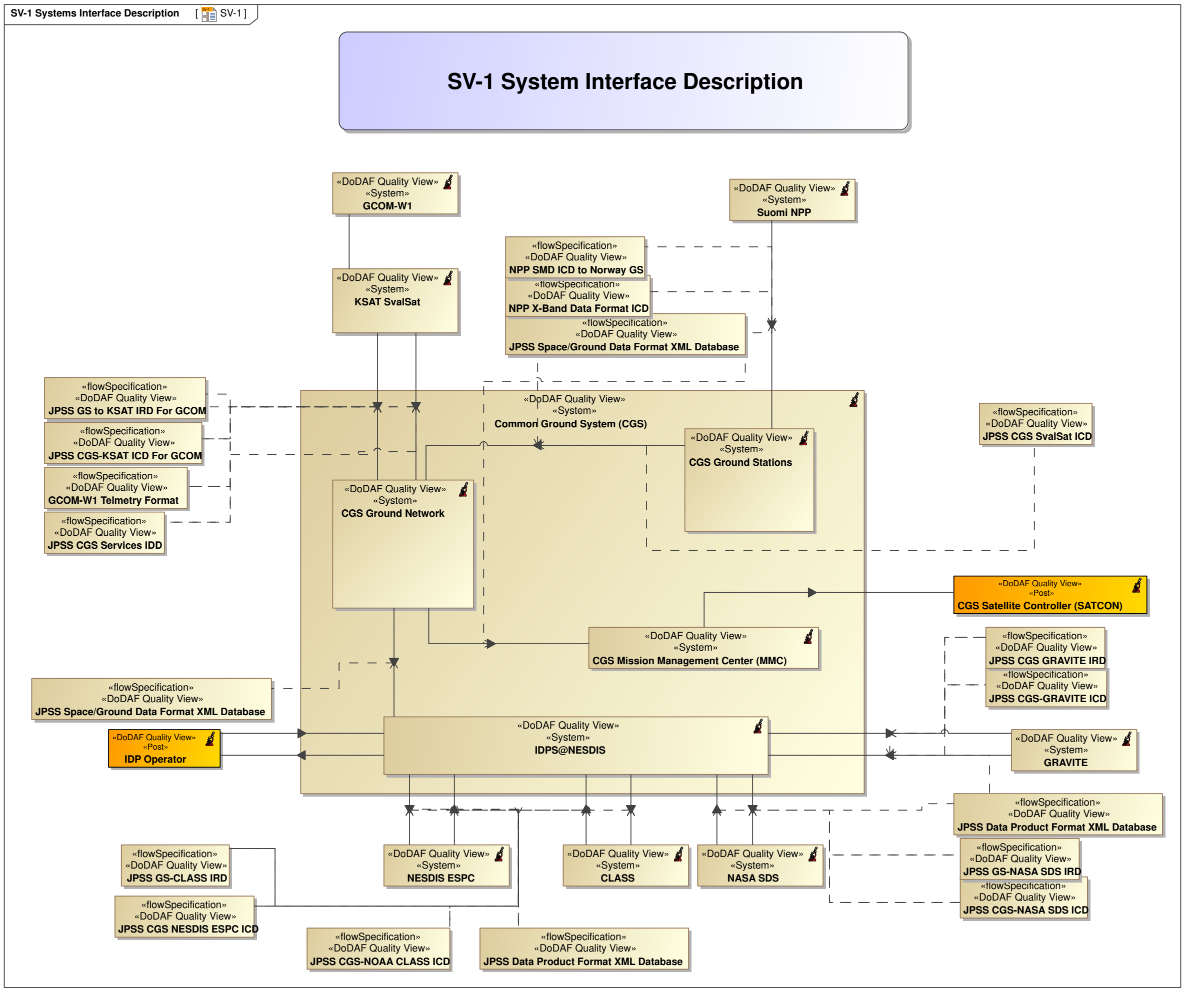

Figure 4.5: Joint Polar Satellite System (JPSS) DoDAF System Interface Description SV-1

OV-1 concept and activity flow objects in an OV-5b [4]. The DIV-2 is not illustrated due to size but the implications can be seen in the OV-5b and SV-4 for the information flows between elements.

The ultimate goal of the DoDAF CONOPs for the JPSS is to illustrate the mission that the system is supposed to accomplish and establish a basis for development of a requirements baseline. For the JPSS system development instance, the MBSE DoDAF architecture was created before the requirements in order to inform the requirements development [202]. The CONOP at a very high level was developed with corresponding capability needs from the customer to support system functionality understanding [203]. The diagrams above show an extensive DoDAF CONOP architecture exist within the developed JPSS DoDAF architecture model. The DoDAF view diagrams illustrate that for a single mission thread in the JPSS system, the SMD mission thread, the JPSS

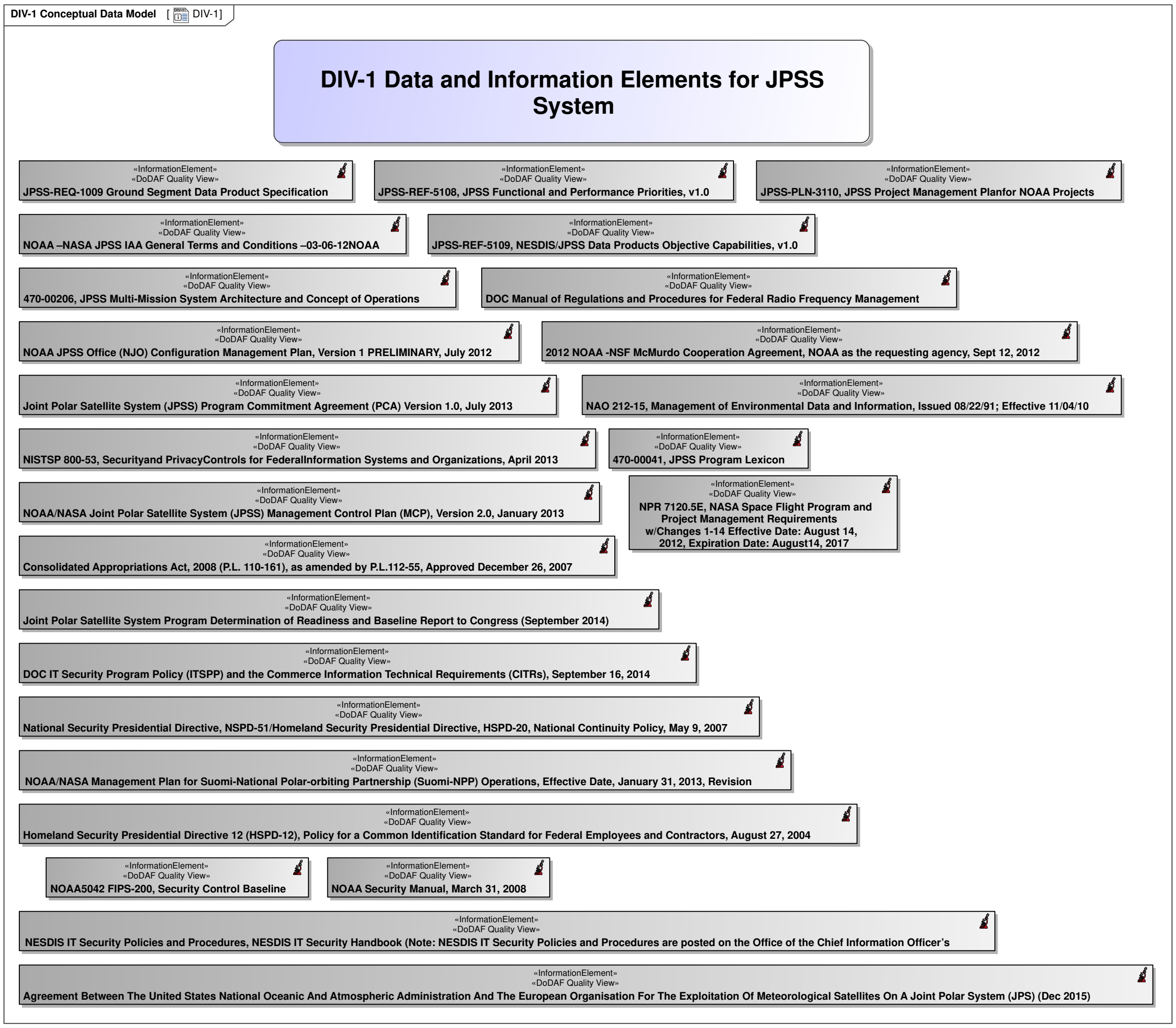

Figure 4.6: Joint Polar Satellite System (JPSS) DoDAF Conceptual Data Model or DIV-1

architectural model covers the approach to CONOP development as laid out in Chapter 2 Section 2.1.3 DoDAF CONOP Design Process. The representative views for the SMD mission thread show some of the following criteria:

- The operational environment and its characteristics [79]
- Major system components and the interconnection among those components [79]
- Interfaces to external systems or procedures [79]
- Capabilities, functions, and features of the current system [79]
- Operational risk factors [79]

- Performance characteristics, such as speed, throughput, volume, frequency [79]
- Provisions for safety, security, privacy, integrity, and continuity of operations in emergencies [4, 79]

4.2 Key JPSS Terms

The JPSS key terms are critical to understand context information that help to identify critical data relating to MBSE, DoDAF, requirement information, and UML/SysML. The JPSS lexicon open source documents helped to provide some of this information as well as data interrogation of the JPSS architectural model. The document acts as an authoritative source for the definition of terms and acronyms that have applicability across the JPSS program in order to maintain consistency of data interpretation [204]. For the purpose of this dissertation, the definitions were pulled from the lexicon documentation that have particular focus on the DoDAF CONOP terminology and association with DoDAF views CV-1, CV-2, DIV-1, DIV-2, OV-1, OV-2, OV-5a, OV-5b, SV-1, and SV-4. The terms are as follows:

- **Capability (Cap):** The proposed system's operational performance parameters, including supportability, are provided to the acquisition community so that they may design it [204]. In this section, you will find Key Performance Parameters (KPP) and additional Technical Performance Measurements (TPM) that assist you through the process of developing, demonstrating, and testing the current increment [204]. Here is an overview of the entire plan for achieving initial and complete capacity development [204].
- **Data Model (DM):** Both a database and its database management system must adhere to the principles of a certain data model in order to function properly [204]. Data models include the hierarchical data model, the network data model, the relational data model, and the object-oriented data model, to name a few. Hierarchical data models are the most common [204]. In software engineering, it is an abstract model that specifies how data is represented and accessible by a computer program or system [204]. The formal definition of

data items and connections among data elements for an area of interest is accomplished via the use of data models [204]. For both business and information technology professionals, a data model is a way-finding tool that employs a set of symbols and text to precisely explain a subset of real information. This helps to improve communication within an organization and ultimately results in an application environment that is more flexible and stable [204]. A data model is a formalized representation of the structure of data or structured data [204]. Communication and accuracy are the two most essential advantages of a data model, and they are why it is so vital for applications that consume and communicate information [204]. It is via the use of a data model that project team members from diverse backgrounds and with varying degrees of expertise may interact with one another and learn from one another [204]. Precision on a data model implies that the words and rules on it can only be construed in a single manner, and are not ambiguous [204]. A data model may also be referred to as a data structure, which is particularly common in the context of computer programming languages [204].

- **Operational Availability (Ao):** 1. The likelihood that a system or piece of equipment, when operated under specified circumstances in an ideal support environment, would perform as intended at all times [204]. 2. The likelihood that the JPSS system will be operationally capable of achieving its KPP, including making the related data products accessible to the JPSS user interface, is expressed as a percentage of the probability [204]. Operations Availability compliance is determined throughout any 30-day period after Operational Handover to NOAA (nominally L+90 days) in order to determine whether the system is operationally available [204]. JPSS spacecraft are expected to function continuously for the duration of their mission after they have reached orbit [204]. Ground system dependability, ground system redundancy, and scheduled observation outages are among the elements that influence availability (Flight system downtime for spacecraft maneuvers, instrument calibration activities, maintenance activities, command loads, and planned ground system sustainment activities) [204]. On-orbit abnormalities or failures, as well as the troubleshooting operations connected with these incidents, are not included in the availability considerations [204].

- **System (Sys):** As an example, an integrated composite of people, goods, and processes such as JPSS has the capacity to meet a stated demand or achieve an established goal [204]. Although the terms system and segment are sometimes used interchangeably, a segment is typically considered to be a substantial subset of a larger system in its own right [204]. To provide an example, there are three or more major segments included inside the GPS (i.e., Space, Ground, User Equipment, and Launch) [204]. Each system and segment is also broken down into and composed of lower level systems, nodes, subsystems, elements, and units that are occasionally organized in a hierarchical or relational fashion, depending on the situation and requirements [204].

While the terminology listed above illustrates the general ideas that represent the DoDAF viewpoints, it is critical to note that not all the terms match in a one to one relationship, meaning DoDAF terms to JPSS terms. The author used interpretation to correlate terminology between DoDAF terms and JPSS terms.

4.3 Definition of QbD for JPSS

The first step in the application of the DoDAF Quality Conceptual Framework (DQCF) is illustrated in Figure 4.7. As discussed in Chapter 3 Section 3.5 Framework Application, contextual mapping allowed the author to apply DQCF to the JPSS DoDAF architectural model. The approach allowed for clear identification of DoDAF CONOP views for the evaluation scope as discussed in the approach of Chapter 3. Highlighted in red dashed boxes indicate the critical mappings from Juran's QbD method to the JPSS DoDAF model architecture driving out the DoDAF CONOP views of the architecture for SMD mission thread. Elements within the corresponding views will be evaluated using the Quality Characteristic Categories (QCC) in Appendix A. The evaluation method used is as described in Chapter 3.

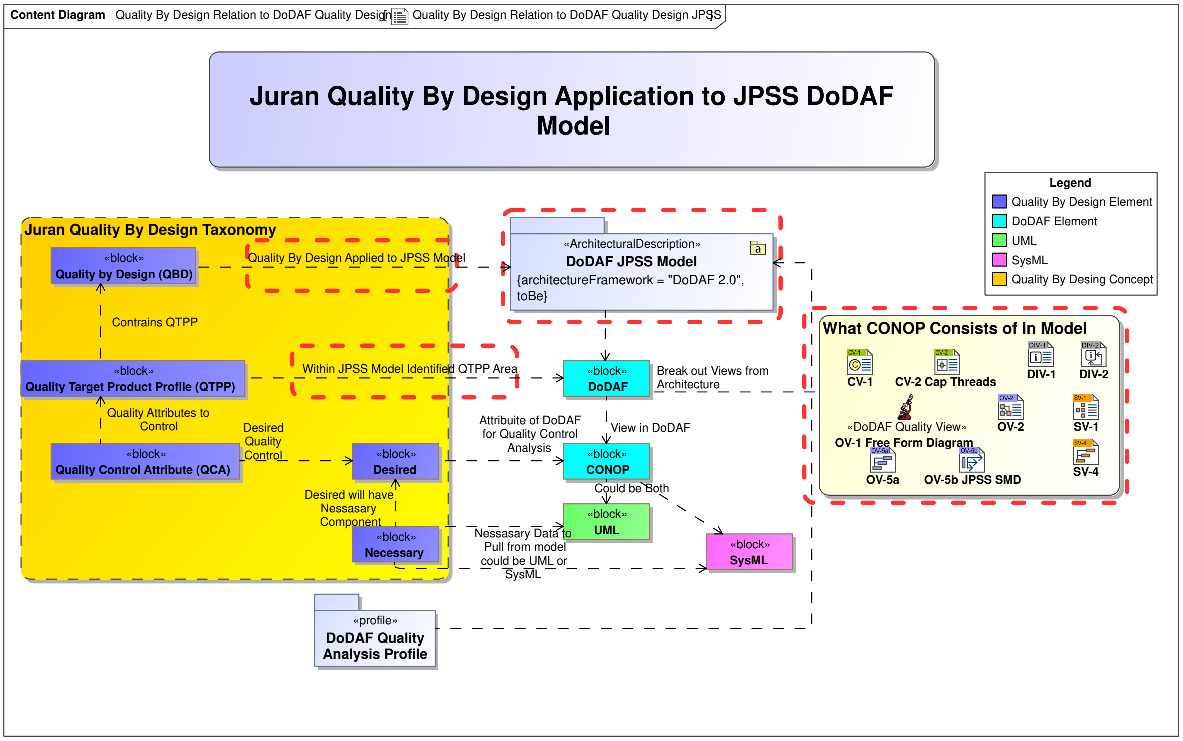

Figure 4.7: Joint Polar Satellite System (JPSS) DoDAF QbD Mapping

4.4 DQCF Application to JPSS

Figure 4.8 shows the DoDAF Quality Conceptual Framework (DQCF) imported into the model as a used project. The import indication is shown as grayed out text for the *«Package»* titles at the bottom of the figure. Importing the DQCF as a used project allows the user to use the profile stereotype *«DoDAF Quality View»* in the model to evaluate model elements with the QCC criteria in Appendix A. Additionally, importing the DQCF as a used project prevents user modification and allows for maintaining the data integrity of the profile and template contents. The figure also shows the containment tree for the JPSS DoDAF architectural model limited to the CONOP views needed for evaluation based on the QbD mapping from previous Section 4.3. The *Containment Tree* or browser folder structure in the model represents what is considered the *«Containment»* relationship of elements within a *«Diagram»* or *«Package»* [107]. For the most part the *«Containment»* relationships are a way of organizing the data in a model, similar to a file structure on a computer drive.

While the *Containment Tree* leads to a nested containment hierarchy of model elements, in reality, it is a means of model organization to reduce complexity and manage development efforts [73].

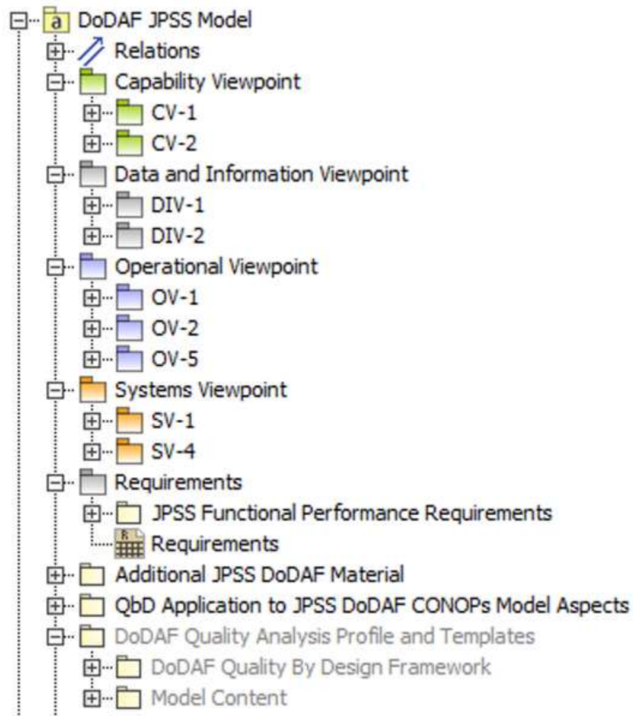

Figure 4.8: DoDAF Conceptual Framework as Used Project in JPSS Model

JPSS DoDAF content data outside of the scope for the JPSS CONOP views associated with the SMD mission thread were moved to a *Additional JPSS DoDAF Material «Package»*. While the excess content may be relevant for full presentation of the JPSS DoDAF architectural model, for this dissertation analysis purposes scope of the data was limited help to reduce complexity.

4.5 JPSS Element Sampling

A count of the elements was needed to understand how much of the model would be evaluated for the JPSS DoDAF CONOP architecture. Table 4.1 gives a high level break down of the elements contained in the JPSS DoDAF CONOP architecture. The table shows how many project diagrams exist for the JPSS DoDAF CONOP architecture, however only views as defined in Chapter 2 Section 2.1.3 the DoDAF CONOP Design Process with focus on the Stored Mission Data (SMD) mission thread were considered. A full detailed count of the elements by metaclass types can be found in Appendix B JPSS DoDAF CONOP Element Break Down.

Table 4.1: JPSS DoDAF CONOP Element Counts

Cameo Project Statistics	**Count**
Project Diagrams	228
All Diagrams	667
Project Elements	10481
All Elements	291158
Project Symbol Styles	5
All Symbol Styles	47

The sampling extracted from this data constituted the elements that will be analyzed by the framework. Table 4.2 shows the break down of the element count by DoDAF view that will be evaluated for the JPSS DoDAF CONOP architectural model. Note that the OV-5 value represents both the OV-5a and OV-5b for the JPSS DoDAF CONOP architectural model. This is a nuance of the Cameo Enterprise Architecture tool where the OV-5 views are combined typically under one diagram type. Each one of these element is confirmed to have an Element ID, UUID, or GUID, making the elements real within the architecture of the model and maintains the data integrity of that element [205]. By maintaining the element GUID, an element can not be fabricated and must come form the Cameo Enterprise Architect Tool.

Table 4.2: JPSS DoDAF Element Evaluation Count

DoDAF CONOP View	**Element Count**
CV-1	8
CV-2	39
DIV-1	44
DIV-2	61
OV-1	43
OV-2	103
OV-5	68
SV-1	16
SV-4	190
Total	*572*

A total of 572 elements of the JPSS model, which represents the JPSS DoDAF CONOP SMD mission thread, are roughly 5.46% of the total JPSS DoDAF CONOP architecture. Figure 4.9 shows the percentage of elements that make up each view for the JPSS DoDAF CONOP. The figure illustrates that the bulk of the elements are concentrated in the OV-2, OV-5, and SV-4 views for the CONOP. These views fall in line with the understanding for development of the DoDAF CONOP development process and are considered important in the weighting of views which will be used later in the modularity calculation. Once the graphical system representation, the OV-1 view, is established, the understanding for operational node communication or information flows of logical resource data to the *«OperationalActivity»* is critical in the system design process [4]. The DoDAF standard states that the OV-2 is the *backbone* to which all other DoDAF elements will be overlaid for the SV-1 interface description to show what *«OperationalPerformer»* providing a customer capability [4]. The OV-2 integrates the corresponding *«OperationalActivity»* of OV-5a Operational Activity Decomposition Tree or OV-5b Operational Activity Model to display interactions of behaviors in the architectural model [4]. The OV-2 transitions as expected to the OV-5 percentage which makes up the OV-5a and OV-5b for the JPSS DoDAF CONOP. For the purpose of analysis and image space for this dissertation, the SMD *«OperationalActivity»* and *«Functions»* were displayed in Appendix B. The author would like to note that to fully represent the system, as is the case with the JPSS, it can sometimes take hundreds of *«OperationalActivity»* diagrams to represent the entire system. The OV-5a and OV-5b are used to clearly outline of *«OperationalPerformer»* that are preforming redundant activities for the system design [4]. The *«OperationalActivity»* will become *Realized «Functions»* in the SV-4 view for the system design that the system must perform. The figure illustrates that in the DoDAF standard execution process the SV-4 *«Functions»* make up a large percentage of the JPSS DoDAF CONOP SMD mission thread.

When these 572 elements are evaluated against the 17 Quality Characteristic Categories (QCC), a total of 9,742 data points are present for the evaluation process. The selections of elements represents a *purposive sampling* and is believed to be representative of the JPSS DoDAF CONOP

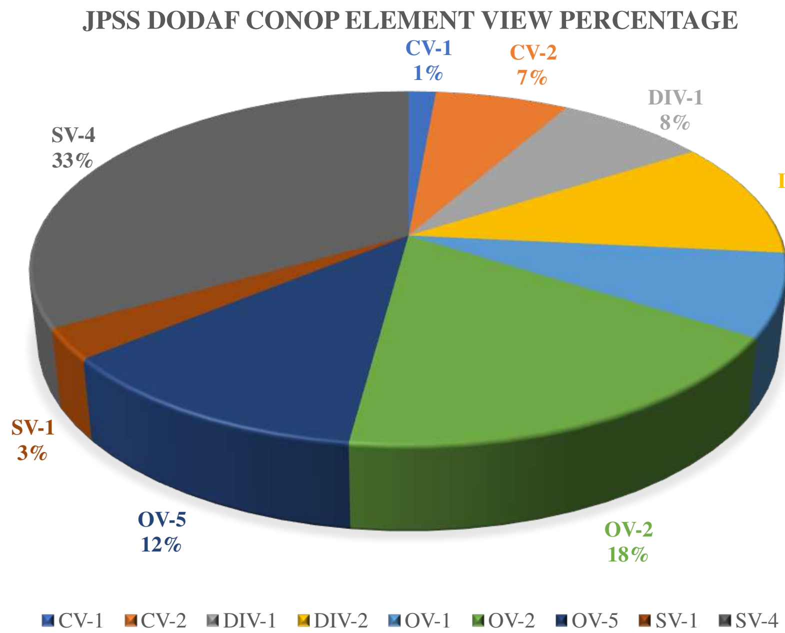

Figure 4.9: JPSS DoDAF CONOP Element View Percentage

SMD mission thread complete population of elements [206]. The accurate representation will be tested against the Kaizer-Meyer-Olkin (KMO) sample adequacy test to verify sampling. While subjectivity may be a factor, the author believes this has been addressed through rigorous scoping and qualification of data selection to meet the needs for analysis purposes.

4.6 JPSS Analysis Results

The following sections of this Chapter now represent the evaluation results for the JPSS DoDAF CONOP SMD mission thread evaluation.

4.6.1 Normality Testing And Descriptives

The first step was to conduct the normality testing for the JPSS data set and the mean values for *DEQ*, *REQ*, and *LEQ* were calculated to assist with this testing. First the author looked at the Skewness and Kurtosis of each of the means for the data set. Table 4.3 show the JPSS Descriptive Statistics for data set. The data in the table is of particular interest to the analysis process that was describe in the analysis approach of Chapter 2 Section 2.2.7. The data shows that while the median value can give you a better interpretation of the consolidated rating variables for each of the individual element, when consolidated across all elements evaluated a problem is presented. The data shows that the *LEQ* descriptives would be completely eliminated from from consideration in the rest of analysis. The mean values for all variables in this instance could provide a more meaningful result for the analysis and were used for further evaluation. Shown later in the PCA analysis, the value of *LEQ* still has an impact to understand model quality. The standard error presented in the table is the standard deviation of the statistical sample population [207]. The standard errors are small for the mean values in the data set, meaning that mean values are more representative of overall population [207]. The author analyzed the data set for Skewness and Kurtosis of each of the means values for each variables.

The closer the values for Skewness and Kurtosis are to 0 indicates a more normal distribution [208]. Remember that Skewness and Kurtosis indicate symmetry and peakness of the formed plot of data [208]. Furthermore, Skewness and Kurtosis can provide some interpretation about the model results when the values are positive or negative [209, 210]. In distribution models, the negatively skewed distribution refers to the model in which more values are shown on the right-hand side of the graph, while the tail of the distribution is spreading on the left-hand side [208]. A positively skewed distribution refers to the model in which more values are shown on the left-hand side of the graph, while the tail of the distribution is spreading on the right-hand side [208]. Given the values of the Likert Scale, an interpretation can be made about the model variable QCC mean values [209, 210]. The values for Skewness and Kurtosis are presented in the table. Based on these values, the data is considered not normally distributed. Perception of the data indicates that more values are on the right-handed side of the graph in Figure B.4, which shows a higher quality for *DEQ*. *LEQ* indicates a larger spread between values Figure B.7. While the values are considered negatively skewed, this could reflect an impact on the quality of the JPSS model. *REQ* indicates a larger spread between values Figure B.10. While the values are considered negatively skewed, this could reflect an impact on the quality of the JPSS model. The values can be both positive showing there are some high valued outliers and negative showing there are some low valued outliers with

Table 4.3: JPSS Descriptives

JPSS Descriptives					
		Mean		Median	
		Statistic	Std. Error	Statistic	Std. Error
DEQ	**Mean**	5.44	0.04	6.19	0.08
	Median	6.00		7.00	
	Variance	1.01		3.94	
	Std. Deviation	1.01		1.99	
	Minimum	3.00		1.00	
	Maximum	7.00		7.00	
	Range	4.00		6.00	
	Skewness	-1.67	0.10	-2.16	0.10
	Kurtosis	1.40	0.20	2.79	0.20
LEQ	**Mean**	5.91	0.03	7.00	0.00
	Median	5.80		7.00	
	Variance	0.53		0.00	
	Std. Deviation	0.73		0.00	
	Minimum	4.60		7.00	
	Maximum	7.00		7.00	
	Range	2.40		0.00	
	Skewness	-0.03	0.10	.	.
	Kurtosis	-0.37	0.20	.	.
REQ	**Mean**	3.44	0.04	2.80	0.09
	Median	3.00		1.00	
	Variance	0.80		4.11	
	Std. Deviation	0.89		2.03	
	Minimum	1.67		1.00	
	Maximum	5.00		7.00	
	Range	3.33		6.00	
	Skewness	-0.12	0.10	0.64	0.10
	Kurtosis	-0.72	0.20	-0.83	0.20

in the data set [211]. The frequency and Q-Q-plot plots for Skewness and Kurtosis of both mean and median can be seen in Appendix B for JPSS evaluation data set.

Now that the Skewness and Kurtosis values as well as the JPSS descriptive statistic have been established, additional checks can be made based on the data set as laid out in the approach for the DQCF framework in Section 2.2.7 of Chapter 2. Both Kolmogorov-Smirnov and Shapiro-Wilk are shown in Table 4.4 to address normality. The table includes the calculated statistic KS Kolmogorov-Smirnov and W Shapiro-Wilk; df or "Degrees of Freedom" meaning number of observations; and *Sig* or significance. The table shows the consolidated mean values of *DEQ*, *LEQ*, and *REQ* were used for evaluation. Both tests are included, but the sample size of elements for evaluation dictates what test is applicable to used to understand the distribution [212]. Due to the element count being greater than 100 elements evaluated, the Kolmogorov-Smirnov test will provide the most accurate answer for the JPSS data set [212]. Because all the mean values are significant for both tests, it can be assumed and confirmed that the data is not normally distributed [212]. With both normality checks in place, it can be safe to assumed that the JPSS data set is not normally distributed. By clarifying this assumption the author avoids any risk to further analysis on the JPSS data set. For all of the plotted data please see Appendix B.

Table 4.4: JPSS Tests of Normality

Tests of Normality						
	Kolmogorov-Smirnova			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
DEQ_mean	0.37	572	0.00	0.63	572	0.00
LEQ_mean	0.31	572	0.00	0.79	572	0.00
REQ_mean	0.19	572	0.00	0.92	572	0.00

4.6.2 Multicollinearity

To prepare the data set for PCA analysis, the author needed to address Multicollinearity between variables in the data set. First, the correlation matrix was calculated for understanding the correlation between variables of a non-parametric nature using Spearman's ρ. Collinearity in this context is a linear association between two variables in the JPSS evaluation data set [213]. Multicollinearity is a situation where two or more variables in the JPSS evaluation data set are highly linearly related [213]. The next objective is to detect what variables have a low tolerance and high Variance Inflation Factors (VIF) which are indicators of collinerarity [214]. The author discovered that several evaluation criterion had very strong correlation to one another in the correlation matrix. Analysis studies suggest that correlation coefficients of a value positive or negative above 0.80 or greater are of potential concern for analysis [215]. Furthermore, if the VIF calculated values are above 10, there is a possible cause for concern and most likely should be eliminated with justification or explained in detail [215]. The author completed a VIF analysis and excluded variables that were considered to be an issue to the analysis, the variables included *DEQ1*, *DEQ2*, *DEQ5*, *DEQ6*, *LEQ2*, and *LEQ5*. The suggested elimination of these variables means that the DQCF quality aspect for these QCC criterion could present an impact that must be investigated before the JPSS DoDAF CONOP architecture PCA analysis to proceed. Upon further interrogation of the values for exclusion the following determinations were made:

- ***DEQ1***: According to the DoDAF element type stated in the DoDAF standard, the element must be found on the appropriate diagram in order to be considered complete.
  - **Result Finding**: Majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *DEQ1* statement, the calculated VIF showed a value of 11.7 which is above the recommended of 10 for VIF calculated value [216]. The SysML element type of *«FlowSpecification»* as seen in Figure 4.5 is a deprecated element type according to SysML standard 1.5 and appears on the SV-1 view diagram [58, 217].
- ***DEQ2***: Does the element present strategic information that explains the existing and/or intended links between an organization's business, mission, and management processes, and the supporting infrastructure associated to the architecture?
  - **Result Finding**: The majority of elements evaluated had some form of relationship to the JPSS DoDAF architecture being direct or indirect. The calculated VIF showed a value of 21.1 which is above the recommended of 10 for VIF calculated value [216]. Direct relationship meaning to another element on same diagram graphically and indirect relationship meaning carried over from another diagram or through another element on different diagram. This means that some degree of modularity is present in the architecture but to what degree remains elusive at this point. Further discussion on the degree of modularity will be addressed in Section 4.6.5 of this Chapter. This part of as-

sessment is concerned with the networked relationships between the graphical elements that have been displayed [157, 160].

- ***DEQ5***: The DoDAF carefully examines each element type to ensure that they sufficiently articulate the need and proposed solution in a manner that would improve audience knowledge or justification for the need in architecture.

  – **Result Finding**: While most of the elements had a purpose for use within the architecture, several elements did not have a purpose as tied directly to a requirement statement for the architecture. Some of the elements, in one example, revolved around alternative functional behavior execution on the SV-4 view in the JPSS SMD mission thread. The calculated VIF showed a value of 18.2 which is above the recommended of 10 for VIF calculated value [216]. The *«Functions»* in question can be seen in Appendix B. The implications of unjustified alternative behavior is that the *«Functions»* present on the diagram had no driving factor present and directly presents a quality issue within the architecture. While alternative behavior is typical and often necessary to include within the model, articulation must be made and related to an *«OperationalActivity»* as part of the primary JPSS SMD mission thread. The articulation was not present in the architecture or documentation for the JPSS SMD mission thread.

- ***DEQ6***: Does the DoDAF element data type presented continue to present key information in a way that is understandable, congruent with, and consistent with all of the various stakeholders communities engaged in developing, delivering, and sustaining capabilities to assist in achieving system design goals?

  – **Result Finding**: While many elements did not have a consistent "Agree" with this criterion, the calculated VIF showed a value of 13.5 which is above the recommended of 10 for VIF calculated value [216]. The high VIF value means the variable must be eliminated in order to mitigate any issues to conduct PCA analysis. By having this criteria eliminated it is suspected that modularity will be impacted. Further discussion on the impact to modularity will be illustrated in Section 4.6.5 of this chapter.

- ***LEQ2***: Based on the UML/SysML element. Is the stereotype used correctly according to standard to provide a collection of diagrammatics, modeling components, a formal vocabulary, and semantics for the desired use in the model [73]? As with any language formal or informal, it may be employed in a variety of ways, and in a variety of incorrect ones as well [73].
  - **Result Finding**: Majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *LEQ2* statement, the calculated VIF showed a value of 11.4 which is above the recommended of 10 for VIF calculated value [216]. The SysML element type of *«FlowSpecification»* as seen in Figure 4.5 is a deprecated element type according to SysML standard 1.5 [58, 217]. The appropriate way is to convert the *«FlowPort»* governed by a *«FlowSpecificaiton»*, to a *«Port»* and type the port with specifications of things that flow through the *«Port»* [58].
- ***LEQ5***: Based on the UML/SysML element, is the element using the correct UML/SysML semantics, or meaning, of linguistic ideas between the two languages to bring value to the system design [73]. A descendant of the UML which was initially established as a modeling language for software design but has been expanded by SysML to accommodate general-purpose systems modeling [73].
  - **Result Finding**: Majority of elements evaluated on the Liker Scale, which presented a "Agree" with the *LEQ5* statement, the calculated VIF showed a value of 16.3 which is above the recommended of 10 for VIF calculated value [216].

After the above determinations were made on the QCC variables, they were removed with the justification of the VIF values.

The remaining QCC variables are shown in Table 4.6, allowing the PCA analysis to continue in the next section.

Table 4.5: JPSS Factors Eliminated due to VIF

Factors Eliminated due to VIF	
QCC Factor	**VIF Value**
DEQ1	**11.7**
DEQ2	**21.1**
DEQ5	**18.2**
DEQ6	**13.5**
LEQ2	**11.4**
LEQ5	**16.3**

Table 4.6: JPSS VIF Calculations

	Collinearity Statistics Tolerance	**VIF**
DEQ3	0.39	2.58
DEQ4	0.30	3.35
LEQ1	0.25	4.04
LEQ3	0.34	2.96
LEQ4	0.31	3.23
REQ1	0.58	1.72
REQ2	0.16	6.30
REQ3	0.27	3.65
REQ4	0.34	2.95
REQ5	0.48	2.09
REQ6	0.24	4.10

The correlation matrix for JPSS evaluation data can be found in Appendix B. The table details every factor including a correlation coefficient and significance on for each observation. When the correlation coefficient is 1.0, the criterion is perfectly correlated with itself [215]. The JPSS correlation matrix does not form an identity matrix and the analysis can continue. Table 4.7 show just the correlation coefficient. The black cells in the diagonal of the table represent the factors correlation with itself. The red color indicates the degree of correlation, the darker the red the stronger the correlation with a factor. The intensity indicates a strong negative or positive correlation between factors, even with the values being below the max of 0.80 [215]. Comparison between factors of the QCC can drive interpretation about the model. *REQ2* for example had the most strongest correlations to all other factors in the JPSS architecture. When looking at the QCC criterion, the criteria deal with relating to a function or detectable process in the model architecture. This function or detectable process is the primary reason for the CONOP development to understand the functional performance of the system.

Table 4.7: JPSS Correlation Matrix

	DEQ3	DEQ4	LEQ1	LEQ3	LEQ4	REQ1	REQ2	REQ3	REQ4	REQ5	REQ6
DEQ3		-0.42	0.36	-0.16	0.07	0.24	-0.27	-0.20	0.21	0.42	0.10
DEQ4	-0.42		0.06	0.67	-0.13	0.07	0.64	0.40	-0.40	-0.53	0.57
LEQ1	0.36	0.06		0.08	0.13	0.10	0.14	0.58	-0.20	0.12	0.20
LEQ3	-0.16	0.67	0.08		-0.09	0.05	0.59	0.27	-0.51	-0.34	0.62
LEQ4	0.07	-0.13	0.13	-0.09		0.03	0.39	0.15	0.17	0.07	-0.08
REQ1	0.24	0.07	0.10	0.05	0.03		-0.21	-0.08	0.15	-0.04	0.04
REQ2	-0.27	0.64	0.14	0.59	0.39	-0.21		0.34	-0.49	-0.37	0.54
REQ3	-0.20	0.40	0.58	0.27	0.15	-0.08	0.34		-0.02	-0.21	0.23
REQ4	0.21	-0.40	-0.20	-0.51	0.17	0.15	-0.49	-0.02		0.41	-0.25
REQ5	0.42	-0.53	0.12	-0.34	0.07	-0.04	-0.37	-0.21	0.41		0.11
REQ6	0.10	0.57	0.20	0.62	-0.08	0.04	0.54	0.23	-0.25	0.11	

4.6.3 Principal Component Analysis

The next analysis step in the DQCF process was to conduct a Principal Components Analysis (PCA) for the remaining values from the previous section. In the previous section factors were removed and their removal was explained based on the Variance Inflation Factors (VIF) values and other factors for analysis. The first step was to determine how accurately the evaluation data set represents the purposeful sampling adequacy for the JPSS DoDAF CONOP architecture. Table 4.8 shows the results of the Kaizer-Meyer-Olkin (KMO) and Bartlett's Test values. The table shows that for the amount of 572 elements evaluated from the scoped JPSS architecture, the data presents a KMO value of 0.59 with a significance of less than 0.05. The KMO value is considered on the lower end of the suggested rating scale of 0.5 to 1.0 but adequate enough to proceed with the analysis [218, 219]. Furthermore, the Bartlett's Test of Sphericity showed that the correlation matrix formed is not an identity matrix [220]. By confirming that the correlation matrix is not identity and has significance of less than 0.05 indicates that the data is acceptable for PCA analysis [221]. The values indicate that even though the relatively small purposeful sampling only representing 5.46%

of the total JPSS CONOP, the sample does adequately represent the JPSS DoDAF architecture. With this in mind, analysis can proceed to understand the details of the JPSS evaluation data set.

Table 4.8: JPSS KMO and Barlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.59
Bartlett's Test of Sphericity	**Approx. Chi-Square**	3512.80
	df	55
	Sig.	0.00

Questions *DEQ3*, *DEQ4*, *LEQ1*, *LEQ3*, *LEQ4*, *REQ1*, *REQ2*, *REQ3*, *REQ4*, *REQ5*, *REQ6* could be reduced to represent factors that influence the quality of the JPSS DoDAF CONOP model. Table 4.9 indicates that the total variance is achieved between 73.0% and 82.5% for a total of four to five factors. From the first component forward, each consecutive component is derived by partially removing the previous component from the preceding component [222]. The first component explains the greatest amount of variation, while the final component explains the least amount of variance [222]. The overall variation described by all components should be between 70% to 80% of the variance, which in this situation would suggest about four to five components [223].

Table 4.9: JPSS Total Variance Explained

Total Variance Explained						
Comp	**Initial Eigenvalues**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	3.5	31.8	31.8	2.9	26.4	26.4
2	1.9	17.3	49.1	1.9	17.6	44.02
3	1.4	12.8	61.9	1.6	14.9	58.9
4	1.2	11.1	73.0	1.4	12.3	71.2
5	1.1	9.5	82.5	1.3	11.3	82.5
6	0.8	7.6	90.1			
7	0.4	3.8	93.9			
8	0.3	2.7	96.6			
9	0.2	1.7	98.3			
10	0.1	0.9	99.2			
11	0.1	0.8	100.0			

When it comes to statistical research, where extracted components often explain just 50% to 60% of the variance, the 70% to 80% of the variance approach may be unworkable [136]. Adjusting for the 50% to 60% of the variance, the total variation for two to three components between 45.7% to 62.0% for two to three components is shown in Table B.4 in Appendix B. The total variance also provides the initial eigenvalues for each component and percentage of accounted for variance in the data set. Eigenvalues that are greater than 1 should be retained and represent the bulk of the JPSS evaluation data set [220]. For this purpose of analysis a focus was put on the oblique rotation or varimax rotation due to the more realistic representation for the data [220, 221]. The varimax rotation tries to maximize the amount of variance through redistribution across all the recommended factors [221]. For the purpose of simplicity of analysis only two factors are used for the eigenvalues giving a maximum of 49.1% of the total variance, which is still acceptable for the 50% to 60% of the variance.

Table 4.10: JPSS Total Variance Matrix Adjusted 2 factor

Total Variance Explained						
Comp	**Initial Eigenvalues**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	3.5	31.8	31.8	3.4	31.0	31.0
2	1.9	17.3	49.1	2.0	18.0	49.1
3	1.4	12.8	61.9			
4	1.2	11.1	73.0			
5	1.1	9.5	82.5			
6	0.8	7.6	90.1			
7	0.1	3.8	93.9			
8	0.3	2.7	96.6			
9	0.2	1.7	98.3			
10	0.1	0.9	99.2			
11	0.1	0.8	100.0			
Extraction Method: Principal Component Analysis.						

Figure 4.10 shows the Scree Plot of the eigenvalues from showing the principal components for total variance of JPSS evaluation data set. Table B.3 in Appendix B indicates the weight aspect of each question to the component factor for the the 70% to 80% of the variance. Table B.5 in

Appendix B indicates the weight aspect of each question to the component factor for the the 50% to 60% of the variance. For the three factor loading plot see Appendix B Figure B.22. Table 4.11 shows the percentage for two factors with the eigenvalues plotted in Figure 4.11. Loadings range anything between -1 and 1 [9]. In this case, loadings near to -1 or 1 imply that the variable has a significant impact on the component [9]. Loadings that are close to 0 imply that the variable has a little impact on the component under consideration [9]. Evaluation of the loadings aid in the identification of each component's characteristics in terms of the variables [9].

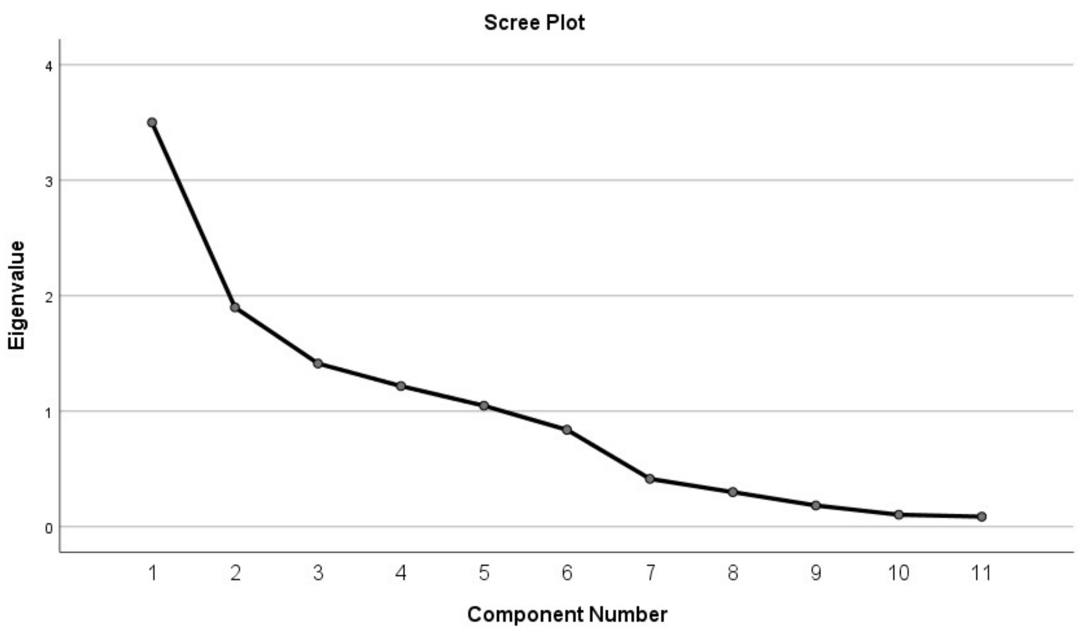

Figure 4.10: JPSS Eigenvalue Scree Plot

When the QCC criteria are analyzed at an abstracted level the picture becomes clear to what drives variance in the JPSS case study data set. *DEQ* and *LEQ* factors primarily show how the DoDAF standard and UML/SysML languages were applied to the overall elements. The finding in the application show factors that could drive improvement in the JPSS DoDAF CONOP architecture quality. Many elements in the model were left without descriptions in the JPSS DoDAF CONOP architecture quality architecture.

Table 4.11: JPSS Component Matrix Adjusted 2 Factor

Component Matrix-a		
	Component	
	1	**2**
DEQ3	-0.19	0.78
DEQ4	0.79	-0.32
LEQ1	0.41	0.66
LEQ3	0.81	-0.15
LEQ4	0.12	0.34
REQ1	-0.04	0.29
REQ2	0.79	-0.02
REQ3	0.57	0.23
REQ4	-0.56	0.35
REQ5	-0.32	0.63
REQ6	0.75	0.19
Extraction Method: Principal Component Analysis. Rotation Method: Varimax		
a. Rotation converged in 3 iterations.		

Leaving descriptions off is critical when performing an outside audit of model quality. The auditor of Quality Systems Engineering is not going to understand every exact detail or have a complete understanding of all documentation related to the system. The description becomes critical for a customer to understand what is being represented in the model. Many of the elements in the JPSS DoDAF CONOP architecture did not have sufficient requirement element instantiation within the architecture.

Quality of the model dips in this aspect for the JPSS architecture while where elements existed, they often did not have adequate instantiation representation. An example would be the alternative behaviors that were present in the functional SMD SV-4 diagram in Appendix B. The JPSS model did not have a triggering event to execute the alternative functions or justification within the model or documentation. Creating behavior without justification can cause scope creep or additional cost in development of the JPSS system design. *LEQ* also had elements present on diagrams that were obsolete when better elements or processes exist. When this occurs you have orphaned

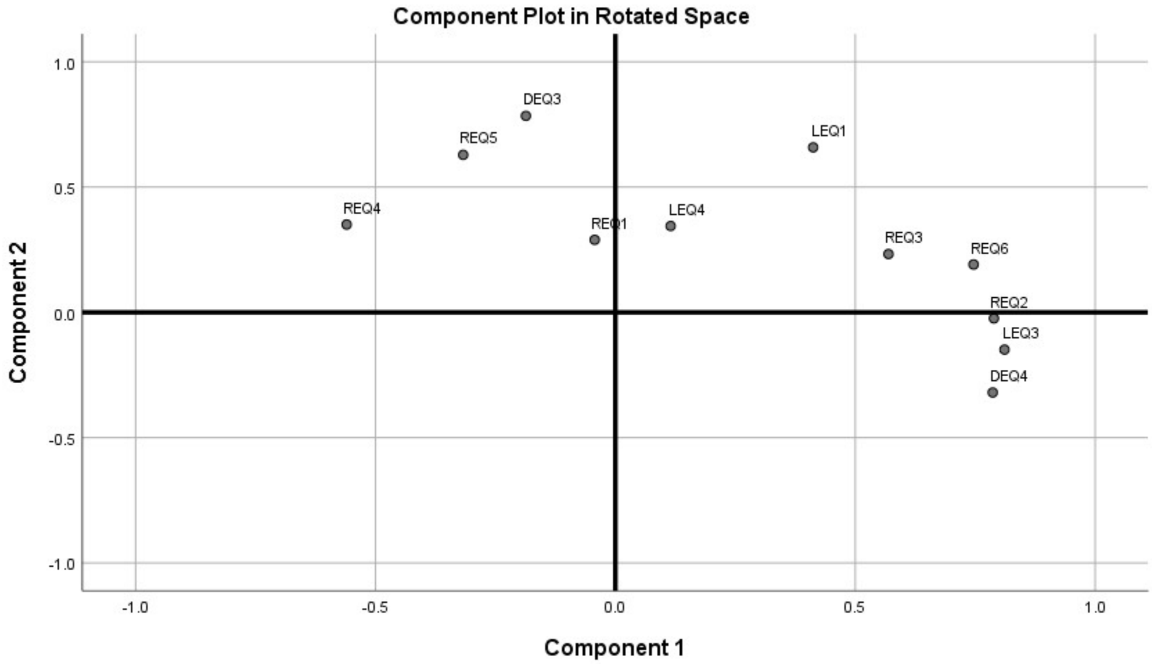

Figure 4.11: Joint Polar Satellite System (JPSS) DoDAF Two factor Loading Plot

elements that can create model "bloat" or excess unjustified material causing confusion for what the elements represent in the architecture. For the factors pertaining to *REQ*, the JPSS DoDAF CONOP seemed to be lacking aspects to instantiate the architecture. While some of the requirements were present at the system level, many lacked the complete decomposition of the requirement statements instantiating elements to lower levels of the system design. An example of this can be seen on the JPSS DoDAF CONOP SV-1 Figure 4.5 in a Appendix B. Multiple *«FlowSpecification»* with the same name are present on the diagram in different areas. While this is a minor presentation for linkage of *«FlowSpecification»* to parts of the system, this could be done through a relation matrix and not shown on that particular DoDAF view. Furthermore, it has been highlighted that the *«FlowSpecification»* is obsolete and needs removal with proper standard implementation. By doing this the JPSS DoDAF CONOP dips in quality for presentation of excess and obsolete material.

4.6.4 Ordinal Logistic Regression

This section discusses the Ordinal Logistic Regression (OLR) application of the JPSS DoDAF CONOP evaluation data set. The OLR analysis has many benefits and was conducted to determine feature extraction interpretation from the JPSS DoDAF CONOP evaluation data set [224]. In the event that OLR violates the proportional odds assumption Multinomial Logistic Regression (MLR) is recommended to use for analysis. Only when the proportional odds assumption is violated will MLR be used over OLR. The proportional odds assumption has a constant relationship between the independent variable and dependent variables [144]. While MLR can be used for ordinal data, communities of practice prefer OLR [144]. The checks and tests completed on the data set are in line with IBM SPSS version 26 for OLR and provide rigor to ensure correct analysis. Table 4.12 shows the model fitting information for the data set. Table 4.12 indicates a significant improvement to the model fit of over the final model relative to the intercept only [225]. The log likelihood addresses the final vs. the null product against $-2\log$, and is used to determine if all of the predicted regression coefficients in the model are zero at the same time [221]. In the JPSS DoDAF CONOP evaluation data set, the intercept only value is calculated at 1685.0 and the final value is $p < 0.05$. Since the significance level of the log likelihood addresses the final test is less than 0.05, you can conclude the final model is redundant and not necessary because both are outperforming the null [215]. The *Chi-Squared* value is the same as the log likelihood intercept only because the value is the delta between log likelihood and final log likelihood [215]. The *Chi-Squared* indication shows that an association exists between the observed element ratings and what is an expected rating for similar element analysis [215]. The *df* indicates the degree of freedom or number of predictors to calculate the *Chi-Squared* [226]. The *Sig.* shows the significance of the *Chi-Squared* calculated statistic, because this value is $p < 0.05$ the model presents a good fit to the evaluation data [226].

Additionally, the following tests were conducted to ensure the model "goodness of fit" to the JPSS evaluation data set. The Pearson and Deviance tests were conducted to understand the observed distribution of the data expected in the independent calculated mean of abstracted vari-

Table 4.12: JPSS Model Fitting Information

Model Fitting Information				
Model	**Model Fitting Criteria**	**Likelihood Ratio Tests**		
	-2 Log Likelihood	**Chi-Square**	**df**	**Sig.**
Intercept Only	1685.00			
Final	0.00	1685.00	11	0.00

ables [146]. The indication for the JPSS evaluation data set is good because both calculated values are non significant, meaning a $p > 0.05$ [147]. If the significance level was low, meaning $p < 0.05$, the predicted model would deviate from the observed model presenting a problem with the JPSS data set requiring further investigation [148]. Table 4.13 shows the calculated values for each of these test.

Table 4.13: JPSS Goodness-of-Fit

Goodness-of-Fit			
	Chi-Square	**df**	**Sig.**
Pearson	221.81	877	1.00
Deviance	130.81	877	1.00

The next values calculated are the Pseudo R-Square values and they are presented in Table 4.14. The values are treated as rough analogues to the R-Squared values in ordinal least squares method for estimating the unknown parameters in an OLR analysis [149]. The consensus is that the values, when calculated, must not be statistically significant or a problem may exist with the data set [149, 150]. Table 4.14 shows that all the values are not statistically significant and analysis can proceed.

Table 4.14: JPSS Pseudo R-Square

Pseudo R-Square	
Cox and Snell	0.95
Nagelkerke	1.00
McFadden	1.00

Located in Appendix B are the JPSS DoDAF CONOP OLR parameter estimates for the evaluation data set. The following are presented explanations of data fields for the each of the columns in Table B.6.

- **Threshold**: This is the response variable in the OLR for the *DEQ mean* and represents the cutoff value for *DEQ mean* low as 3.0 and high as 6.17.
  - **Threshold [*DEQ mean* = 3.00]**: is the estimated cutpoint on the latent variable used to differentiate low *DEQ mean* from middle and high *DEQ mean* when values of the predictor variables are evaluated at zero. Elements that had a value of -37.45 or less on the underlying latent variable that gave rise to our *DEQ mean* variable would be classified as low *DEQ mean*
  - **Threshold [*DEQ mean* = 6.17]**: is the estimated cutpoint on the latent variable used to differentiate low and middle *DEQ mean* from high *DEQ mean* when values of the predictor variables are evaluated at zero. Elements that had a value of -4.58 or greater on the underlying latent variable that gave rise to our *DEQ mean* variable would be classified as high *DEQ mean*
- **Estimate**: These are the ordered log-odds (logit) regression coefficients. The standard interpretation of the ordered logit coefficient is that for a one unit increase in the predictor, the response variable level is expected to change by its respective regression coefficient in the ordered log-odds scale while the other variables in the model are held constant.
- **Location**: These are the covariates and factors in the analysis for OLR.
  - Variables that are not present in the table were removed based on the previous analysis and constituted only the following as contributing factors: *DEQ3*, *DEQ4*, *LEQ1*, *LEQ3*, *LEQ4*, *REQ1*, *REQ2*, *REQ3*, *REQ4*, *REQ5*, *REQ6*.
  - **DEQ 3,4**: This is the ordered log-odds estimate for a one unit increase in *DEQ 3,4* score on the expected *DEQ mean* level given the other variables are held constant in the model.

- **LEQ 1,3,4**: This is the ordered log-odds estimate for a one unit increase in *LEQ 1,3,4* score on the expected *DEQ mean* level given the other variables are held constant in the model.
- **REQ 1-6**: This is the ordered log-odds estimate for a one unit increase in *REQ 1-6* score on the expected *DEQ mean* level given the other variables are held constant in the model.
- **DoDAF View**: shows the views of the SAR DoDAF CONOP.

- **Std. Error**: These are the standard errors of the individual regression coefficients.
- **Wald**: The ratio of Estimate to Std. Error, squared, equals the Wald statistic.
- **df**: degrees of freedom for each of the tests of the coefficients, defines the Chi-Square distribution to test whether the individual regression coefficient is zero given the other variables are in the model.
- **Sig.**: These are the p-values of the coefficients or the probability that, within a given model, the null hypothesis that a particular predictor's regression coefficient is zero given that the rest of the predictors are in the model.
  - The green indicates statistical significance below 0.05 for the data set.
- **95% Confidence Interval**: Confidence Interval (CI) for an individual regression coefficient given the other predictors are in the model.

The coefficients are predicting the log odds of being in a higher or lower category on the *DEQ mean* dependent variables [150]. The tables shows that for every one increase on the independent variables *LEQ* and *REQ*, there is a predicted increase of ending up at a higher level of dependent variable [144]. This means that as the independent variable value increases, there is a increase on the dependent variable [144]. The following list illustrates interpretations for the QCC values that presented statistical significance based on the OLR analysis:

- ***DEQ 3*: ** Based on the DoDAF element type, the descriptions define a strategy for managing change, as well as the transitional processes required to evolve the state of a business or mission to one that is more efficient, effective, current, and capable of providing those actions required to fulfill its goals and objectives, which are represented by the architecture in the description.
  - **Result Finding:** The element evaluations indicated that statistical significance of $p < 0.05$ for the responses received to this QCC criteria. Missing description to understand what element is representing for the architecture were common place in the JPSS architecture.
- ***DEQ 4*: ** Based on the DoDAF element type, do related sub-elements at each tier of the system design or desired level achieve goals and objectives corresponding to the scope and purpose that have been established.
  - **Result Finding:** The element evaluations indicated that statistical significance of $p < 0.05$ for the responses received to this QCC criteria. Element types were used in the architecture were missing *«ActualMeasurementTypes»* as well as *«ValueProperties»* to explain the data selection.
- ***LEQ 3*: ** Based on the UML/SysML element, is the element related through relationship in the architecture and the relationship type correct [73].
  - **Result Finding:** The element evaluations indicated that statistical significance of $p < 0.05$ for the responses received to this QCC criteria. The primary rating understanding for the model elements did not always have some relation to some justification for need within the JPSS architecture. In some cases obsolete element type were used which drove the quality of this QCC criteria to be rated as mostly "Disagree"
- ***LEQ 4*: ** Based on the UML/SysML element, does the element describe the underlying ideas or justifications behind its use, such as the choice of analytic method or design approach [73].

The element may serves as a source of information or a reference to the reasoning behind the modeling choice [73].

  - **Result Finding:** The element evaluations indicated that statistical significance of $p < 0.05$ for the responses received to this QCC criteria. The JPSS model contained orphaned elements existed that often did not have relationships to parts of the DoDAF architecture.

- ***REQ 4*:** The DoDAF Element is derived from some standardized source or defined by customer. Justification would be a means to document the reason for having the element in the model [168, 169].

  - **Result Finding:** The element evaluations indicated that statistical significance of $p < 0.05$ for the responses received to this QCC criteria. The Performance measurable values are not completely specified the *DIV-1* was not complete which is a large contributing factor and directly impacts test verification which effects the *REQ6* variable.

- ***REQ 5*:** Performance measurable values are completely specified. The DoDAF Element performance design attributes which allow the verification for a system design [168, 169].

  - **Result Finding:** The element evaluations indicated that statistical significance of $p < 0.05$ for the responses received to this QCC criteria. DoDAF Element performance design attributes which allow the verification for a system design, not all elements had performance design attributes associated with them in the JPSS architecture and the *DIV-1* was not complete which is a contributing factor and strictly impacting the JPSS overall ability to complete verification.

- ***REQ 6*:** Based on the DoDAF Element, a case can be conceived to assess all aspects of the DoDAF Element for a system design. Refers to the ability to verify or audit the DoDAF Element through the process of verification.

- **Result Finding:** The element evaluations indicated that statistical significance of $p < 0.05$ for the responses received to this QCC criteria. While case can be conceived to assess all aspects of the DoDAF elements for a system design, the analysis showed that non consistent decomposition from System to Sub-system in the architecture for the JPSS SMD material.

- ***DoDAF Views*:** Most of the JPSS DoDAF views presented little contribution to the overall OLR analysis. The author did make note that the DoDAF OV-2 did not fully communicate the logical resource flows from the *«OperationalPerformers»* which are critical to the *«OperationalActivies* and are needed to completing the DIV-1 and DIV-2.

To review additional details about probability estimates for the model, see Appendix B, Probability For JPSS Response Table B.7. The top of each column is the Estimated Cell Probability for Response Category for the *DEQ_Mean*. These probabilities can be used to predict the outcome of each of the down selected variable responses currently in the JPSS DoDAF CONOP architecture.

The *REQ* factors from the DQCF QCC mean value was 3.44 and median of 3.0 or "Somewhat Disagree"/"Disagree" this was reflective of the more negative coefficients for the Ordinal Logistic Regression (OLR) for the *REQ* variables, While higher level requirement existed specifics for alternative behavior or complete system performance level breakdown context was missing. An example of missing requirements would be the alternative behaviors that were present in the functional SMD SV-4 diagram in Appendix B. By creating behavior without justification caused additional cost and increased schedule for development for the JPSS system design. Also, the adequate quality rating is driven by the fact of incomplete modeling consistency with in the application of DoDAF and UML/SysML standards. The Government Accountability Office (GAO) found that the JPSS program was encountering difficulties in testing the ground system's performance criteria, which may result in a delay in validating requirement [227]. This was confirmed by historical information of the program when in August of 2017, the JPSS system was delayed in schedule and main factors delaying the JPSS launch were technical issues discovered during testing of the satellite's advanced technology [194]. Additional factors from the DQCF include the *DEQ* value of 5.44 and median of 6.0 or "Somewhat Agree"/"Agree" for the majority of elements evaluated, meaning the quality was consistent with the application of DoDAF standard within the JPSS DoDAF CONOP architecture. The *LEQ* value of 5.91 and median of 5.8 or "Somewhat Agree"/"Somewhat Agree" for the majority of elements evaluated, that the evaluation was in agreement with the application of UML/SysML standard for the most part within the JPSS DoDAF CONOP architecture. The *DEQ* and *LEQ* were most likely the outcome because of the tool and team conformed to UML/SysML/DoDAFstandards during the development process. Using the Equation 3.3 from Chapter 3 a overall determination can be made about the quality of the JPSS architecture. The *DEQ* was very close to a value of 3.96 or "Good" rating. The *LEQ* was a value of 4.27 but still a "Good" rating. The *REQ* was a score of 2.62 in a "Poor" to "Acceptable" rating. The analysis reflects a sensitivity to *REQ* factors in the model and could cause greater impact to quality if not addressed. The JPSS overall score is a 3.62 or "Acceptable" to "Good" rating. Understanding the implication of these scores can provide insight into the understanding of programmatics for a system design see Section 3.6 of Chapter 2.

4.6.5 Modularity Calculation

Now that an understanding for quality of the JPSS DoDAF CONOP architecture has been established based on the Quality Characteristic Categories (QCC), the author wanted to understand the modularity as it stands in the current JPSS DoDAF CONOP architecture. Using the DoDAF Quality Conceptual Framework (DQCF) Modularity Design Structure (MDS) Matrix and the adapted YuTian equation as prescribed in Chapter 3 Section 3.5 the equation 3.1 can be used to make a determination on the degree of modularity of the model. Recall that the Multicollinearity analysis showed that *DEQ2*, *DEQ6* and nearly all of *REQ* variables had key indicators that modularity will be impacted in most likely a negative way. The Multicollinearity analysis indicated the following for *DEQ2*, *DEQ6* and all of *REQ* variables:

- ***DEQ2***: Does the element present strategic information that explains the existing and/or intended links between an organization's business, mission, and management processes, and the supporting infrastructure associated to the architecture?
  - **Result Finding**: All of the element evaluated had some form of relationship to the JPSS DoDAF architecture being direct or indirect. This means that some degree of modularity is present in the architecture but to what degree remain elusive at this point.
- ***DEQ6***: Does the DoDAF element data type presented continue to present key information in a way that is understandable, congruent with, and consistent with all of the various stakeholders communities engaged in developing, delivering, and sustaining capabilities to assist in achieving system design goals.
  - **Result Finding**: While these elements did not have a consistent agreement for each of the elements evaluated, the VIF calculated showed a value of 13.5 which is above the recommended value of 10 for VIF [216]. The VIF high value means the variable must be eliminated to mitigate any issues for PCA analysis caused by multicollineararity. By having this eliminated from the criteria means that it is suspected that modularity will be impacted JPSS DoDAF architecture.
- ***REQ1-6***: Deals with the aspect of the requirement instantiation of an element to establish system contextual meaning in the architecture.
  - **Result Finding**: The operational functional performance requirement should drive the development of a CONOP architecture for a system design as stated in Section 2.1.3 DoDAF CONOP Design Process in Chapter 2 [4,79]. The Principal Components Analysis (PCA) and OLR analysis found key significance in the *REQ* criteria from the QCC for the JPSS architecture.

For the purpose of modularity calculation analysis, only the Stored Mission Data (SMD) thread will be evaluated as was done in other sections of this Chapter. To clarify the approach to the degree of modularity analysis for the JPSS DoDAF CONOP architecture, some assumptions were made to bound the problem to the appropriate space for the analysis. The assumptions are as follows:

- Data inconsistency exists in the JPSS DoDAF CONOP.
  - Inconsistency was established during the Multicollinearity analysis for several QCC from the DQCF.
  - Several descriptions were missing through out the JPSS DoDAF CONOP.
- The author used any relationship that existed between DoDAF elements within the architecture for the assessment of the degree of modularity.
  - The purpose of an multiple-domain matrix allows for modeling the scoped system aspect while maintaining consistency of multiple domains, each having multiple elements or element types, connected by various relationship types [228].
- The top of the MDS Matrix *column* will represent the *from* or *source* and the *row* as the will represent *to* or *target*.
- The symbol of "$\nearrow$" present an arrow representing the create relationship.
- Direct relationship from one element in a column to the same element in a row will be blacked out along the diagonal for the MDS, Figure 3.3 shows an example diagram.
- The MDS Matrix is representative of a Multiple-Domain Matrix allowing different element types to be considered under the various DoDAF views [228].
- The analysis will use human clustering technique prescribed by YuTian's team due to consideration for the these listed assumptions or constraints on analysis [174].
  - While the human clustering technique is not the most accurate method, the approximation is close enough for acceptable interpretation when determining factors for the degree of modularity.

  - Clustering is the identification of highly interactive groups of elements and arranging in modular understanding [174].

- MDS are considered binary and normalized for easier calculations consistent with YuTian's approach.
- *log(base2)* was used for the calculation as based on YuTian's teams analysis.
- w weight of view importance will use pairwise comparison of which views are more important.
- Type I mismatch error is for inside of a cluster [174].
- Type II mismatch error is for outside of a cluster [174].
- OV-5 DoDAF view is combined with OV-5a and OV-5b views.
- A 0.33 weighting was used as prescribed by YuTian's team for all terms in the equation.
- The full relationship matrix of 572 elements was not included due to size constraints within the document.
  - A MDS of 572 element by 572 elements yields a matrix grid of after removing the diagonal total grid space is 326657.
- The product architecture is the JPSS DoDAF CONOP with focus on the SMD thread.
- Considerations for "bus" architectures will not be a factor in this analysis based on the definition of a Bus from YuTian's teams analysis.

In order to understand the weighted importance of each of the DoDAF views with the JPSS DoDAF CONOP the standard views used pairwise weighting methodology [229]. The pairwise weighting decision-maker compares each item with the rest of the group and gives a preferential level to the item [178]. The weights were determined based on Table 3.2 in Chapter 3 Section 3.2 for each DoDAF view. The weight of importance Table 3.3 can be found in Chapter 3 Section 3.2.

The next goal was to conduct corresponding clustering of data to understand how data is contained in the modules within the model. An example of how this was done is shown in the Figure 3.3 in Chapter 3 Section 3.2. The approach from Chapter 3 was taken across the entire 572 element count for the JPSS DoDAF CONOP to determine the degree of modularity. The clustering arrangement is as follows in Table 4.15.

Table 4.15: JPSS Clustering Arrangements

Clustering Arrangements				
	n_c	cl_i	$\|S_1\|$	$\|S_2\|$
JPSS Model	9	14, 28, 69, 76, 77, 107, 120, 181, 334	60108.33	8773.54

Table 4.16 shows the description length and ratios for the JPSS DoDAF CONOP. The clustering ratios can be calculated using the Widrow–Hoff iteration which is the approach that YuTian's team did within their analysis, however for the purpose this analysis will use the assumption of 0.33 as suggested by YuTian's team [174]. Equation 3.1 was used with the values from Table 4.15 and the results are in Table 4.16.

The findings were quite interesting when looking at the resultant values for clustering within the JPSS DoDAF CONOP model. The case study shows that the modules or the DoDAF views have several interactions exterior (from one view to another), but minimal interactions within the view. Some exceptions to the exterior connections are the internal interactions which include the DoDAF view OV-5b and SV-4. These views have interactions between elements on the view because of their nature of development which contains *«controlflows»* or *«objectflows»*. The analysis only considers interactions that were outside of the views to drive development of elements on other views as well as linked data consistent across different views within the JPSS DoDAF CONOP architecture.

The method shows a promising ability to evaluate and quantify the degree of modularity while identifying contributing factors within the JPSS DoDAF CONOP architecture model. Table 4.16 shows the various calculations on the JPSS DoDAF MDS. From the values in the table, the JPSS

Table 4.16: JPSS Description Length and Ratio for Clustering

	Description Length	Ratio
JPSS CONOP Model	196	0.33
Type I Mismatch	32351	0.33
Type II Mismatch	1827	0.33
Total MDL	33437	

model had a value of 196 which is considered a low degree of modularity given the amount of elements associated with the model. The factors that drive the value include the number of elements within the MDS, relations between DoDAF views, the ratios, and the clustering of DoDAF elements based on views. The type I mismatch value of 32351 shows that while relationships do exist in the clusters and the clusters are quite large, they have considerable mismatch or missing relations, meaning the cluster is modular. The type II mismatch value of 1827 is also considered a low value but while relations exist in the model and within the denoted clusters, not everything is related within the model or the cluster. The full analysis gives the JPSS model and MDL of 33437 which still is considered a long description length. YuTian's interpretation of this MDL is that if the model description is simple, the model description is short [174]. In contrast, many data mismatches would exist, and the mismatched data description would become longer [174]. A complicated model reduces the description of mismatched data, but the model description would be longer [174]. The previous Section 4.6.3 of this chapter showed from the beginning that *DEQ2*, *DEQ6* and nearly all of *REQ* variables also presented a negative outlook for the degree of modularity but the model is considered to high degree of modularity. The analysis shows that in order for engineering teams to design for a high degree of modularity, the engineering team must start with that fact as a goal in the beginning and continue to monitor modularity during development. For the case of the JPSS DoDAF CONOP, the architecture was developed to drive requirements development without the consideration for modularity in the design process, and this was reflected in the large mismatch error in the analysis of this section.

4.6.6 JPSS Conclusions

Chapter 4 represents the bulk of analysis and comprehension of quality using the outlined DoDAF Quality Conceptual Framework (DQCF) against case study one. The chapter covered the JPSS CONOP Stored Mission Data (SMD) mission thread, JPSS key terms for DoDAF understanding, application of QbD to the JPSS CONOP, the element sampling from the model, and statistical analysis methods. Each one of the represented sections provides justification for the methodology used while maintaining data integrity and highlighted key findings relating to quality of the DoDAF architecture. The data must be interpreted with caution due to some of the key assumptions made but the innovative method symbolizes a sound approach to investigate quality of architectures. Not only were the findings observable, but the analysis brought quantifiable understanding using statistical methods with supporting foundational theory. The DQCF illustrates a more robust approach to quantify quality comprehension of DoDAF architectures models.

Chapter 5

Search and Rescue Case Study

The second case study is of the Search and Rescue (SAR) DoDAF CONOP architecture with focus on the Command and Control signaling mission thread. The most current open source versions of SAR DoDAF architectural model and SAR documentation were used to assist the author in context capture, DoDAF Quality Conceptual Framework (DQCF) application, illustration, and analysis for the case study. The SAR DoDAF architectural model consists of operations for locating and retrieving persons in distress, providing for their immediate needs and delivering them to a place of safety [230]. The Search and Rescue (SAR) operations are an integrated set of services or operations designed to locate and rescue people who are in distress, provide them with immediate medical attention or other needs, and transport them to a safe location [231]. SAR operations must be carried out as a collaborative effort involving a variety of organizations, including the military (sea, air, and land), government agencies, voluntary organizations, and private enterprises [231]. The primary mission of the SAR DoDAF architectural system is to capture all search and rescue capabilities, in conjunction with the Department for Transport and police, while maintaining a United Kingdom military/civilian SAR capability to ensure the most effective and timely response available to assist people in hazardous situations [230, 232]. The architecture analysis will primarily focus on the Command and Control signaling mission thread of a ship in distress and the capabilities associated with accomplishing that mission. The DoDAF, UML, and SysML stereotypes will be presented with guillemets «» to indicate a model element specific language.

5.1 CONOP for SAR

The SAR DoDAF CONOP purpose is to communicate system functional and operational information that will accomplish the system mission under normal operating conditions. The model-based SAR DoDAF architectural system deign presents a single phase of capabilities but includes organizational data transmissions between the different system levels. Furthermore, the ultimate goal of the SAR DoDAF architectural was to prescribed DoDAF framework examples for all Department architectures and represents a substantial shift in approach [233].

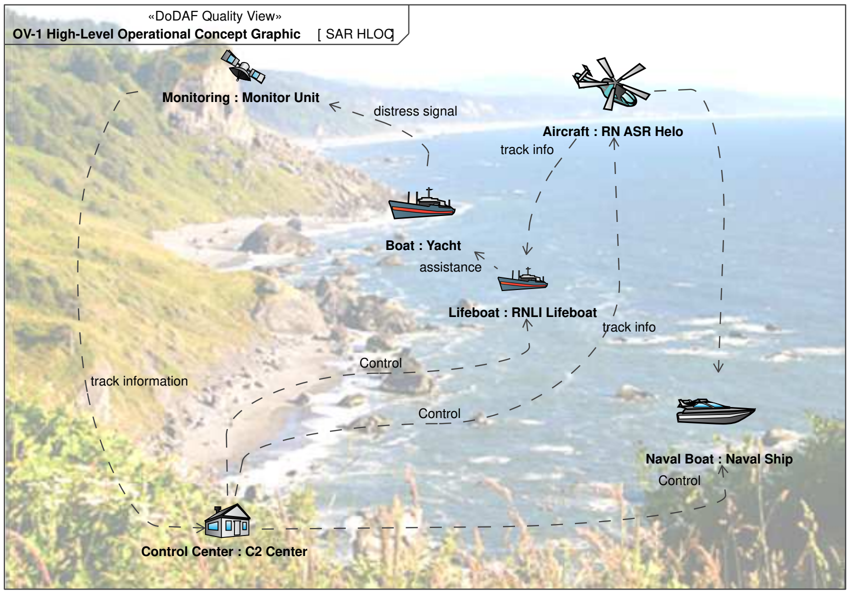

Figure 5.1: Search and Rescue (SAR) DoDAF Operational View OV-1

Figure 5.1 shows the high level OV-1 for the SAR DoDAF system. Several acronyms are present in the diagrams specific for the SAR system. For further context details on the meaning of these acronyms, see Appendix C Table C.1. Figure 5.1 provides a description for the DoDAF Operational View OV-1 for the operational concept of the SAR architectural design. Figure 5.1 shows an image of the corresponding mission, organization and high-level *«OperationalPerformers»* for the system [195]. The SAR OV-1 indicates relations between *«OperationalPerformers»* and what data is being transmitted between the *«OperationalPerformers»* [196]. Note that the image reflects the environments of operation constraints for the system such as maritime sea, land, and air [234]. The OV-1 presents information that provides links from *«OperationalResources»* on the Operational Resource Flow OV-2 diagram to the *«OperationalPerformers»* for the SAR system architecture.

Figure 5.2 shows the Operational Resource Flow or OV-2 for the SAR DoDAF architectural model. The SAR OV-2 shows the logical "who and what" without prescribing the "how" for the

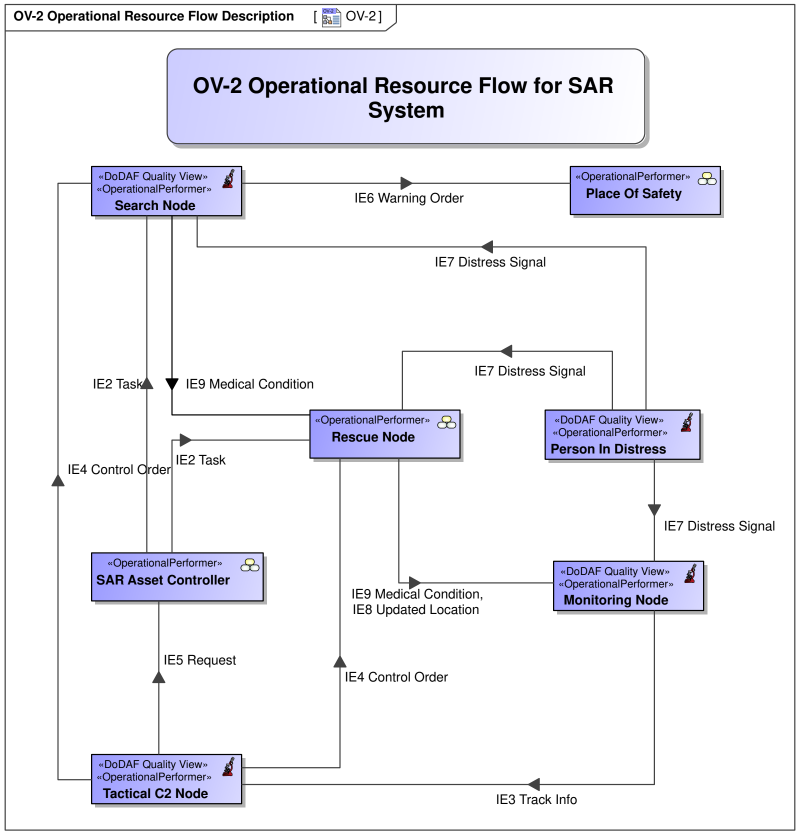

Figure 5.2: Search and Rescue (SAR) DoDAF Operational View OV-2

system [4]. The flow relations in the figure show the pattern of resource information specific to organizations, other systems or locations, allowing flows to be established without prescribing the way that the *«ResourceFlow»* is specifically handled [4]. The *«ResourceFlow»* will be used to understand the resources that the *«OperationalActivities»* for the system might need but are not specific in the scope of the SAR system architecture [4]. Figure 5.3 shows the *«OperationalPerformers»* as well a the hierarchy to the relations between each *«OperationalPerformers»*. The Operational Activity Decomposition Tree or OV-5a shows a structural aspect to the *«OperationalActivities»* and gives a hierarchy to the developed of *«OperationalActivities»* addressing the *«Capabilities»* needed for the system with general aspect at the top and more specific as the tiers are descended on the diagram [4]. Additionally, *«OperationalActivities»* can indicate logical interaction information between *«OperationalPerformers»* [4]. The *«OperationalActivities»* exchanges within an Operational Activity model or OV-5b and can be seen in Appendix C SAR OV-5b Operational View Command and Control signaling Figure C.1.

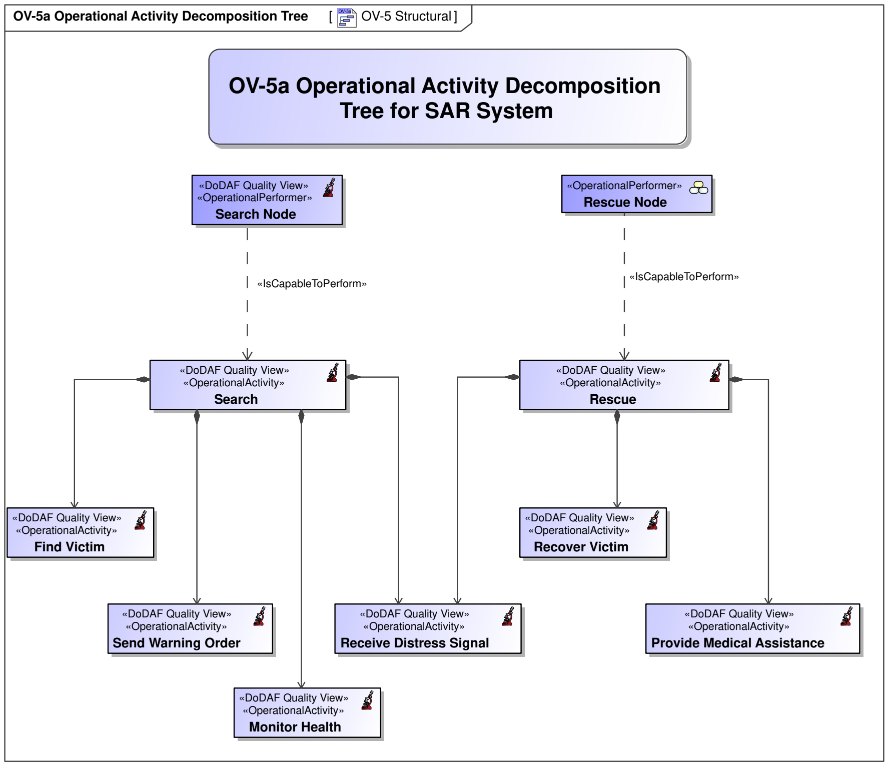

Figure 5.3: Search and Rescue (SAR) DoDAF Operational View OV-5a

The textual data present on the OV-1 diagram helps to describe what data is being conveyed between elements in order to accomplished the SAR system's mission [4]. The OV-1 uses textual context linkage to illustrate the mission for the SAR system to address needed DoDAF Capability View CV-1 shown in Figure 5.4. The CV-1 documents the *«EnterpriseVision»* and mission for the SAR system with high level *«EnterpriseGoals»* that must be accomplished [199]. Illustrated in Figure 5.4, is the phased implementation of the SAR system *«capabilities»* against a given time-line of execution to which primary *«capabilities»* will be integrated into the system [4]. The CV-1 gives strategic context for groupings of *«capabilities»* for the architecture by capturing the vision through a bounded period of time or *«ActualEnterprisePhase»* [4]. The CV-1 tells planners when *«capabilities»* can be expected to be addressed during the system lifecycle development as well as showing future transformation of the system. Note that both of the phases present on the CV-1 diagram illustrate the SAR architecture phases, of the two phase present one is not connected to any *«capabilities»* for development. Having an element present on the CV-1 diagram with no relationships to another *«ActualEnterprisePhase»* or *«EnterpriseGoals»* indicates a quality dip in the SAR DoDAF CONOP architectural model. The phased implementation of *«ActualEnterprisePhase»* linkage to the SAR DoDAF Capability Taxonomy or CV-2, gives additional timeline phasing *«capabilities»* for the system [4].

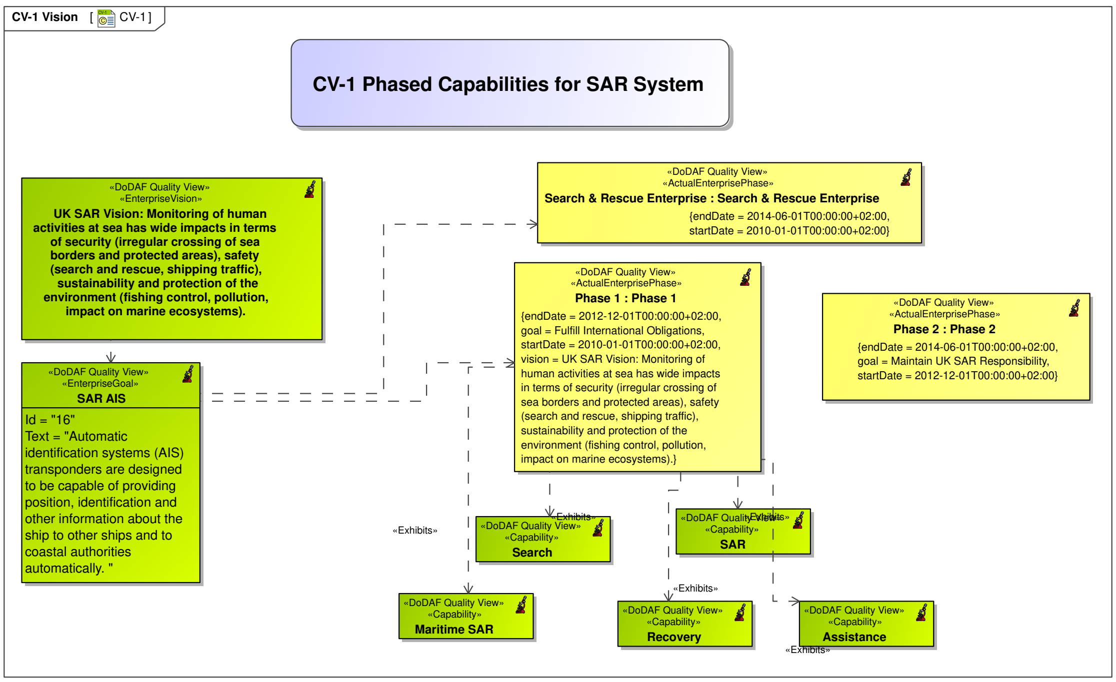

Figure 5.4: Search and Rescue (SAR) DoDAF Capability View CV-1

Figure 5.5 shows the *«capabilities»* of the SAR at an abstract level. The abstraction of the CV-2 is designed to drive "needs" for the system without prescribing a solution to the needed *«capabilities»* [4]. Figure 5.5 shows a structure aspect to the CV-2 giving a hierarchy to the development of *«capabilities»* with a generalized aspect at the top and more specific as the tiers are descended on the diagram [4]. The *«capabilities»* will be referenced in the *«OperationalActivities»* or Systems Functional Flow, bringing the system behavior to meet the capability need and interconnection of data for different aspects of the system design. The interconnection of data lead to the capture of the SAR System Interface Description or SV-1. Figure 5.6 shows the SAR SV-1 diagram. Figure 5.6 shows the connections between internal and external *«System»* blocks with directional *«AssociateionProperties»* interfacing the data exchanges [4].

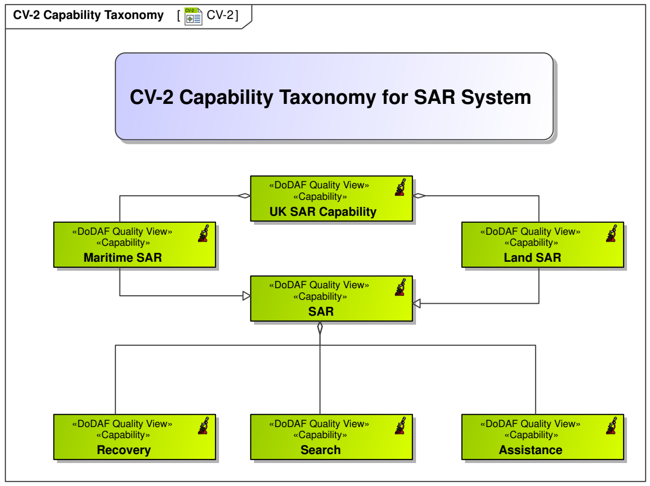

Figure 5.5: Search and Rescue (SAR) DoDAF Capability Taxonomy View CV-2

The represented *«Post»* show human interface components to the SAR system and what information is passed via Command and Control signaling to various *«ResourceArtifacts»*. The interactions described in the SV-1 bring the operational and system architecture to specify the logical architecture from the OV-2 [4]. When designing a system, the logical architecture outlines functional groups, selects particular logical components to implement functional architectures, and reflects the connection linkages and data interface links between logical components [200]. The logical architecture also describes how the logical scheme of the system, including logical non-redundant architecture and logical redundant architecture, is formed using BDDs and IBDs, and how the mapped relationship between functional architecture and logical architecture without redundancy, as well as between logical architecture with redundancy and functional architecture with redundancy, is established [200]. The grouping of element in the SV-1 brings the *«capabilities»* and *«OperationalPerformers»* to address each specific capability. The figure shows both hardware and software combined to meet the human interfaces for the system design. The complementary representation with the actual *«Function»* exchanges within an System Functionality Description model or SV-4 and can be seen in Appendix C. SAR SV-4 System View Command and Control signaling for Search and Rescue (SAR) can be seen in Figure C.2.

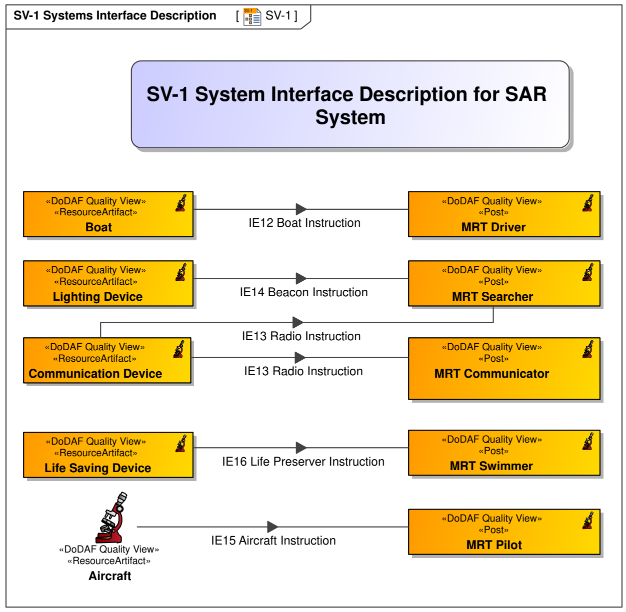

Figure 5.6: Search and Rescue (SAR) DoDAF System Interface Description SV-1

The final aspect of the SAR DoDAF views is the Conceptual Data Model or DIV-1. Figure 5.7 shows the conceptual data model for Command and Control signaling which indicates information for requirements and rules that manage or constrain the system design [201]. The provided *«InformationElement»*s provide factual grounding for concepts, associations, and attributes that are used to govern the design process from business to technical standards [4]. The items captured on the DIV-1 are part of the system design data model, and tie data of technical nature to the architecture concept [4]. The DIV-1 bridges the gap to bring in the logical and physical data together [4].

The Logical Data Model or DIV-2 relates information in an OV-1 concept or activity flow object on an OV-5b [4]. The DIV-2 is shown in Figure 5.8 and illustrates the implications from the OV-5b *«OperationalActivities»* and SV-4 *«Function»* for the information flows between elements in the system [4]. The details of the communication data can be seen within the connected information flows for the logical data model of the SAR system [4]. While all the data presented can be in

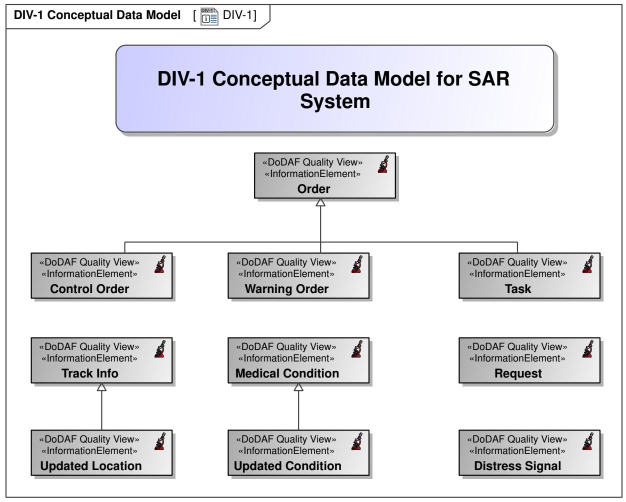

Figure 5.7: Search and Rescue (SAR) DoDAF Conceptual Data Model or DIV-1

many different formats, what is being relayed is critical data contained in *«InformationElements»* to address the needed data exchanges.

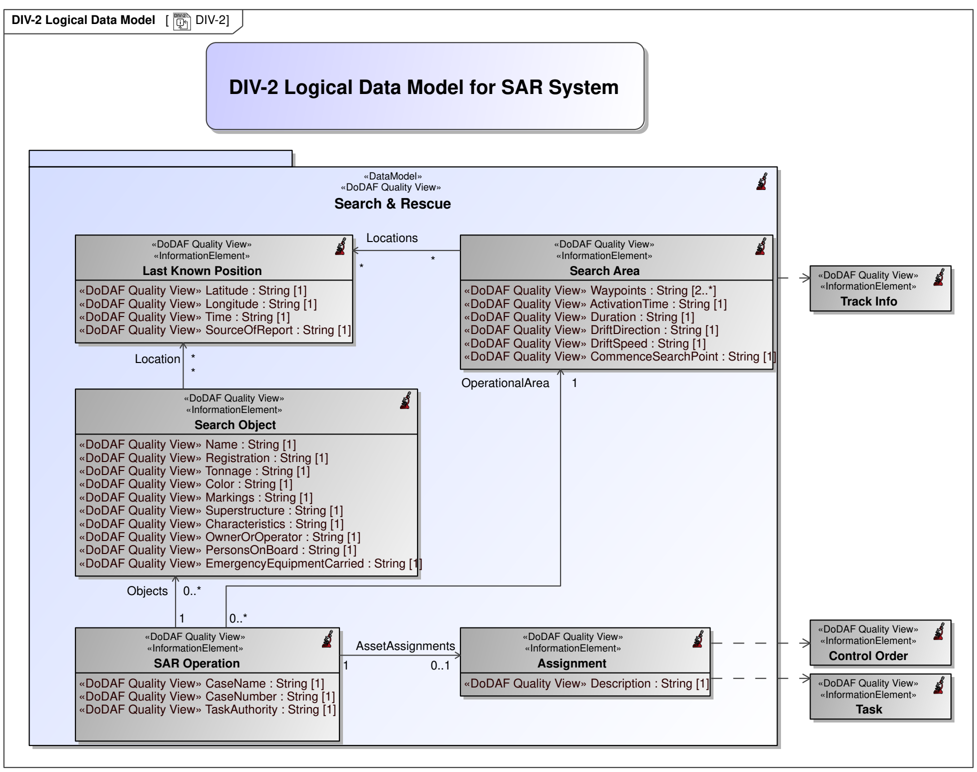

Figure 5.8: Search and Rescue (SAR) DoDAF Logical Data Model or DIV-2

The ultimate goal of the DoDAF CONOPs for the SAR DoDAF architectural model is to illustrate the mission that the system is supposed to accomplish. Due to the size of the diagrams, the author will only show diagrams from the Command and Control signaling mission thread. The diagrams above show an extensive DoDAF CONOP architecture that exist within the developed SAR DoDAF architecture model. The DoDAF view diagrams illustrate that for a single mission thread in the SAR system, the Command and Control signaling mission thread, the SAR architectural model covers the approach to CONOP development as laid out in Chapter 2 Section 2.1.3 DoDAF CONOP Design Process. The representative views for the Command and Control signaling mission thread show some of the following criteria:

- The operational environment and its characteristics [79]
- Major system components and the interconnection among those components [79]
- Interfaces to external systems or procedures [79]
- Capabilities, functions, and features of the current system [79]
- Operational risk factors [79]
- Performance characteristics, such as speed, throughput, volume, frequency [79]
- Provisions for safety, security, privacy, integrity, and continuity of operations in emergencies [4, 79]

5.2 Key SAR Terms

The key terms are critical to understand what information stands out to identify key relationships among data. The SAR open source documents helped to provide some of this information as well as data interrogation of the SAR architectural model. The document acts as an authoritative source for the definition of terms and acronyms that have applicability across the development effort in order to maintain consistency of their interpretation [230]. For the purpose of this dissertation, the definitions were pulled from the lexicon documentation that have particular focus on the DoDAF CONOP terminology and association with DoDAF views CV-1, CV-2, DIV-1, DIV-2, OV-1, OV-2, OV-5a, OV-5b, SV-1, and SV-4. The terms are as follows:

- **Capability:** Generic capability or procedures include a broad variety of capabilities, processes, and teams that may be required in order to support the core generic strategy and its supporting infrastructure [230]. A single block of flats or a whole area may be required to be evacuated in an emergency situation, for example, It is possible that generic skills will be necessary in order to cope with both forms of activity [230]. It includes the people who are mobilized by a plan, as well as their equipment and training. It also includes the planning, doctrinal, and control structures that are used to carry out their operations [230].

- **Data Model:** This refers to a model of a model in its strictest sense [230]. A representation of the entities (and data components) relevant to an architecture, including the connections between entities and their properties or features, is referred to as SAR in this context [230].

- **Function:** A resource is responsible for performing a function [230]. In the context of information technology systems, it is most often used to refer to data transformations [230]. However, it also includes human activities and software functions that are involved in processing data or physical materials, as well as other operations [230].

- **Operational Availability:** An activity is any action that is carried out in the course of running the operations of a company [230]. It is a broad phrase that does not suggest a specific position in a hierarchical structure (e.g., it could be a process or a task as defined in other documents and it could be at any level of hierarchy) [230]. It is used to depict operational behaviors rather than the functionalities of hardware and software systems [230]. Depending on the context, operational activity may involve military actions or commercial procedures [230].

- **System:** System architecture is a collection or arrangement of interdependent systems that are linked or integrated in order to achieve a higher level of capabilities [230]. The loss of a single component system will reduce the performance of the whole system, but will have no effect on the performance of the individual component systems themselves [230].

While the terminology listed above illustrates the general ideas that represent the DoDAF viewpoints, it is critical to note that not all the terms match in one to one relationship, meaning DoDAF terms to SAR terms. The author used interpretation to correlate terminology between DoDAF terms and SAR terms.

5.3 Definition of QbD for SAR

The first step in the application of the DoDAF Quality Conceptual Framework (DQCF) is illustrated in Figure 5.9. As discussed in Chapter 3 Section 3.5 Framework Application, contextual mapping allowed the author to apply DQCF to the SAR DoDAF architectural model. The approach allowed for clear identification of DoDAF CONOP views for the evaluation scope as discussed in the approach of Chapter 3. Highlighted in red dashed boxes indicate the critical mappings from Juran's QbD method to the SAR DoDAF model architecture driving out the DoDAF CONOP views of the architecture for Command and Control signaling mission thread. Elements within the corresponding views will be evaluated using the Quality Characteristic Categories (QCC) in Appendix A evaluation method as described in Chapter 3.

5.4 DQCF Application to SAR

Figure 5.10 shows the DoDAF Quality Conceptual Framework (DQCF) imported into the model as a used project. The import indication is shown as grayed out text for the *«Package»* titles at the bottom of the figure. Importing the DQCF as a used project allows the user to use the profile stereotype *«DoDAF Quality View»* in the model to evaluate model elements with the QCC criteria in Appendix A. Additionally, importing the DQCF as a used project prevents user modification and allows for maintaining the data integrity of the profile and template contents. The figure also shows the containment tree for the SAR DoDAF architectural model limited to the CONOP views needed for evaluation based on the QbD mapping from previous Section 5.3. The

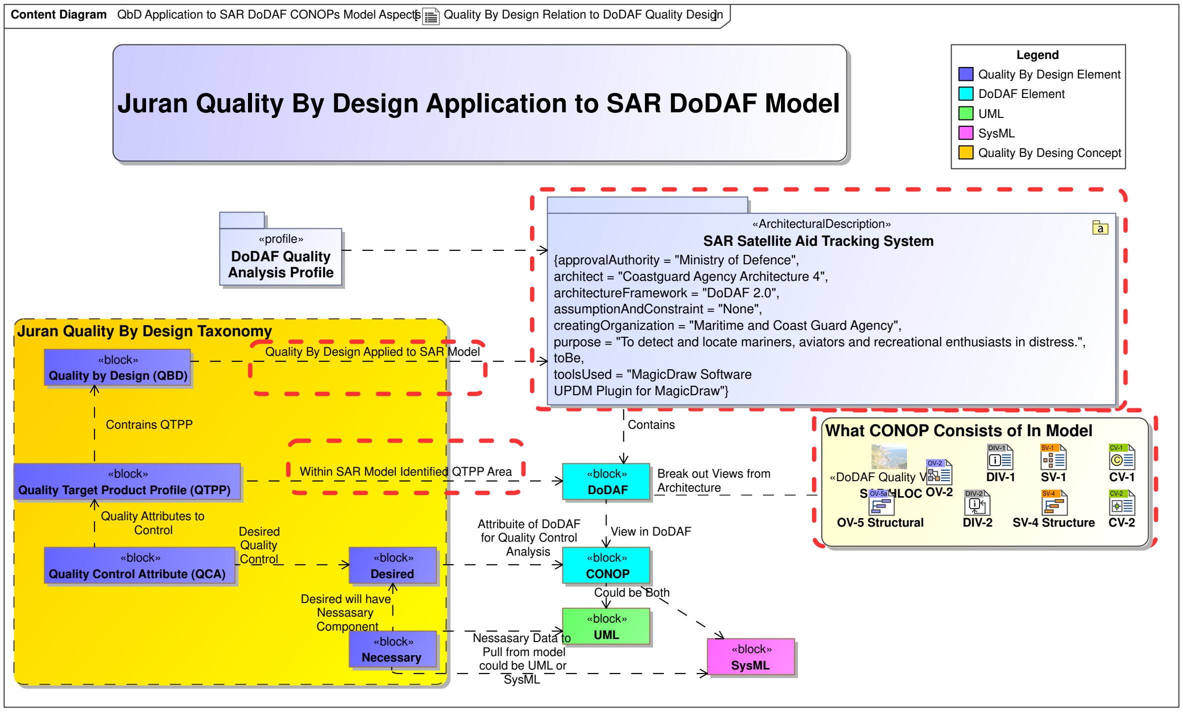

Figure 5.9: Search and Rescue (SAR) DoDAF QbD Mapping

Containment Tree or Browser Folder structure in the model presents what is consider the *«Containment»* relationship of elements on or within a *«Diagram»* or *«Package»* [107]. For the most part the *«Containment»* is a way of organizing the data in a model, similar to a file structure on a computer drive. While the *Containment Tree* leads to a nested containment hierarchy of model elements, in reality is a means of model organization to reduce complexity and manage development efforts [73].

SAR DoDAF content data outside of the scope for the SAR CONOP views associated with the Command and Control signaling mission thread were moved to a *Additional SAR DoDAF Material «Package»*. While the excess content may be needed for full presentation of the SAR DoDAF architectural model, for this dissertation analysis purposes scope of the data was limited help to reduce complexity.

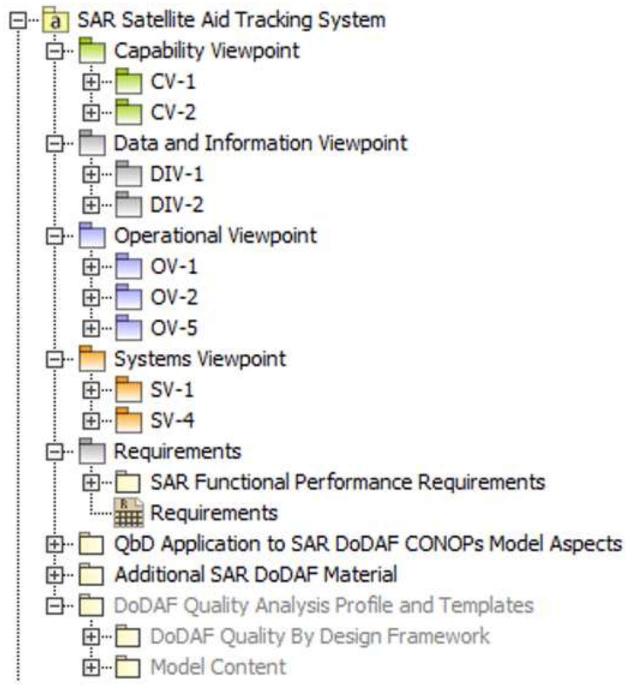

Figure 5.10: DoDAF Conceptual Framework as Used Project in SAR Model

5.5 SAR Element Sampling

Count of the total elements was needed to understand how much of the model would be evaluated for the SAR DoDAF architecture. Table 5.1 gives a high level break down of the elements contained in the DoDAF CONOP architecture. The table shows how many project diagrams exist for the SAR DoDAF CONOP architecture model; however, only ones defined in Chapter 2 Section 2.1.3 the DoDAF CONOP Design Process with focus on Command and Control signaling mission thread were considered. A full detailed count of the elements by metaclass type can be found in Appendix C SAR DoDAF CONOP Element Break Down.

Table 5.1: SAR DoDAF CONOP Element Counts

Cameo Project Statistics	**Count**
Project Diagrams	197
All Diagrams	342
Project Elements	9303
All Elements	133473
Project Symbol Styles	7
All Symbol Styles	41

The sampling extracted from all of this data constituted the following elements that will be analyzed by the DQCF framework. Table 5.2 shows the breakdown of the element count that will be evaluated for the SAR DoDAF CONOP model. Note that the OV-5 value represents both the OV-5a and OV-5b for the SAR DoDAF CONOP architectural model. This is a nuance of the Cameo Enterprise Architecture tool where the OV-5 views are combined typically under one diagram type. Each one of these elements is confirmed to have an Element ID, UUID, or GUID, making the elements real within the architecture of the model and maintains the data integrity of that element [205]. By maintaining the element GUID, an element can not be fabricated and must come form the Cameo Enterprise Architect Tool.

Table 5.2: SAR DoDAF Element Evaluation Count

DoDAF CONOP View	Element Count
CV-1	13
CV-2	23
DIV-1	7
DIV-2	111
OV-1	7
OV-2	160
OV-5	46
SV-1	134
SV-4	89
Total	*590*

The total of 590 elements of the SAR model, which represents the SAR DoDAF CONOP is roughly 6.34% of the total SAR DoDAF architecture. Figure 5.11 shows the percentage of elements that make up each view for the SAR DoDAF CONOP. The figure shows that the bulk of element constitute the DIV-2, OV-2, OV-5, SV-1, and SV-4 for the CONOP. These views fall in line with the understanding for development of the DoDAF CONOP development process and a considered important in weighting of views which will be used later for modularity calculation. Once the graphic system representation is established or OV-1 view, understanding for operational node communication or information flows of logical resource data to the *«OperationalActivity»* is critical in the system design process [4]. The DoDAF standard states that the OV-2 is the *backbone* to which all other DoDAF element will be overlaid for the SV-1 interface description to shows what *«OperationalPerformer»* is providing a capability [4]. The OV-2 integrates the corresponding *«OperationalActivity»* of OV-5a Operational Activity Decomposition Tree or OV-5b Operational Activity Model to display interactions of behaviors in the architectural model [4]. The OV-2 transitions as expected to the OV-5 percentage which makes up the OV-5a and OV-5b for the SAR DoDAF CONOP. For the purpose of analysis and image space for this dissertation, the Command and Control signaling for search and rescue *«OperationalActivity»* and *«Functions»* were displayed in Appendix C. The author would like to note that to fully represent the system, as is the case with the SAR, it can sometimes take hundreds of *«OperationalActivity»* diagrams to represent the entire system. The OV-5a and OV-5b are used to clearly outline *«OperationalPerformer»* that are preforming redundant activities for the system design [4]. The *«OperationalActivity»* will become the *Realized «Functions»* in the SV-4 for the system design that the system must perform. The figure illustrates that in the DoDAF standard execution process the OV-2 elements make up a large percentage of the SAR DoDAF CONOP architecture.

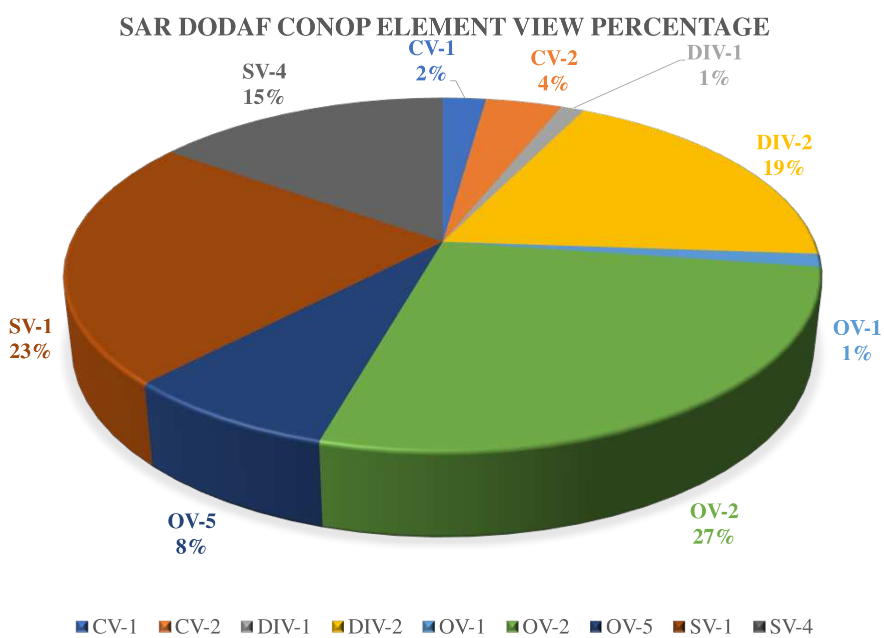

Figure 5.11: SAR DoDAF CONOP Element View Percentage

When these 590 elements are evaluated against the 17 Quality Characteristic Categories (QCC) criterion, a total of 10,030 data points are present for the evaluation process. The selections of elements represents a *purposive sampling* and is believed to be representative of the SAR DoDAF CONOP Command and Control signaling mission thread complete population of elements [206]. he accurate representation will be tested against the Kaizer-Meyer-Olkin (KMO) sample adequacy test to verify sampling. While subjective may be a factor, the author believes subjectivity has been addressed through rigorous scoping and qualification of data selection to meet the needs for analysis purposes.

5.6 SAR Analysis Results

The following sections of the case study represent the evaluation results for the SAR DoDAF CONOP Command and Control signaling mission thread evaluation.

5.6.1 Normality Testing And Descriptives

The first step was to look in depth at the descriptive statistics for the SAR evaluation data set and the mean values for *DEQ*, *REQ*, and *LEQ* were calculated to assist with this testing. First, the author looked at the Skewness and Kurtosis of each of the means for the dataset. Table 5.3 shows the SAR Descriptive Statistics for evaluation data set. The data in the table is of particular interest to the analysis process that was describe in the analysis approach of Chapter 2 Section 2.2.7. The data shows that while the median value can give you a better interpretation of the consolidated rating variables for each of the individual elements, when consolidated across all elements evaluated a problem is presented. The data shows that the median for *DEQ* and *REQ* descriptives would be completely eliminated from from consideration in the rest of analysis. The median values for *DEQ* standard error, the dependent variable standard error, is very high which indicates that the value is not representative of the sample. The mean values for all variables in this instance could provide a more meaningful result for the analysis and were used for further evaluation. The standard error presented in the table is the standard deviation of the statistical sample population [207]. The standard errors are small for the mean values in the data set, meaning that mean values are more representative of overall population [207]. The author analyzed the data set for Skewness and Kurtosis of each of the means values for each variables. The closer the values for Skewness and Kurtosis are to 0 indicates an more normal distribution [208]. Remember that Skewness and Kurtosis indicate symmetry and peakness of the formed plot of data [208]. Furthermore, Skewness and Kurtosis can provide some interpretation about the model results when the values are positive or negative values [209, 210]. In distributed models, the negatively skewed distribution refers to the model in which more values are shown on the right-hand side of the graph, while the tail of the distribution is spread on the left-hand side [208]. A positively skewed distribution refers to the model in which more values are shown on the left-hand side of the graph, while the tail of the distribution is spread on the right-hand side [208]. Given the values of the Likert Scale, an interpretation can be made about the model variable QCC mean values [209, 210]. The values for Skewness and Kurtosis are presented in the table. Based on these values, the data is considered to not be normally distributed.

The data indicates that more values are on the right-handed side of the graph in Figure C.4, which shows a higher quality for *DEQ*. *LEQ* indicates that more values are on the right-handed side of the graph as well in Figure C.7. *REQ* indicates a larger spread between values Figure C.10. While the values are considered negatively skewed, this could have an impact on the quality of the SAR model. The values can be both positive, meaning that there are some high valued outliers, and negative, meaning some low valued outliers with in the data set [211]. The frequency and Q-Q-plot plots for Skewness and Kurtosis of both mean and median can be seen in Appendix C for SAR evaluation data set. Now that the Skewness and Kurtosis values and the SAR descriptive statistics were calculated, additional checks can be made based on the prescribed approach to statistical methods for the DQCF framework in Section 2.2.7 of Chapter 2. Both Kolmogorov-Smirnov and Shapiro-Wilk are shown in Table 5.4 to address normality. The table includes the calculated statistic*KS* Kolmogorov-Smirnov and *W* Shapiro-Wilk; *df* or "Degrees of Freedom" meaning number of observations; and *Sig* or significance. The table shows the consolidated mean values of *DEQ*, *LEQ*,

Table 5.3: SAR Descriptives

SAR Descriptives					
		Mean		**Median**	
		Statistic	**Std. Error**	**Statistic**	**Std. Error**
DEQ	**Mean**	5.10	0.07	5.89	0.87
	Median	6.00		7.00	
	Variance	2.86		4.51	
	Std. Deviation	1.69		2.12	
	Minimum	1.00		1.00	
	Maximum	7.00		7.00	
	Range	6.00		6.00	
	Skewness	-1.73	0.10	-1.64	0.10
	Kurtosis	1.43	0.20	0.95	0.20
LEQ	**Mean**	5.37	0.07	6.22	0.08
	Median	5.80		7.00	
	Variance	2.93		4.04	
	Std. Deviation	1.71		2.01	
	Minimum	1.00		1.00	
	Maximum	7.00		7.00	
	Range	6.00		6.00	
	Skewness	-1.89	0.10	-2.20	0.10
	Kurtosis	2.35	0.20	2.85	0.20
REQ	**Mean**	4.75	0.09	5.19	0.10
	Median	6.00		7.00	
	Variance	4.60		6.27	
	Std. Deviation	2.15		2.50	
	Minimum	1.00		1.00	
	Maximum	7.00		7.00	
	Range	6.00		6.00	
	Skewness	-0.78	0.10	-0.84	0.10
	Kurtosis	-0.95	0.20	-1.10	0.20

and *REQ* that were used for evaluation. Both tests are included, but the sample size of elements for evaluation dictates what test is applicable to use in order to understand the distribution [212]. Due to the element count being greater than 100, the Kolmogorov-Smirnov test will provide the most accurate answer for the SAR data set [212]. Because the mean values are significant for both tests, it can be assumed and confirmed that the data is not normally distributed [212]. With both normality checks in place, it can be safe to assume that the SAR data set is not normally distributed. By clarifying this assumption, the author avoids any risk to further analysis on the SAR data set. For all of the plot data, please see Appendix C.

Table 5.4: SAR Tests of Normality

Tests of Normality						
	Kolmogorov-Smirnov			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
DEQ_Mean	0.37	590	0.00	0.59	590	0.00
LEQ_Mean	0.38	590	0.00	0.62	590	0.00
REQ_Mean	0.30	590	0.00	0.80	590	0.00

5.6.2 Multicollinearity

To prepare the data set for PCA analysis, the author needed to address Multicollinearity between variables in the data set. First, the correlation matrix was calculated for understanding the correlation between variables of a non-parametric nature using Spearman's ρ. Collinearity in this context is a linear association between two variables in the SAR evaluation data set [213]. Multicollinearity is a situation where two or more variables in the SAR evaluation data set are highly linearly related [213]. The correlation matrix for SAR evaluation data can be found in Appendix C. The table details the every factor including a correlation coefficient and significance on for each observation. When the correlation coefficient is 1.00, the criterion is perfectly correlated with itself [215]. The SAR correlation matrix does not form an identity matrix, meaning that the value of 1.00 is along the diagonal of the matrix from top left to bottom right [235]. Based on the analysis, the correlation matrix does not form a identity matrix, and the analysis can continue.

The next objective is to detect what variables have a low tolerance and high Variance Inflation Factors (VIF); these are indicators of collinerarity [214]. The author discovered that several evaluation criterion had very strong correlation to one another in the correlation matrix. Analysis studies suggest that correlation coefficients of values, positive or negative, above 0.80 are of potential concern for analysis [215]. Furthermore, if the VIF calculated values are above 10, this indicates a possible cause for concern, and most likely should be eliminated with justification or explained in detail [215]. The author completed a Variance Inflation Factors (VIF) analysis and excluded variables that were considered to be an issue to the analysis. The variables included *DEQ2*, *DEQ4*, *DEQ6*, *LEQ2*, *LEQ3*, *LEQ4*, *LEQ5*, *REQ1*, *REQ2*, *REQ3*, *REQ4*, and *REQ6*. The suggested elimination of these variables means that the DQCF quality aspect for these QCC criterion could present an impact that must be investigated before the SAR DoDAF CONOP architecture PCA analysis is to proceed. Upon further interrogation of the values for exclusion, the following determinations were made:

- ***DEQ2***: Does the element present strategic information that explains the existing and/or intended links between an organization's business, mission, and management processes, and the supporting infrastructure associated to the architecture?
  - **Result Finding**: The majority of elements evaluated had some form of relationship to the SAR DoDAF architecture being direct or indirect. The calculated VIF showed a value of 17.1 which is above the recommendation of 10 for VIF calculated value [216]. A direct relationship is a relationship to another element on the same diagram graphically. An indirect relationship is one which is carried over from another diagram or through another element on a different diagram. This means that some degree of modularity is present in the architecture but to what degree remains elusive at this point. Further discussion on the degree of modularity will be addressed in Section 5.6.5 of this Chapter. This part of assessment is concerned with the networked relationships between the graphical elements that have been displayed [157, 160].
- ***DEQ4***: Based on the DoDAF element type, do related sub-elements at each tier of the system design or desired level achieve goals and objectives corresponding to the scope and purpose that have been established.
  - **Result Finding**: The calculated VIF showed a value of 11.1 which is above the recommended of 10 for VIF calculated value [216]. Many elements had corresponding sub elements in the model. While this factor must be eliminated for the purpose of the PCA

analysis, this factor did drive some concerns for quality. An example of note would be on the CV-1 diagram which illustrates the SAR architecture phases. Of the two phases present, one is not connected to any *«capabilities»* for development. Having an element present on the CV-1 diagram with no relationships to another *«ActualEnterprisePhase»* or *«EnterpriseGoals»* indicates a quality dip which is reflective of the VIF value being close to 10 but still considered high.

- ***DEQ6***: Does the DoDAF element data type presented continue to present key information in a way that is understandable, congruent with, and consistent with all of the various stakeholders communities engaged in developing, delivering, and sustaining capabilities to assist in achieving system design goals.
  - **Result Finding**: While many elements did not have a consistent "Agree" with this criterion, the calculated VIF showed a value of 16.5 which is above the recommended of 10 for VIF calculated value [216]. The high VIF value means the variable must be eliminated in order to mitigate any issues to conduct PCA analysis. By having this criteria eliminated it is suspected that modularity will be impacted. Further discussion on the impact to modularity will be illustrated in Section 5.6.5 of this Chapter. Consistency and continuity for element data are important considerations when addressing modularity within an architecture, and this part of assessment addresses these considerations. This means that some degree of modularity is present in the architecture but to what degree remain elusive at this point. The element presented in the SAR DoDAF CONOP with in the scope of the Command and Control signaling had details to support the elements.
- ***LEQ2***: Based on the UML/SysML element, is the stereotype used correctly according to standard to provide a collection of diagrammatics, modeling components, a formal vocabulary, and semantics for the desired use in the model [73]. As with any language, it may be employed in a variety of ways, and in a variety of incorrect ones as well [73].

- **Result Finding**: The majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *LEQ2* statement, the calculated VIF showed a value of 38.1 which is above the recommended of 10 for VIF calculated value [216]. An example would be the element *«FunctionalAction» Receive TDM* that was present in the functional Figure C.2 in Appendix C. The SAR model execution did not have a SysML termination to the *«ControlFlow»* functions or justification with in the model or documentation. By creating behavior without justification could cause scope creep, or additional cost for development for the SAR system design.

- ***LEQ3***: Based on the UML/SysML element, is the element related through relationship in the architecture and the relationship type correct [73].

  - **Result Finding**: The majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *LEQ3* statement, the calculated VIF showed a value of 39.0 which is above the recommended of 10 for VIF calculated value [216]. Example would be the element *«OperationalActivityAction» Process Warning Order* that was present in the functional Figure C.1 in Appendix C. The SAR model execution did not have a SysML termination to the *«ControlFlow»* for the *«OperationalActivityAction»*. By creating behavior without proper termination, this could cause model execution problems and potential for rework development for the SAR system design.

- ***LEQ4***: Based on the UML/SysML element, does the element describe the underlying ideas or justifications behind its use, such as the choice of analytic method or design approach [73]. The element may serves as a source of information or a reference to the reasoning behind the modeling choice [73].

  - **Result Finding**: Majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *LEQ3* statement, the calculated VIF showed a value of 54.9 which is above the recommended of 10 for VIF calculated value [216]. The the very high VIF indicates a related independent variable has a high degree of correlation with the other variables in the model [216]. *LEQ4* has a high possible correlation with *REQ4* due to similar justification to the architecture but different meaning for the justification.

- ***LEQ5***: Based on the UML/SysML element, is the element using the correct UML/SysML semantics, or meaning, of linguistic ideas between the two languages to bring value to the system design [73]. A descendant of the UML which was initially established as a modeling language for software design but has been expanded by SysML to accommodate general-purpose systems modeling [73].

  – **Result Finding**: The majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *LEQ5* statement, the calculated VIF showed a value of 60.3 which is above the recommended of 10 for VIF calculated value [216]. The very high VIF indicates a related independent variable has a high degree of correlation with the other variables in the model [216]. *«ActivityFinal»* vs *«FinalFlow»* the impact of these stereotypes are only felt during compiled execution of a model activity. In several cases in the SAR model improper used was done so the diagram would not execute or compile properly.

- ***REQ1***: Circumstance are identified completely and precisely defined. All factors that influence the DoDAF Element are specified and precisely defined. Circumstance of the DoDAF Element design attributes consists of states/modes, environments, constraints or combinations which constrain the system design [167–169].

  – **Result Finding**: The majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *REQ1* statement, the calculated VIF showed a value of 16.4 which is above the recommended of 10 for VIF calculated value [216]. For most elements present in the SAR model states/modes, environments, constraints or combinations were present and indicated logical data connections including connection to the DIV-1 and DIV-2.

- ***REQ2***: Is the DoDAF Element related to function and is that function identified completely and detectable. Is the DoDAF Element functional process detectable during execution to perform some action within the system [168, 169].
  - **Result Finding**: Majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *REQ2* statement, the calculated VIF showed a value of 28.5 which is above the recommended of 10 for VIF calculated value [216]. Majority of elements were related to *«FunctionalAction»* elements in the architecture, one case an element had a ";" semicolon as the actual name and presents some inconsistency in the architecture.
- ***REQ3***: All required inputs are completely defined and detectable. Input of each DoDAF Element should be detectable at the system boundary which initiate functions; may include system state transitions [168, 169, 236].
  - **Result Finding**: Majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *REQ3* statement, the calculated VIF showed a value of 24.8 which is above the recommended of 10 for VIF calculated value [216]. The data logical architecture DIV-2 was well defined for the SAR DoDAF CONOP for the Command and Control signaling, however data type were standard string and not connected to *«ActualMeausrementSet»* or *«MeasurementSet»* stereotypes.
- ***REQ4***: The DoDAF Element is derived from a standardized source or defined by customer. Justification would be a means to document the reason for having the element in the model [168, 169].
  - **Result Finding**: Majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *REQ4* statement, the calculated VIF showed a value of 22.4 which is above the recommended of 10 for VIF calculated value [216]. *REQ4* has a high possible correlation with *LEQ4* due to similar justification to the architecture but different meaning for the justification.

- ***REQ6***: Based on the DoDAF Element, a case can be conceived to assess all aspects of the DoDAF Element for a system design. Refers to the ability to verify or audit the DoDAF Element through the process of verification.
  - **Result Finding**: Majority of elements evaluated on the Likert Scale, which presented a "Agree" with the *REQ6* statement, the calculated VIF showed a value of 14.3 which is above the recommended of 10 for VIF calculated value [216]. The ability to verify or audit the some of the DoDAF elements through the process of verification, would have been relatively simple but given several mistakes in diagrams this was still not sufficient to include for PCA analysis.

After the above variables were eliminated, the VIF values are shown in Table 5.6. The removal of the variables will allow the following to be used in PCA analysis in the next section.

Table 5.5: SAR Factors Eliminated due to VIF

Factors Eliminated due to VIF	
QCC Factor	**VIF Value**
DEQ2	**17.1**
DEQ4	**11.1**
DEQ6	**16.5**
LEQ2	**38.1**
LEQ3	**39.0**
LEQ4	**55.0**
LEQ5	**60.4**
REQ1	**16.4**
REQ2	**28.6**
REQ3	**24.9**
REQ4	**22.5**
REQ6	**14.3**

5.6.3 Principal Component Analysis

The next analysis step in the DQCF process was to conduct a Principal Components Analysis (PCA) for the remaining values from the previous section. In the previous section, factors were

Table 5.6: SAR VIF Calculations

	Collinearity Statistics Tolerance	**VIF**
DEQ1	0.40	2.50
DEQ3	0.97	1.03
DEQ5	0.40	2.48
LEQ1	0.49	2.06
REQ5	0.49	2.06

removed and their removal was explained based on the Variance Inflation Factors (VIF) values and other factors for analysis. The first step was to determine how accurately the evaluation data set represents the purposeful sampling adequacy for the SAR DoDAF CONOP architecture. Table 5.7 shows the results of the KMO and Bartlett's Test values. The table shows that despite the amount of 590 elements from the SAR architecture with a the primary focus on Command and Control signaling, the data KMO value is 0.55 with a significance of less than 0.5. The KMO value is considered on the lower end of the suggested rating scale of 0.5 to 1.0 but adequate enough to proceed with the analysis [218, 219]. Furthermore, the Bartlett's Test of Sphericity showed that the correlation matrix formed is not an identity matrix [220]. By confirming that the correlation matrix is not identity and has significance of less than 0.05 indicates that the data is acceptable for PCA analysis [221]. The values indicate that even though the relatively small purposeful sampling only representing 6.34% of the total SAR CONOP, the sample does adequately represents the SAR DoDAF architecture. With this understanding in mind, analysis could proceed to understand the details of the SAR evaluation data set.

Table 5.7: SAR KMO and Barlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.55
Bartlett's Test of Sphericity	**Approx. Chi-Square**	994.03
	df	10
	Sig.	0.00

Questions *DEQ1*, *DEQ3*, *DEQ6*, *LEQ1*, and *REQ5* could be reduced to represent the quality of the model. Table 5.8 indicates that the total variance is achieved 70.7% for a total of two factors. From the first component forward, each consecutive component is derived by partially removing the previous component from the preceding component [222]. The first component explains the greatest amount of variation, while the final component explains the least amount of variance [222]. When it comes to statistical research, extracted components often explain just 50% to 60% of the variance [136]. No real adjustment is needed for the 50% to 60% of the variance when the total variance is achieved at 70.7% for a total of two factors. The table also provides the initial eigenvalues for each component and percentage of accounted for variance in the data set. Table 5.9 shows the percentage for two factor with the eigenvalues plotted in Figure 5.13. Loadings range from between -1 to 1 [9]. In this case, loadings near -1 or 1 imply that the variable has a significant impact on the component [9]. Loadings that are close to 0 imply that the variable has little impact on the component under consideration [9]. Evaluation of the loadings aid in the identification of each component's characteristics in terms of the variables [9]. Eigenvalues that are greater than 1 should be retained for and represent the bulk of the SAR evaluation data set [220]. For this purpose of analysis, a focus was put on the oblique rotation or varimax rotation due to the more realistic representation for the data [220, 221]. The varimax rotation tries to maximise the amount of variance through redistribution across all the recommended factors [221]. Figure 5.12 shows the Scree Plot of the eigenvalues from showing the principal components for total variance of SAR evaluation data set.

Table 5.8: SAR Total Variance Explained

Total Variance Explained						
Comp	**Initial Eigenvalues**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	2.2	43.4	43.4	1.8	36.2	36.2
2	1.2	27.3	70.7	1.7	34.5	70.7
3	1.0	19.0	89.7			
4	0.3	5.7	95.5			
5	0.2	4.6	100.0			
Extraction Method: Principal Component Analysis.						

Table 5.9 shows the weighted aspect of each question to the component factor loading. When the QCC criteria are analyzed at an abstracted level, the picture becomes clear to what drives variance in the SAR case study data set. *DEQ* and *LEQ* factors primarily show how the DoDAF standard and UML/SysML languages were applied to the overall elements. The finding in the application shows factors that could drive improvement in the SAR DoDAF CONOP architecture quality.

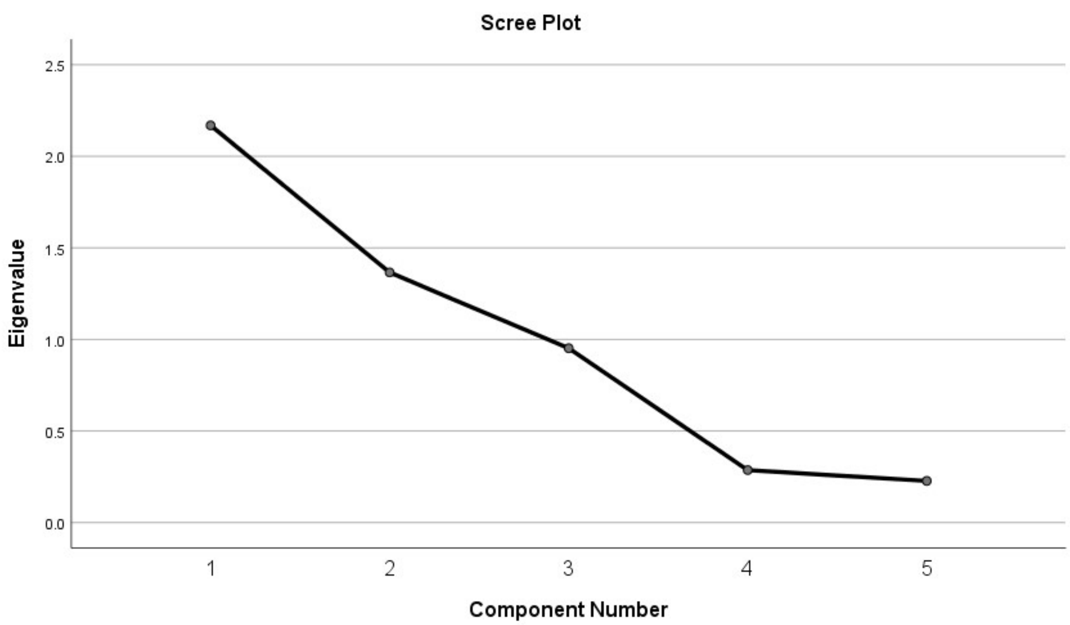

Figure 5.12: SAR Eigenvalue Screen Plot

Many elements in the model were left without descriptions in the SAR DoDAF CONOP architecture quality architecture. Leaving descriptions off is critical when performing an outside audit of model quality. The auditor or Quality System Engineer would not know every exact detail or have complete understanding of all documentation related to the system. The descriptions or missing names for elements becomes critical for a customer to understand what is being represented in the model. Many of the elements in the SAR DoDAF CONOP architecture did not have a sufficient requirement element instantiation within the architecture.

Table 5.9: SAR Component Matrix

Component Matrix-a		
	Component	
	1	**2**
DEQ1	0.93	0.08
DEQ5	-0.04	0.36
REQ5	0.94	0.06
LEQ1	0.14	0.90
DEQ3	0.14	0.88
Extraction Method: Principal Component Analysis. Rotation Method: Varimax		
a. Rotation converged in 3 iterations.		

Quality of the model dips in this aspect for the SAR. While elements existed, they often did not have adequate requirement representation. An example would be the element *Receive TDM* that was present in the functional Command and Control signaling SV-4 diagram in Appendix C. The element execution did not have a SysML termination to the *«ControlFlow»* for the *«OperationalActivityAction»*. By creating behavior without proper termination, this could cause model execution problems and potential for rework development for the SAR system design. For the factors pertaining to *DEQ* the SAR DoDAF CONOP, they seemed to have many lacking aspects that would be identified with further analysis under Ordinal Logistic Regression Section 5.6.4. While some of the *DEQ* were present at the system level, many lack the complete instantiation of the architecture to lower levels for element development. An example of this can be seen on the SAR DoDAF CONOP SV-1 Figure 5.6. Multiple *«ResourceArtifacts»* are not connected but are present on the diagram. While this is a minor presentation for linkage of *«ResourceArtifacts»* to parts of the system, this should be completed to show complete linkage in the architecture. By doing this the SAR DoDAF CONOP dips in quality for presentation of elements.

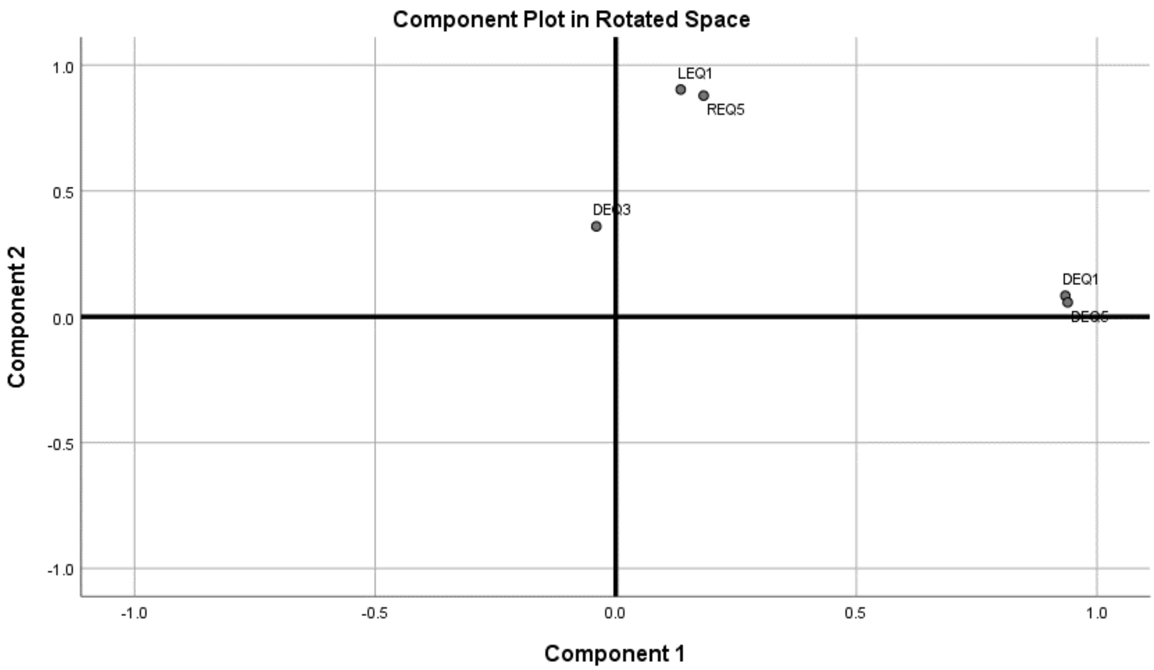

Figure 5.13: SAR DoDAFTwo factor Loading Plot

5.6.4 Ordinal Logistic Regression

This section discusses the Ordinal Logistic Regression (OLR) application of the SAR DoDAF CONOP evaluation data set. The OLR analysis has many benefits and was conducted to determine feature extraction interpretation from the SAR DoDAF CONOP evaluation data set [224]. In the event that OLR violates the proportional odds assumption, Multinomial Logistic Regression (MLR) is recommended for analysis. Only when the proportional odds assumption is violated will MLR be used over OLR. The proportional odds assumption has a constant relationship between the independent variable and dependent variables [144]. While MLR can be used for ordinal data; communities of practice prefers OLR for statistical analysis [144]. The checks and tests completed on the data set are in line with IBM SPSS version 26 for OLR and provide rigor to ensure correct analysis.

Table 5.10 shows the model fitting information for the data set. The table indicates a significant improvement to the model fit over the final model relative to the intercept only [225]. The log likelihood addresses the final vs the null product against -2log and is used to determine if all of the

Table 5.10: SAR Model Fitting Information

Model Fitting Information				
Model	**Model Fitting Criteria**	**Likelihood Ratio Tests**		
	-2 Log Likelihood	**Chi-Square**	**df**	**Sig.**
Intercept Only	1355.30			
Final	530.58	824.71	5	0.00

predicted regression coefficients in the model are zero at the same time [221]. In the SAR DoDAF CONOP evaluation data set, the intercept only value is calculated at 1355.30 with a final of 530.58 at a significance of $p < 0.05$. Since the significance level of the log likelihood addresses the final test is less than 0.05, you can conclude the final model is better and outperforming the null [226]. The final value informs you that the model makes better predictions than you would have made if you had just guessed based on the marginal probabilities of the outcome categories [226]. The *Chi-Squared* value is different as the log likelihood intercept only because the value is the delta between log likelihood and final log likelihood [215]. The *Chi-Squared* indication is that an association exists between the observed element ratings and what would be an expected rating for similar element analysis [215]. The *df* indicates the degree of freedom or number of predictors to calculate the *Chi-Squared* [226]. The *Sig.* shows the significance of the *Chi-Squared* calculated statistic, because this value is $p < 0.05$ the model presents a good fit to the evaluation data [226].

Table 5.11: SAR Correlation Matrix

	DEQ1	**DEQ3**	**DEQ5**	**LEQ1**	**REQ5**
DEQ1		0.06	0.78	0.20	0.22
DEQ3	0.06		0.02	0.23	0.12
DEQ5	0.78	0.02		0.12	0.16
LEQ1	0.20	0.23	0.12		0.69
REQ5	0.22	0.12	0.16	0.69	

Additionally, the following tests were conducted to ensure the model is a "goodness of fit" to the SAR evaluation data set. The Pearson and Deviance test were conducted to understand the observed distribution of the data expected in the independent calculated mean of abstracted variables [146]. The indication for the SAR evaluation data set is presented where Pearson's calculated value was significant meaning a $p < 0.05$ and the Deviance calculated value was non-significant meaning meaning a $p > 0.05$ [147]. This presented a unique case that needed to be evaluated further with the down selected variables for the SAR Correlation Matrix in Table C.2 of Appendix C. The correlation matrix is presented in Table 5.11. The black cells in the diagonal of the table represent the factors relation with itself. The red color indicates the degree of correlation; the darker the red, the stronger the correlation with a factor. The correlation matrix did show that a *DEQ1* and *DEQ5* still had a high correlation with a value of 0.78 which is close to the limit value of 0.80 max to consider [215]. The strong correlation indicates that the presented elements for the system were not always correct and incomplete in the model effecting the score, example was the CV-1 extra elements on diagram. Furthermore, the correlation matrix did indicate a strong correlation between *LEQ1* and *REQ5* with a value of 0.69 which is close to the limit value of 0.80 max to consider [215]. The correlation indicates that a driving factor were the descriptions of performance measures in the models that were missing and not considered to be sufficient to conduct verification. While the Pearson value is unique to this data set it is not necessary applicable to consider the significance to halt the SAR OLR analysis. The SAR evaluation data set is considered to be ordinal, not normally distributed, data set and therefore Pearson does not apply [237].

Table 5.12: SAR Goodness-of-Fit

Goodness-of-Fit			
	Chi-Square	**df**	**Sig.**
Pearson	18117.79	535	0.00
Deviance	438.87	535	0.95

While Pearson was significant, it is not applicable for this case, but if the Deviance was significant, the OLR model may deviate from the observed model presenting a problem with the SAR data set requiring further investigation [148]. Table 5.12 shows the calculated values for Pearson and Deviance tests. The next values calculated are the Pseudo R-Square, and they are presented in Table 5.13. The values are treated as rough analogues to the R-Squared values in ordinal least squares method for estimating the unknown parameters in a OLR [149]. The consensus is that the values, when calculated, must not be statistically significant or a problem may exist with the data set [149, 150]. Table 5.13 shows that all the values are not statistically statistically significant and analysis can proceed.

Table 5.13: SAR Pseudo R-Square

Pseudo R-Square	
Cox and Snell	0.75
Nagelkerke	0.79
McFadden	0.46

Located in Appendix C are the SAR DoDAF CONOP OLR parameter estimates for the evaluation data set. The following are presented for each of the column data in Table C.3.

- **Threshold**: This is the response variable in the OLR for the *DEQ mean* and represents the cutoff value for *DEQ mean* low as 1.0 and high as 6.33.
  - **Threshold [*DEQ mean* = 1.00]**: the estimated cutpoint on the latent variable used to differentiate low *DEQ mean* from middle and high *DEQ mean* when values of the predictor variables are evaluated at zero. Elements that had a value of -53.12 or less on the underlying latent variable that gave rise to our *DEQ mean* variable would be classified as low *DEQ mean*.
  - **Threshold [*DEQ mean* = 6.33]**: the estimated cutpoint on the latent variable used to differentiate low and middle *DEQ mean* from high *DEQ mean* when values of the predictor variables are evaluated at zero. Elements that had a value of -16.23 or greater on the underlying latent variable that gave rise to our *DEQ mean* variable would be classified as high *DEQ mean*.
- **Estimate**: the ordered log-odds (logit) regression coefficients. The Standard interpretation of the ordered logit coefficient is that for a one unit increase in the predictor, the response

variable level is expected to change by its respective regression coefficient in the ordered log-odds scale while the other variables in the model are held constant.

- **Location**: These are the covariates and factors in the analysis for OLR.
  - Variables that are not present in the table were removed based on the previous analysis and constituted only the following as contributing factors: *DEQ1*, *DEQ3*, *DEQ5*, *LEQ1*, *REQ5*.
  - **DEQ 1, 3, 5**:This is the ordered log-odds estimate for a one unit increase in *DEQ 1, 3, 5* score on the expected *DEQ mean* level given the other variables are held constant in the model.
  - **LEQ 1**:This is the ordered log-odds estimate for a one unit increase in *LEQ 1* score on the expected *DEQ mean* level given the other variables are held constant in the model.
  - **REQ 5**:This is the ordered log-odds estimate for a one unit increase in *REQ 5* score on the expected *DEQ mean* level given the other variables are held constant in the model.
  - **DoDAF View**: the views of the SAR DoDAF CONOP.
- **Std. Error**: These are the standard errors of the individual regression coefficients.
- **Wald**: The ratio of Estimate to Std. Error, squared, equals the Wald statistic.
- **df**: degrees of freedom for each of the tests of the coefficients, defines the Chi-Square distribution to test whether the individual regression coefficient is zero given the other variables are in the model.
- **Sig.**: These are the p-values of the coefficients or the probability that, within a given model, the null hypothesis that a particular predictor's regression coefficient is zero given that the rest of the predictors are in the model.
  - The green indicates statistical significance below 0.05 for the data set.

- **95% Confidence Interval**: Confidence Interval (CI) for an individual regression coefficient given the other predictors are in the model.

The coefficients are predicting the log odds of being in a higher or lower category on the *DEQ mean* dependent variables [150]. The tables shows that for every one increase on the independent variables *LEQ* and *REQ* their is a predicted increase of ending up at a higher level of dependent variable [144]. This means that as the independent variables *LEQ* and *REQ* value increase there is a increase on the dependent variable *DEQ mean* [144]. The following list illustrates interpretations for the QCC values that presented statistical significance based on the OLR analysis:

- ***DEQ 1*****:** According to the DoDAF element type stated in the DoDAF standard, the element must be found on the appropriate diagram in order to be considered complete.
  - **Result Finding:** An example would be the element *«FunctionalAction» Receive TDM* that was present in the functional Figure C.2 in Appendix C the element flow did not terminate. The SAR model execution did not have a SysML termination to some of the *«ControlFlow»* functions. Names were missing or improperly presented in one case an element had a ";" semicolon as the actual name element ID "_16_8beta_8f40297_1264755020203_887654_49788". The SAR DoDAF CONOP architecture original objective was to incorporate much of the DoDAF standard to see full implementation within a model [4].

- ***DEQ 3*****:** Based on the DoDAF element type, the descriptions define a strategy for managing change, as well as the transitional processes required to evolve the state of a business or mission to one that is more efficient, effective, current, and capable of providing those actions required to fulfill its goals and objectives, which are represented by the architecture in the description.
  - **Result Finding:** Corresponding descriptions were not always present to tell what the element is representing for the architecture. Without supporting documentation, the

terminology was lost or redundant when names were used for two different stereotypes on different diagrams.

- ***DEQ 5*****:** The DoDAF carefully examines each element type to ensure that they sufficiently articulate the need and proposed solution in a manner that would improve audience knowledge or justification for the need in architecture.
  - **Result Finding:** Several elements did not have instantiation for need in the architecture, this was consist ratings presented Table C.4 indicated neutral. The SV-4 specifically focused on the Command and Control signaling functionality for the SAR DoDAF CONOP and had inconsistencies Which were reflected in the correlation to *DEQ 3*.
- ***LEQ 1*****:** Based on the UML/SysML element, the purpose of a modeling description is to make it possible to describe a particular topic of interest or context of the system design [73].
  - **Result Finding:** Majority of elements presented most elements with a “Strongly Disagree” and had descriptions missing in nearly all SAR elements evaluated. *LEQ 1* was also correlated to *REQ 5* and was shown by significance in the correlation matrix in Appendix C.
- ***REQ 5*****:** Performance measurable values are completely specified. The DoDAF element performance design attributes which allow the verification for a system design [168, 169].
  - **Result Finding:** DoDAF Element performance design attributes which allow the verification for a system design, not all elements had performance design attributes associated with them in the SAR architecture. The element did have data that could be verified most of the element had string data type which presented as outside verification for the elements. The element performance was not clear outside of the named data. Information such as what the data contained, structure, or measurement was not present.

To view additional details about probability estimates for the model, see Appendix C, Probability For SAR Response Table C.4. The top of each column is the Estimated Cell Probability for Response Category for the *DEQ_Mean*. These probabilities can be used to predict the outcome of each of the down selected variable responses currently in the SAR DoDAF CONOP architecture.

The *REQ* mean value of 4.75 and median of 6.0 or "Neutral"/"Agree". This was reflective for the OLR. While a higher level requirement existed, specifics for alternative behavior or complete system level break down were not present in the architecture. The standard deviation for the *REQ* is higher than the *DEQ* and *LEQ* meaning there is a higher deviation within the data set off the mean value for the *REQ*. Quality of the model dips in this aspect for the SAR. While elements existed, they often did not have adequate representation or any justification at all for existence in the architecture. Additionally, the *LEQ* had a mean value of 5.37 and median of 5.8 or "Somewhat Agree"/"Agree" for the majority of 480+ elements evaluated, meaning the quality was consistent with the application of UML/SysML standard within the SAR DoDAF CONOP architecture. Some systemic problems included activities without terminations or no initial starts to the activity execution. An example would be the element *Receive TDM* that were present in the functional Command and Control signaling SV-4 diagram in Appendix C. The activity terminates at the function without any termination UML/SysML modeling symbol used. The *DEQ* mean value of 5.10 and median of 6.0 or "Somewhat Agree"/"Agree" for the majority of 350+ elements evaluated, meaning the quality was consistent with the application of DoDAF standard within the SAR DoDAF CONOP architecture. The *DEQ* and *LEQ* were most likely the outcome because of the tool and team conformed to UML/SysML/DoDAFstandards during the development process. Using the Equation 3.3 from Chapter 3, an overall determination can be made about the quality of the SAR architecture. The *DEQ* was very close to a value of 3.73 or "Good" rating. The *LEQ* had a value of 3.91 which is a "Good" rating. The *REQ* had a score of 3.50 which is a "Poor" to "Acceptable" rating. The analysis reflects a sensitivity to *REQ* factors in the model and could cause greater impact to quality if not addressed. The JPSS overall score is a 3.72 or

"Acceptable" to "Good" rating. Understanding the implication of these scores can provide insight into the understanding of programmatics for a system design see Section 3.6 of Chapter 2.

5.6.5 Modularity Calculation

Now that an understanding for quality of the SAR DoDAF CONOP architecture has been established based on the Quality Characteristic Categories (QCC), the author wanted to understand the modularity as it stands in the current SAR DoDAF CONOP architecture. Using the DoDAF Quality Conceptual Framework (DQCF) Modularity Design Structure (MDS) Matrix and the adapted YuTian equation as prescribe in Chapter 3 Section 3.5 the equation 3.1 can be used to make a determination on the degree of modularity of the model. Recall that the Multicollinearity analysis showed that *DEQ2*, *DEQ6*, and nearly all of *REQ* variables had key indicators that modularity will be impacted in most likely a negative way. The Multicollinearity analysis indicated the following for *DEQ2*, *DEQ6*, and nearly all of *REQ* variables:

- ***DEQ2***: Does the element present strategic information that explains the existing and/or intended links between an organization's business, mission, and management processes, and the supporting infrastructure associated to the architecture?
  - **Result Finding**: Majority of elements evaluated had some form of relationship to the SAR DoDAF architecture being direct or indirect. The calculated VIF showed a value of 17.1 which is above the recommended of 10 for VIF calculated value [216]. Direct relationship meaning to another element on same diagram graphically and indirect relationship meaning carried over from another diagram or through another element on different diagram. This means that some degree of modularity is present in the architecture but to what degree remains elusive at this point. Further discussion on the degree of modularity will be addressed in Section 5.6.5 of this Chapter. This part of assessment is concerned with the networked relationships between the graphical elements that have been displayed [157, 160].

- ***DEQ6***: Does the DoDAF element data type presented continue to present key information in a way that is understandable, congruent with, and consistent with all of the various stakeholders communities engaged in developing, delivering, and sustaining capabilities to assist in achieving system design goals.

  - **Result Finding**: While many elements did not have a consistent "Agree" with this criterion, the calculated VIF showed a value of 16.5 which is above the recommended of 10 for VIF calculated value [216]. The high VIF value means the variable must be eliminated in order to mitigate any issues to conduct PCA analysis. By having this criteria eliminated it is suspected that modularity will be impacted. Further discussion on the impact to modularity will be illustrated in Section 5.6.5 of this Chapter. Consistency and continuity for element data are important considerations when addressing modularity within an architecture, and this part of assessment addresses these considerations. This means that some degree of modularity is present in the architecture but to what degree remain elusive at this point. The element presented in the SAR DoDAF CONOP with in the scope of the Command and Control signaling had details to support the elements.

- ***REQ5***: Characterizes the requirement instantiation of an element to establish system contextual meaning in the architecture.

  - **Result Finding**: The operational functional performance requirement should drive the development of a CONOP architecture for a system design as stated in Section 2.1.3 DoDAF CONOP Design Process in Chapter 2 [4,79]. The Principal Components Analysis (PCA) and OLR analysis found key significance in the *REQ5* criteria from the QCC for the SAR architecture.

For the purpose of Modularity Calculation analysis, only the Command and Control signaling thread will be evaluated as was done in other sections of this Chapter. To clarify the approach to the degree of modularity analysis for the SAR DoDAF CONOP architecture, some assumptions were made to bound the problem to the appropriate space for the analysis. The assumptions are as follows:

- Data inconsistency exists in the SAR DoDAF CONOP.
  - Inconsistency was established during the Multicollinearity analysis for several QCC from the DQCF.
  - Several descriptions were missing throughout the SAR DoDAF CONOP.
- The author used any relationship that existed or was created between DoDAF elements within the architecture for the assessment of the degree of modularity.
  - The purpose of a multiple-domain matrix allows for modeling the scoped system aspect while consisting of multiple domains. Each of these has multiple elements or element types connected by various relationship types [228].
- The top of the MDS Matrix *column* will represent the *from* or *source* and the *row* as the will represent *to* or *target*.
- The symbol of "$\nearrow$" presents an arrow representing the creation of a relationship.
- Direct relationships from one element in a column to the same element in a row will be blacked out along the diagonal for the MDS, Figure 3.3 shows an example diagram.
- The MDS matrix is representative of a Multiple-Domain Matrix allowing different element types to be considered under the various DoDAF views [228].
- The analysis will use human clustering techniques prescribed by YuTian's team due to consideration for the these listed assumptions or constraints on analysis [174].
  - While this is not the most accurate method, the approximation is close enough for acceptable interpretation when determining factors for the degree of modularity.
  - Clustering is the identification of highly interactive groups of elements and arranging in modular understanding [174].

- MDS is considered binary and normalized for easier calculations consistent with YuTian's approach.
- $\log_2$ was used for the calculation as based on YuTian's teams analysis.
- Weight, w, of view importance will use pairwise comparison as to which views are more important.
- Type I mismatch error is for inside of a cluster [174].
- Type II mismatch error is for outside of a cluster [174].
- OV-5 DoDAF view is combined with OV-5a and OV-5b views.
- A 0.33 weighting was used as prescribed by YuTian's team for all terms in the equation.
- The full relationship matrix was not included due to size. With 590 elements, this could not be constrained within the document.
  - A MDS of 590 elements by 590 elements yields a matrix grid of after removing the diagonal total grid space is 347510.
- The product architecture is the SAR DoDAF CONOP with focus on the SMD thread.
- Considerations for "bus" architectures will not be a factor in this analysis based on the definition of a Bus.

In order to understand the weight importance of each of the DoDAF views with the SAR DoDAF CONOP, the standard views use pairwise weighting methodology [229]. The pairwise weighting decision-maker should compare each item with the rest of the group and give a preferential level to the item [178]. The weights were determined based on Table 3.2 in Chapter 3 Section 3.2 for each DoDAF view. The weight of importance Table 3.3 can be found in Chapter 3 Section 3.2.

The next goal is to put the corresponding data in clustering locations to understand how data is contained in modules in the model through the MDS. An example of how this was done is shown in a dependency matrix in Figure 3.3 in Chapter 3 Section 3.2. The approach was taken across the entire 590 element count for the SAR DoDAF CONOP to determine the degree of modularity. The clustering arrangement is as follows in Table 5.14.

Table 5.14: SAR Clustering Arrangements

Clustering Arrangements				
	n_c	cl_i	$\|S_1\|$	$\|S_2\|$
SAR Model	9	12, 12, 23, 40, 81, 157, 195, 236, 282	66120.45	11300.39

Table 5.15 shows the description length and ratios for the SAR DoDAF CONOP. The clustering ratios can be calculated using the Widrow–Hoff iteration which is the approach that YuTian's team did within their analysis; however, for the purpose this analysis, the assumption of 0.33 was used as suggested by YuTian's team [174]. Equation 3.1 was used with the values from Table 5.14 and the results are in Table 5.15.

The findings were quite interesting when looking at the resultant values for the clustering within the SAR DoDAF CONOP model. The case study shows that the modules or the DoDAF views have several interactions exterior from one view to another, but minimal interactions within the view. Some exceptions to the exterior connections are the internal interactions which include the DoDAF views, OV-5b and SV-4. These views have interactions between elements on the view because of their nature of development which contains *«controlflows»* or *«objectflows»*. The author's analysis only looks at interactions that were outside of the views to drive development of elements on other views as well as linking data consistent across different views within the SAR DoDAF CONOP architecture.

The method shows a means to evaluate and quantify the degree of modularity while identifying contributing factors within the SAR DoDAF CONOP architecture model. Table 5.15 shows the various calculations on the SAR DoDAF MDS. From the values in the table, the SAR model

Table 5.15: SAR Description Length and Ratio for Clustering

	Description Length	Ratio
SAR CONOP Model	139	0.33
Type I Mismatch	13767	0.33
Type II Mismatch	2353	0.33
Total MDL	16260	

had a value of 139, which when considering the amount of elements associated with the model, is considered a lower value with a high degree of modularity. The factors that drive the value include: the number of elements within the MDS, relations between DoDAF views, the ratios, and the clustering of DoDAF elements based on views. The type I mismatch value of 13767 shows that while relationships do exist in the clusters and the clusters are quite large, there is considerable mismatch or missing relations meaning the cluster is not very modular. The type II mismatch value of 2353 is also considered a low value, but while relations exist in the model and within the denoted clusters, not everything is related within the model or the cluster. The full analysis gives the SAR model and MDL of 16260 which is still considered a long description length. YuTian's interpretation of this MDL is that if the model description is simple, the model description is short [174]. In contrast, many data mismatches would exist, and the mismatched data description would become longer [174]. A complicated model reduces the description of mismatched data, but the model description would be longer [174]. The previous Section 5.6.3 of this chapter showed from the beginning that *DEQ2*, *DEQ6*, and nearly all of *REQ* variables also presented a negative outlook for the degree of modularity, but the model is considered to have too high a degree of modularity. The analysis shows that for a high degree of modularity design, the model should be designed with that original intent and provide for continuous monitoring during its development. For the case of the SAR DoDAF CONOP, the architecture was developed to illustrate the capabilities of the DoDAF standard without the consideration for modularity in the design process, but modularity was reflected in the small MDL in the analysis of this section.

5.6.6 SAR Conclusions

Chapter 5 represents the bulk of analysis and comprehension of quality using the outlined DoDAF Quality Conceptual Framework (DQCF) against Case Study Two. The chapter covered the SAR CONOP Command and Control signaling mission thread, SAR key terms for DoDAF understanding, application of QbD to the SAR CONOP, element sampling from the model, and statistical analysis methods. Each one of the represented sections provides justification for the methodology used while maintaining data integrity and highlighting key findings relating to quality of the DoDAF architecture. The data must be interpreted with caution due to some of the key assumptions made, but the innovative method symbolizes a sound approach to investigate quality of architectures. Not only were the findings observable, but the analysis brought quantifiable understanding using statistical methods with supporting foundational theory. The DQCF illustrates a more robust approach to quantify quality comprehension of DoDAF architectures models.

Chapter 6

Summary and Conclusion

The following chapter summarizes the results of research, presents conclusions, and provides recommendations for future work.

6.1 Synthesis of Results

Chapter 1 provided insight into the background of this dissertation as well as formulation of the research problem to narrow the present methodological gap within the knowledge base of systems engineering when it comes to determining quality of DoDAF architectures. Chapter 2: Overview of Approach and Chapter 3: Conceptual Framework and Overview, outlined the concepts for conducting architecture evaluation activities integrated within an DoDAF Quality Conceptual Framework (DQCF) construct. Topics outlined within the Chapters shown in Figure 3.12 of Chapter 3 play critical roles in the establishment of the concepts crucial to the DQCF to address quality of DoDAF architecture models [238]. The DQCF provides a means to interrogate quality in depth to include the application of the DoDAF standard, the UML/SysML standards, and requirement architecture instantiation, as well as capturing a way to collect the degree of modularity to understand the DoDAF architecture complexity. The DQCF illustrates how QbD and DoDAF architecture contextually map to the respective UML/SysML base languages. Quality metric definitions through Quality Characteristic Categories (QCC) in Appendix A within the DQCF provide an implementation methodology with respect to modeling standards of DoDAF architecture models. Statistical methods of analysis help to validate collected data sets and provide interpretation of the QCC through quantifiable insight into the quality of the DoDAF architecture. Case study evaluations provided a practical application of the DQCF and present an in-depth quality analysis of case study's DoDAF CONOP architectures. This dissertation as well as the DQCF provides some of the following advances:

- Re-contextualization mapping of Quality By Design (QbD) to create a new DoDAF Quality Conceptual Framework (DQCF) for Department of Defense Architecture Framework (DoDAF) architecture models

- Competencies required for the Systems Engineering Quality Role to apply the DQCF

- The QCC can be established and when applied using a suitable framework can capture an understanding of the quality of a MBSE environment

- Development of QCC within the DQCF to capture quality understanding as they relate to Model-Based Systems Engineering (MBSE) environment

- Application of certain QCC as quality attributes can quantify the design volatility of DoDAF architectures

- Fundamental statistical methods can be applied to certain data, generated by a suitable quality framework to provide validity of metrics to interrogate the DoDAF architectures quality

- Provided an adapted form of YuTian team's equation 3.1 to quantify Minimum Description Length (MDL) for assessing the degree of modularity

The concatenation of all of these theories, metrics, statistical methods, understanding for modularity, and additional research papers have led to the development of the DQCF.

6.2 Summary of Case Studies

The following section provides summaries of each of the case studies and comparisons between the case study analysis results developed using the DQCF.

6.2.1 Case Study One Summary

The first case study was the National Oceanic and Atmospheric Administration (NOAA)/ National Aeronautics and Space Administration (NASA) Joint Polar Satellite System (JPSS) DoDAF CONOP architecture with focus on the Stored Mission Data (SMD) mission thread. The most current open source versions of Joint Polar Satellite System (JPSS) DoDAF architectural model and JPSS documentation were used to assist the author in context capture, DoDAF Quality Conceptual Framework (DQCF) application, illustration, and analysis. The JPSS is a next-generation earth observation program that collects and communicates global environmental data via polar-orbiting satellites [193]. The primary mission of the JPSS system is to understand/predict changes in weather, climate, oceans, coasts, and space environment [193].

The analysis indicated in totality that the JPSS DoDAF CONOP has “acceptable” to “good” with concerns that impact quality this is judged on the factors of QCC criteria of the DQCF. Several key factors play a role in the “acceptable” to “good” quality of the JPSS model architecture. The factors include:

- When evaluating documentation on the architecture, a key concern was found in that the architecture was generated before the requirements which can present issues with architecture instantiation [202].
- Terminology did not have a one to one relationship with DoDAF standard terminology.
- The total of 572 elements of the JPSS DoDAF CONOP SMD mission thread are roughly 5.46% of the total JPSS DoDAF CONOP architecture.
- The analysis showed that the bulk of elements were located in the OV-2, OV-5, and SV-4 views for the CONOP.
- The Kaizer-Meyer-Olkin (KMO) value of 0.59 with a significance of less than 0.05, indicated that the data was accurate representation of the architecture.
- The Skewness and Kurtosis in Appendix B frequency plots indicated that higher quality for *DEQ* values and more varied for *LEQ* and *REQ*.
- **DEQ Findings:**
  - *DEQ2* and *DEQ6* showed some degree of modularity is present in the architecture.

- Not all elements were located on correct diagram; deprecated element types were used in the architecture.
- The implications of unjustified alternative behavior present on the diagrams had no driving factor present.
- Many elements had missing description difficulty understanding what elements were representing for the architecture was common place.
- Element types were used in the architecture were missing performance indication or standard to explain the data selection.

- **LEQ Findings:**
  - Model elements did not always have a need within the architecture.
  - The model contained orphaned elements that often did not have relationships to parts of the architecture.

- **REQ Findings:**
  - Many of the elements in the JPSS DoDAF CONOP architecture did not have a sufficient requirement element instantiation with in the architecture.
  - The performance measurable values were not completely specified directly impacts test verification.
  - Not all elements had performance design attributes associated with them and the *DIV-1* was not complete strictly impacting overall ability to complete verification.
  - The analysis showed that non consistent decomposition from System to Sub-system in the architecture.
  - The Principal Components Analysis (PCA) and OLR analysis found key significance in the *REQ* criteria from the QCC for the JPSS architecture.

The *REQ* factors from the DQCF QCC mean value was 3.437 and median of 3.0 or "Somewhat Disagree"/"Disagree". This was reflective of the more negative coefficients for the Ordinal Logistic Regression (OLR) for the *REQ* variables. While higher level requirement existed, specifics for alternative behavior or complete system performance level breakdown context was missing. An example of missing requirements would be the alternative behaviors that were present in the functional SMD SV-4 diagram in Appendix B. By creating behavior without justification caused additional cost and increased schedule for development for the JPSS system design. Also, the adequate quality rating is driven by the fact of incomplete modeling consistency within the application of DoDAF and UML/SysML standards. The Government Accountability Office (GAO) found that the JPSS program was encountering difficulties in testing the ground system's performance criteria, which may result in a delay in validating requirements [227]. This was confirmed by historical information of the program, when in August of 2017, the JPSS system was delayed in schedule and main factors delaying the JPSS launch were technical issues discovered during testing of the satellite's advanced technology [194]. Additional factors from the DQCF include the *DEQ* value of 5.44 and median of 6.0 or "Somewhat Agree"/"Agree" for the majority of elements evaluated, meaning the quality was consistent with the application of DoDAF standard within the JPSS DoDAF CONOP architecture. The *LEQ* value of 5.91 and median of 5.8 or "Somewhat Agree"/"Somewhat Agree" for the majority of elements evaluated, that the evaluation was in agreement with the application of UML/SysML standard for the most part within the JPSS DoDAF CONOP architecture. The *DEQ* and *LEQ* were most likely the outcome because of the tool and team conformed to UML/SysML/DoDAFstandards during the development process. Using the Equation 3.3 from Chapter 3, an overall determination can be made about the quality of the JPSS architecture. Table 6.1 shows the Quality and Degree of Modularity rating for the JPSS DoDAF CONOP SMD mission thread. The table shows that the *DEQ* was yellow to green, but was very close to a value of 3.96 or "Good" rating. The *LEQ* was a green score of a value of 4.27, but still a "Good" rating. The *REQ* was a red score of 2.62 in a "Poor" to "Acceptable" rating. The analysis reflects a sensitivity to *REQ* factors in the model and could cause greater impact to quality if not addressed. The JPSS overall score is a 3.62 or "Acceptable" to "Good" rating.

Table 6.1: JPSS Quality and Degree of Modularity

Overall Model Quality		
	Mean Value	**Quality Score**
DEQ	5.4	4.0
LEQ	5.9	4.2
REQ	3.4	2.6
Total		3.6
Degree of Modularity		
Model		196
Type I		32351
Type II		1827
Total MDL		34374

The JPSS model MDL value associated with the model is considered a lower value with a high degree of modularity. The factors that drive the value include: the number of elements within the MDS, relations between what were considered modules or DoDAF views, the weight ratios calculated for each view and three factors of MDL, and the clustering of DoDAF elements. The full MDL analysis gives the JPSS model a value of 33437, which is still considered the long description length. The factors for *DEQ2*, *DEQ6*, and nearly all of *REQ* variables also presented a negative outlook for the degree of modularity but the model is considered to high degree of modularity. The degree of modularity assessment was used in order to grasp functional reusability understanding of architecture aspects for development of system design. The analysis shows that in order for engineering teams to design for a high degree of modularity, the engineering team must start with that fact as a goal in the beginning and continue to monitor modularity during development. For the case of the JPSS DoDAF CONOP SMD mission thread, the architecture was developed to drive requirements development without the consideration for modularity in the design process, and this was reflected in the large mismatch error in the analysis. Furthermore, the model degree of modularity hints at the possibility of reusability understanding of the SMD mission thread analyzed in the architecture.

6.2.2 Case Study Two Summary

The second case study is the Search and Rescue (SAR) DoDAF CONOP architecture with focus on the Command and Control signaling mission thread. The most current open source versions of the SAR DoDAF architectural model and SAR documentation were used to assist the author in context capture, DoDAF Quality Conceptual Framework (DQCF) application, illustration, and analysis for the case study. The SAR DoDAF architectural model consists of operations for locating and retrieving persons in distress providing for their immediate needs and delivering them to a place of safety [230]. The Search and Rescue (SAR) operations are an integrated set of services or operations designed to locate and rescue people who are in distress, provide them with immediate medical attention or other needs, and transport them to a safe location [231]. SAR operations must be carried out as a collaborative effort involving a variety of organizations, including the military (sea, air, and land), government agencies, voluntary organizations, and private enterprises [231]. The primary mission of the SAR DoDAF architectural system is to capture all search and rescue capabilities, in conjunction with the Department for Transport and police, while maintaining a United Kingdom military/civilian SAR capability to ensure the most effective and timely response available to assist people in hazardous situations [230, 232].

The analysis indicated in totality that the SAR DoDAF CONOP has “acceptable” to “good” with concerns that impact quality this is judged on the factors of QCC criteria of the DQCF. Several key factor play a role in the “acceptable” to “good” quality of the SAR model architecture. The factors include:

- When evaluating documentation on the architecture, the ultimate goal of the SAR DoDAF architectural was to prescribe DoDAF framework examples for all Department architectures and represent a substantial shift in approach [233].

- Terminology did not have a one to one relationship with DoDAF standard terminology.

- A total of 590 elements of the SAR model which represent the SAR DoDAF CONOP is roughly 6.34% of the total SAR DoDAF architecture.
- The analysis showed that the bulk of element constitute the DIV-2, OV-2, OV-5, SV-1, and SV-4 for the CONOP.
- The Kaizer-Meyer-Olkin (KMO) value is 0.55 with a significance of less than 0.5 indicating that the data was an accurate representation of the architecture.
- The Skewness and Kurtosis in Appendix C, that higher quality for *DEQ* and *LEQ* more varied for the *REQ*.
- **DEQ Findings:**
  - *DEQ2* and *DEQ6* showed some degree of modularity is present in the architecture.
  - Unrelated elements on DoDAF views would cause a quality dip.
  - Several *DEQ* values had high VIF causing multicollinearity and needed to be removed for PCA analysis.
- **LEQ Findings:**
  - Several activities and other behaviors did not have proper termination and would cause model execution problems and potential for rework development for the SAR system design.
  - Several *LEQ* values had high correlation with other evaluation factors in *DEQ* and *REQ*.
  - In several cases, improper stereotypes were used and would only be realized during compiled execution of a model activity.
- **REQ Findings:**

– Many of the elements in the SAR DoDAF CONOP architecture did not have a sufficient requirement element instantiation within the architecture.
– The ability to verify or audit some of the DoDAF elements through the process of verification would have been difficult due to errors.
– Many elements did not have data that could be verified.
– Many element performance indications were not clear or their measurements were not present.

The *REQ* mean value of 4.75 and median of 6.0 or “Neutral”/“Agree” was reflective in the negative to positive coefficients for the OLR. While higher level requirements existed, specifics for alternative behavior or complete system level break down were not present the architecture. The standard deviation for the *REQ* is higher than the *DEQ* and *LEQ*. This shows there is a higher variation within the data set from the mean value for the *REQ*. The quality of the model dips in this aspect for the SAR. While elements existed, they often did not have adequate requirement representation or any justification at all for existence in the architecture. Additionally, the *LEQ* was mean value of 5.37 and median of 5.8 or “Somewhat Agree”/“Agree” for the majority of 480+ elements evaluated, meaning the quality was consistent with the application of UML/SysML standard within the SAR DoDAF CONOP architecture. Some systemic problems included activities without termination or no initialization to the activity execution. An example would be the element *Receive TDM* that was present in the functional Command and Control signaling SV-4 diagram in Appendix C. The activity terminates at the function without any termination UML/SysML modeling symbol used. The *DEQ* mean value of 5.10 and median of 6.0 or “Somewhat Agree”/“Agree” for the majority of 350+ elements evaluated, meaning the quality was consistent with the application of DoDAF standard within the SAR DoDAF CONOP architecture. The *DEQ* and *LEQ* were most likely the outcome because of the tool and team conformed to UML/SysML/DoDAFstandards during the development process. Using the Equation 3.3 from Chapter 3, an overall determination can be made about the quality of the SAR architecture. Table 6.2 shows the Quality and Degree of Modularity rating for the SAR DoDAF CONOP Command and Control signaling mission thread.

The table shows that the *DEQ* was yellow to green, but was very close to a value of 3.73 or "Good" rating. The *LEQ* was a green score of a value of 3.91 which is a "Good" rating. The *REQ* was a red score of 3.50 in a "Poor" to "Acceptable" rating. The analysis reflects a sensitivity to *REQ* factors in the model and could cause greater impact to quality if not addressed. The JPSS overall score is a 3.72 or "Acceptable" to "Good" rating.

Table 6.2: SAR Quality and Degree of Modularity

Overall Model Quality		
	Mean Value	**Quality Score**
DEQ	5.1	3.7
LEQ	5.4	3.9
REQ	4.8	3.5
Total		3.7
Degree of Modularity		
Model	139	
Type I	13767	
Type II	2353	
Total MDL	16260	

The SAR model MDL value associated with the model is considered a lower value with a high degree of modularity. The factors that drive the value include: the number of elements within the MDS, relations between what were considered modules or DoDAF views, the weight ratios calculated for each view and three factors of MDL, and the clustering of DoDAF elements. The full analysis give the SAR model and MDL of 16260, which is still considered a long description length. The factors for *DEQ2*, *DEQ6*, and nearly all of *REQ* variables also presented a negative outlook for the degree of modularity; but, the model is considered to high degree of modularity. The degree of modularity assessment was used in order to grasp functional reusability understanding of architecture aspects for development of system design. The analysis shows that in order for engineering teams to design for a high degree of modularity, the engineering team must start with that fact as a goal in the beginning and continue to monitor modularity during development. For the case of the SAR DoDAF CONOP Command and Control signaling mission thread, the architecture was developed to drive requirements development without the consideration for modularity in the design process, and this was reflected in the large mismatch error in the analysis. Furthermore, the model degree of modularity hints at the possibility of reusability understanding of the Command and Control signaling mission thread analyzed in the architecture.

6.3 Conclusions

The implications of DQCF could save hundreds of millions of dollars on many different DoD programs. The Ground Based Strategic Deterrent (GBSD) program alone was valued at 85.6 billion dollars and the implications for quality to a program of that cost is at least between 2% to 20% [60]. The cost for quality for the GBSD program could be between 1.712 and 17.12 billion dollars for the DoD through 2075 [239]. The technical approach using the DQCF provides a unique quality-based perspective on system development that establishes a baseline understanding that presents an opportunity to realize both cost and schedule savings during development of DoD programs. The DQCF presents an advantage to the industry and DoD in a new methodical approach to quality within MBSE. The ability to quantify the overall ratings of each various variables provides insight of the coherent design of the system model as well as application of standards. Specifically, the variables rating can provide insight into sensitivities of the system design that could be used to identify risks to the system development process. However, despite the fact that there is no ideal technique for quality evaluation, the suggested approach using the DQCF demonstrated promising ability to first detect then assess quality. In truth, basic scoring techniques have increased in favor primarily because they are quick and straightforward to utilize [94]. In general, programs have a tolerance for risk, and these risks must be regulated within the program's acceptable bounds. Uncertainties may be connected to the project's benefits, as well as its ability to be finished on time, within budget, and to specifications [192]. Control risk management is often used to ensure that the outcome of corporate activities falls within a predetermined range [192]. Ultimately, the idea is to detect and mitigate sensitivity identified using the variable quantifications.

While the JPSS and SAR DoDAF CONOP architectures were considered of "acceptable" to "good" quality for various reasons, the DQCF provided a systematic means of determining the quality of models. The analysis shows that the architecture development has a sensitivity to the *REQ* factors, which support requirement development or support architecture instantiation. If an analysis was conducted earlier in development, like the one presented in this dissertation, a sensitivity to the *REQ* factors could be seen early and mitigated or avoided all together. The SAR DoDAF CONOP architecture was designed with the purpose to demonstrate the capabilities of the DoDAF standard and was reflected when the quality was analyzed. The JPSS DoDAF CONOP architecture was developed first to drive requirements development and secondly to instantiate the architecture which was reflected when the quality was analyzed. The DQCF allows for a moment in time analysis instead of look at delta between developments; however, it can be used to make delta determinations. The statistical methods allow engineering teams to pull data to understand quality trends in the architecture. The statistical methods also give an in-depth investigation into what is driving poor quality in the design of a model architecture. The OLR analysis allows for interpretation and predicting problem areas and can be used to understand where development effort need to be increased. The overall primary contribution of this research was a new methodological approach to detect and determine quality of a DoDAF architecture model. The case studies help to demonstrate a new DoDAF Quality Conceptual Framework (DQCF) as a means to investigate quality of DoDAF architecture in depth to include the application of DoDAF standard, the UML/SysML standards, requirement architecture instantiation, as well as modularity to understand architecture complexity. By providing a renewed focus on a quality-based systems engineering process when applying the DoDAF, improved trust in the system and data architecture of the completed models can be achieved. The results of the case study analyses reveal how a quality-focused systems engineering process can be used during development to provide a product design that better meets the customer's intent and ultimately provides the potential for the best quality product.

6.4 Preliminary Validation

The dissertation research has led to a conference publication titled *Digital Engineering Transformation of Requirements Analysis within Model-Based Systems Engineering* and the paper is referenced within this dissertation. The dissertation research influenced understanding for the National Defense Industrial Association (NDIA) developed metric titled *Functional Architecture Completeness and Volatility* which is also referenced within this dissertation. The dissertation research help to contribute to *Digital Engineering Measurement Framework* Systems Engineering Research Center (SERC) which will be published in March 2022. The research has led to five invention disclosures, three technical abstracts, three technical poster videos, and several training sessions in support of the author's role as a senior digital engineering lead at his current company. Additionally, the material was reviewed by U.S. government and industry systems engineering practitioners with experience in MBSE, DoDAF, and systems engineering architectural design. The three consulted experts for the methodology approach and design had a combined experience of 84 years DoD systems engineering experience.

6.5 Future Work

The creation of this dissertation revealed a number of issues that might be explored further as potential future study areas to expand upon this research. Topics for future study work might be the application of DQCF to a variety of other DoDAF aspects or circumstances and the use of various other MBSE instruments. Future work may include:

- Implications of Configuration Management for MBSE DoDAF Architectures
- Add additional QCC criteria for other framework support such as (UAF, Zackman, TOGAF, etc.)
- Complete application of the DQCF to a program or project under development or execution
- Application to additional case studies to provide more in depth analysis to deal with outlier cases

- Address costing analysis to show impacts to improved quality of architecture over time
- Python OpenCV Text Detection for element text recognition in the graphical architecture against verified element standard library
- Using methodology to apply digital engineering quality across different areas of engineering, Information Technology architecture or logistical architecture

Including additional DQCF variables could drive more sensitivity out of the data to better understand impacts that drive specific model quality aspects. Given that one of the primary inputs supplied by the decision makers is the weightings for the degree of modularity, it would be beneficial to do a more comprehensive sensitivity analysis, focusing in particular on the modularity aspects. Furthermore, optimizations of higher complexity might be carried out, perhaps with the assistance of High-Performance Computing Resources (HCR) for large Design Structure Matrix (DSM). The advancements in the integration of MBSE and automation tools, in particular, might be examined further.

6.6 Disclaimer

The views and opinions expressed in this dissertation and case study analyses are solely the author's. The views and opinions do not represent any position of the U.S. Department of Defense, National Aeronautics and Space Administration (NASA), Dassault Systèmes, Colorado State University, any employment entity, or any other organization, group, or individual.

Appendix A

Quality Characteristic Categories

Each element under evaluation would be evaluated against the following Quality Characteristic Categories (QCC) to determine quality of that specific element. The author would like to stress that it is not always necessary for a score to be reflected as positive or negative. A neutral value is acceptable due to the fact that some elements might not require a rating under specific category given contextual meaning of the element in the architecture. A neutral value must have a thorough explanation because this could present an issue for analysis if not adequately explained. The data collected based on these evaluation criterion will be rated on the seven point Likert scale discussed in Chapter 2 Section 2.2.7 Statistical Analysis Methods. Making subjective judgments about what is significant becomes necessary when doing any examination of this type using Likert scale [240]. Using subjective attributes such as the QCC which is essentially a Likert scale can successfully assist to both develop and test substantive theories thereby mitigating as much subjectivity as possible [95]. By using a Likert scale to survey a sample of model elements, system models, elements, and content can be evaluated through the application of numerical ratings, providing a promising approach for quantifying deterministic values of quality [96]. The author believes that this criterion presents an accurate picture of what is to be rated and sufficiently can be used to evaluate elements. For the purpose of analysis this criterion does not evaluate the diagram image, packages or folder structure for containment. The criterion are as follows:

- **DoDAF Element Quality *(DEQ)***
  - **Category Definition**: Deals with the aspect of the DoDAF element that meet standard and establish element in the architecture.
    - **DEQ1**: According to the DoDAF element type stated in the DoDAF standard, the element must be found on the appropriate diagram in order to be considered complete.

* **DEQ2***: Does the element present strategic information that explains the existing and/or intended links between an organization's business, mission, and management processes, and the supporting infrastructure associated to the architecture.
  - ***Note:** This part of assessment is concerned with the networked relationships between the graphical elements that have been displayed [160] [157].
* **DEQ3**: Based on the DoDAF element type, the descriptions define a strategy for managing change, as well as the transitional processes required to evolve the state of a business or mission to one that is more efficient, effective, current, and capable of providing those actions required to fulfill its goals and objectives, which are represented by the architecture in the description.
* **DEQ4**: Based on the DoDAF element type, do related sub-elements at each tier of the system design or desired level achieve goals and objectives corresponding to the scope and purpose that have been established.
* **DEQ5**: The DoDAF carefully examines each element type to ensure that they sufficiently articulate the need and proposed solution in a manner that would improve audience knowledge or justification for the need in architecture.
* **DEQ6***: Does the DoDAF element data type presented continue to present key information in a way that is understandable, congruent with, and consistent with all of the various stakeholders communities engaged in developing, delivering, and sustaining capabilities to assist in achieving system design goals.
  - ***Note:** Consistency and continuity for element data are important considerations when addressing modularity within an architecture, and this part of assessment addresses these considerations.

- **Language Element Quality *(LEQ)***
  - **Category Definition**: Deals with the aspect of the UML/SysML element that meet standards and establish element in the architecture.

* **LEQ1**: Based on the UML/SysML element, the purpose of a modeling description is to make it possible to describe a particular topic of interest or context of the system design [73].
  - **Example:** UML for SysML sets the criteria through definition of the domain concepts that should be considered [73]. The UML/SysML is structured through concepts descriptions that are required to represent structure, behavior, characteristics, requirements, and other system modeling constructs, as well as other aspects of modeling [73].
* **LEQ2**: Based on the UML/SysML element, is the stereotype used correctly according to standard to provide a collection of diagrammatics, modeling components, a formal vocabulary, and semantics for the desired use in the model [73]. As with any language formal or informal, it may be employed in a variety of ways, and in a variety of incorrect ones as well [73].
  - **Example:** The choice between *«continuous»* / *«discrete»* is a critical modeling assumption and is an important contextual decision [241] [73]. To get use the wrong stereotype will constrains the represented element [241] [73]. UML/SysML elements can be used to create nonsensical models aspects [73].
* **LEQ3**: Based on the UML/SysML element, is the element related through relationship in the architecture and the relationship type correct [73].
  - **Example:** A significant amount of time is spent in structuring the model, which includes relationships such as *«include»*, *«extend»*, and *«generalization»*, with the assumption that such structure is required in every model or required for the system's architectural design [73]. Commonly utilize the *«include»* connection to divide a element down into smaller elements by conducting functional decomposition of the system [73]. As a result, none of the elements by themselves provide any real value, as it becomes extremely difficult to understand what a system does as a result of this difficulty [73].

* **LEQ4**: Based on the UML/SysML element, does the element describe the underlying ideas or justifications behind its use, such as the choice of analytic method or design approach [73]. The element may serves as a source of information or a reference to the reasoning behind the modeling choice [73].
* **LEQ5**: Based on the UML/SysML element, is the element using the correct UML/SysML semantics, or meaning, of linguistic ideas between the two languages to bring value to the system design [73]. A descendant of the UML which was initially established as a modeling language for software design but has been expanded by SysML to accommodate general-purpose systems modeling [73].

- **Requirement Element Quality *(REQ)***
  - **Category Definition**: Deals with the aspect of the requirement instantiation of an element to establish system contextual meaning in the architecture to understand developed requirements or outline requirement development support. The criteria attempt to provide an understanding of the functional coherent design for the system.
    * **REQ1**: Circumstance are identified completely and precisely defined. All factors that influence the DoDAF Element are specified and precisely defined. Circumstance of the DoDAF Element design attributes consists of states/modes, environments, constraints or combinations which constrain the system design [167] [168] [169].
    * **REQ2**: Is the DoDAF Element related to function and is that function identified completely and detectable. Is the DoDAF Element functional process detectable during execution to perform some action within the system [168] [169].
    * **REQ3**: All required inputs are completely defined and detectable. Input of each DoDAF Element should be detectable at the system boundary which initiate functions; may include system state transitions [168] [169] [236].

* **REQ4**: The DoDAF Element is derived from some standardized source or defined by customer. Justification would be a means to document the reason for having the element in the model [168] [169].
* **REQ5**: Performance measurable values are completely specified. The DoDAF Element performance design attributes which allow the verification for a system design [168] [169].
* **REQ6**: Based on the DoDAF Element, a case can be conceived to assess all aspects of the DoDAF Element for a system design. Refers to the ability to verify or audit the DoDAF Element through the process of verification.

Appendix B

Joint Polar Satellite System Case Study Additional Data

Table B.1: National Polar-orbiting Operational Environmental Satellite System (NPOESS) Acronyms List

Acronym	Definition
557WW	557th Weather Wing
6 SOPS	6th Space Operations Squadron
AGS	Attitude Ground Support
AFWA	Air Force Weather Agency
AK	Alaska
AMSR	Advanced Microwave Scanning Radiometer
APC	(JPSS) Alternate Processing Center
APID	Application Packet Identifier
APMC	Agency-level Program Management Council
ASD	AMSR2 APID Sorted Data
ATMS	Advanced Technology Microwave Sounder
C3	Command, Control and Communications
CARA	Conjunction Assessment and Risk Analysis
CCB	Configuration Control Board
CERES	Clouds and the EarthÕs Radiant Energy System
COURL	Consolidated Observing Users Requirements List
CLASS	Comprehensive Large Array-Data Stewardship System
CrIS	Cross-track Infrared Sounder
DMSP	Defense Meteorological Satellite Program

DOC	U.S. Department of Commerce
DoD	Department of Defense
DUS/O	Deputy Under Secretary of Commerce for Oceans and Atmosphere for Operations Environmental Data Record
EOS	NASA Earth Observing System
EPS-SG	European Polar System - Second Generation
ESPC	Environmental Satellite Processing Center
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FDF	Flight Dynamics Facility
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FT	Field Terminal
GCOM	Global Change Observation Mission
GCOM-W	GCOM-Water
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HRD	High Rate Data
HSPD	Homeland Security Presidential Directive
JAXA	Japan Aerospace Exploration Agency
JPSS	Joint Polar Satellite System
KPP	Key Performance Parameter
KSAT	Kongsberg Satellite Services
LASP	Laboratory for Atmospheric and Space Physics
L1RD	Level 1 Requirements Document
LEO	Low-Earth Orbiting or Orbit
LORWG	Low Earth-Orbiting Requirements Working Group
LST	Local Solar Time

LTAN	Local Time Ascending Node
MCP	Management Control Plan
MGS	McMurdo Ground Station
MetOp	EUMETSAT Meteorological Operational satellites Memorandum of Understanding
NAO	NOAA Administrative Order
NASA	National Aeronautics and Space Administration
NAVOCEANO	Naval Oceanographic Office
NCC	Near Constant Contrast
NCEI	National Centers for Environmental Information
NESDIS	National Environmental Satellite, Data, and Information Service
NIST	National Institute of Standards and Technology
NJO	NOAA JPSS Office
NOAA	National Oceanic and Atmospheric Administration
NOSC	NOAA Observing Systems Council
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPD	NASA Policy Directive
NPP	National Polar-orbiting Partnership
NPR	NASA Procedural Requirement
NSA	National Security Agency
NSF	National Science Foundation
NSOF	NOAA Satellite Operations Facility
NSPD	National Security Presidential Directive
NWS	National Weather Service
OMPS	Ozone Mapping and Profiler Suite
PID	Program Implementation Document

PMC	Program Management Council
POES	NOAA Polar-orbiting Operational Environmental Satellites Radiation Budget Instrument
POP	Points of Presence
RBI	Radiation Budget Instrument
RDR	Raw Data Record
SDR	Sensor Data Record
SDS	Science Data Segment
SMD	Stored Mission Data
SN	NASA Space Network
S-NPP	Suomi NPP
SS	Space System
STAR	NOAAÕs Center for Satellite Applications and Research Temperature Data Record
TDRSS	Tracking and Data Relay Satellite System
USAF	United States Air Force
USMCC	United States Mission Control Center
VCDU	Virtual Channel Data Unit
VIIRS	Visible Infrared Imaging Radiometer Suite
WOTIS	Wallops Orbital Tracking Information System
WSF	Weather Satellite Follow-on
xDR	Data Record

Table B.2: JPSS Correlations Matrix

		Correlations										
		DEQ3	**DEQ4**	**LEQ1**	**LEQ3**	**LEQ4**	**REQ1**	**REQ2**	**REQ3**	**REQ4**	**REQ5**	**REQ6**
DEQ3	**Corr. Coeff.**	1.00	-0.42	0.36	-0.16	0.07	0.24	-0.27	-0.20	0.21	0.42	0.10
	Sig. (2-tailed)		0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.01
	N	572	572	572	572	572	572	572	572	572	572	572
DEQ4	**Corr. Coeff.**	-0.42	1.00	0.06	0.67	-0.13	0.07	0.64	0.40	-0.40	-0.53	0.57
	Sig. (2-tailed)	0.00		0.15	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572
LEQ1	**Corr. Coeff.**	0.36	0.06	1.00	0.08	0.13	0.10	0.14	0.58	-0.20	0.12	0.20
	Sig. (2-tailed)	0.00	0.15		0.07	0.00	0.02	0.00	0.00	0.00	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572
LEQ3	**Corr. Coeff.**	-0.16	0.67	0.08	1.00	-0.09	0.05	0.59	0.27	-0.51	-0.34	0.62
	Sig. (2-tailed)	0.00	0.00	0.07		0.04	0.26	0.00	0.00	0.00	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572
LEQ4	**Corr. Coeff.**	0.07	-0.13	0.13	-0.09	1.00	0.03	0.39	0.15	0.17	0.07	-0.08
	Sig. (2-tailed)	0.12	0.00	0.00	0.04		0.54	0.00	0.00	0.00	0.10	0.07
	N	572	572	572	572	572	572	572	572	572	572	572
REQ1	**Corr. Coeff.**	0.24	0.07	0.10	0.05	0.03	1.00	-0.21	-0.08	0.15	-0.04	0.041
	Sig. (2-tailed)	0.00	0.09	0.02	0.26	0.54		0.00	0.06	0.00	0.37	0.33
	N	572	572	572	572	572	572	572	572	572	572	572
REQ2	**Corr. Coeff.**	-0.27	0.64	0.14	0.59	0.39	-0.21	1.00	0.34	-0.49	-0.37	0.54
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572
REQ3	**Corr. Coeff.**	-0.20	0.40	0.58	0.27	0.15	-0.08	0.34	1.00	-0.02	-0.21	0.23
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.00	0.059	0.00		0.569	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572
REQ4	**Corr. Coeff.**	0.21	-0.40	-0.20	-0.51	0.17	0.15	-0.49	-0.02	1.00	0.41	-0.25
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57		0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572
REQ5	**Corr. Coeff.**	0.42	-0.53	0.12	-0.34	0.07	-0.04	-0.37	-0.21	0.41	1.00	0.11
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.10	0.37	0.00	0.00	0.00		0.01
	N	572	572	572	572	572	572	572	572	572	572	572
REQ6	**Corr. Coeff.**	0.10	0.57	0.20	0.62	-0.08	0.04	0.54	0.23	-0.25	0.11	1.00
	Sig. (2-tailed)	0.01	0.00	0.00	0.00	0.07	0.33	0.00	0.00	0.00	0.01	
	N	572	572	572	572	572	572	572	572	572	572	572

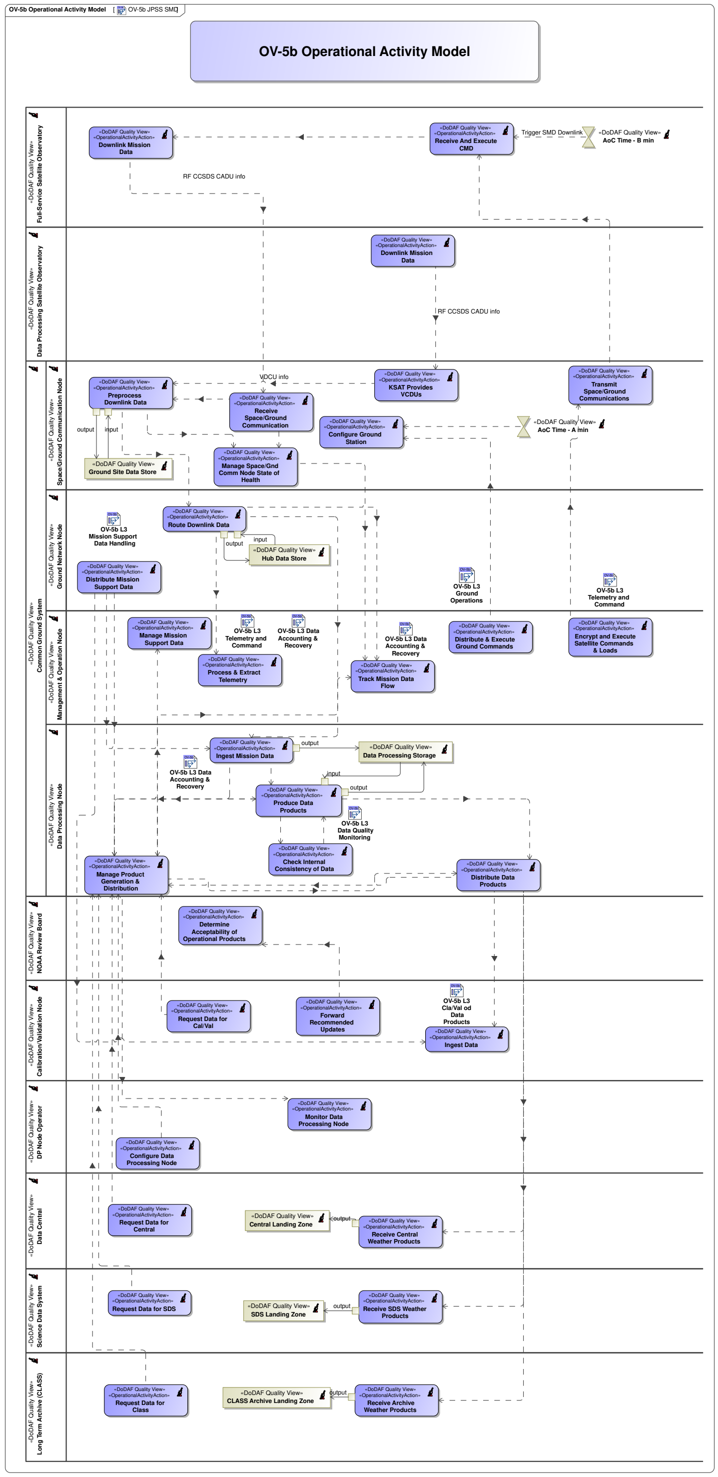

Figure B.1: Joint Polar Satellite System (JPSS) DoDAF OV-5b SMD Diagram View

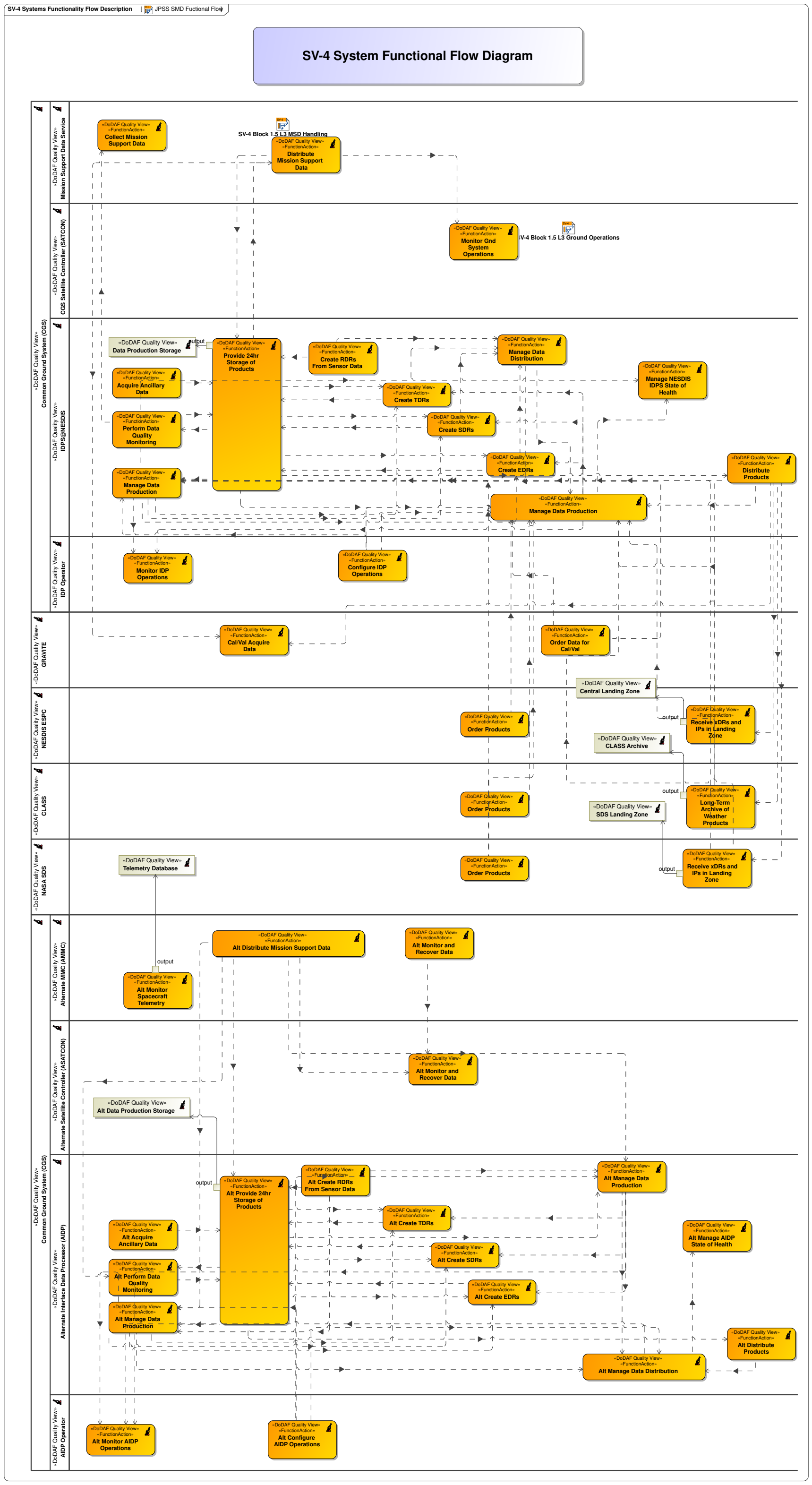

Figure B.2: Joint Polar Satellite System (JPSS) DoDAF SV-4 Functional Flow SMD Diagram View

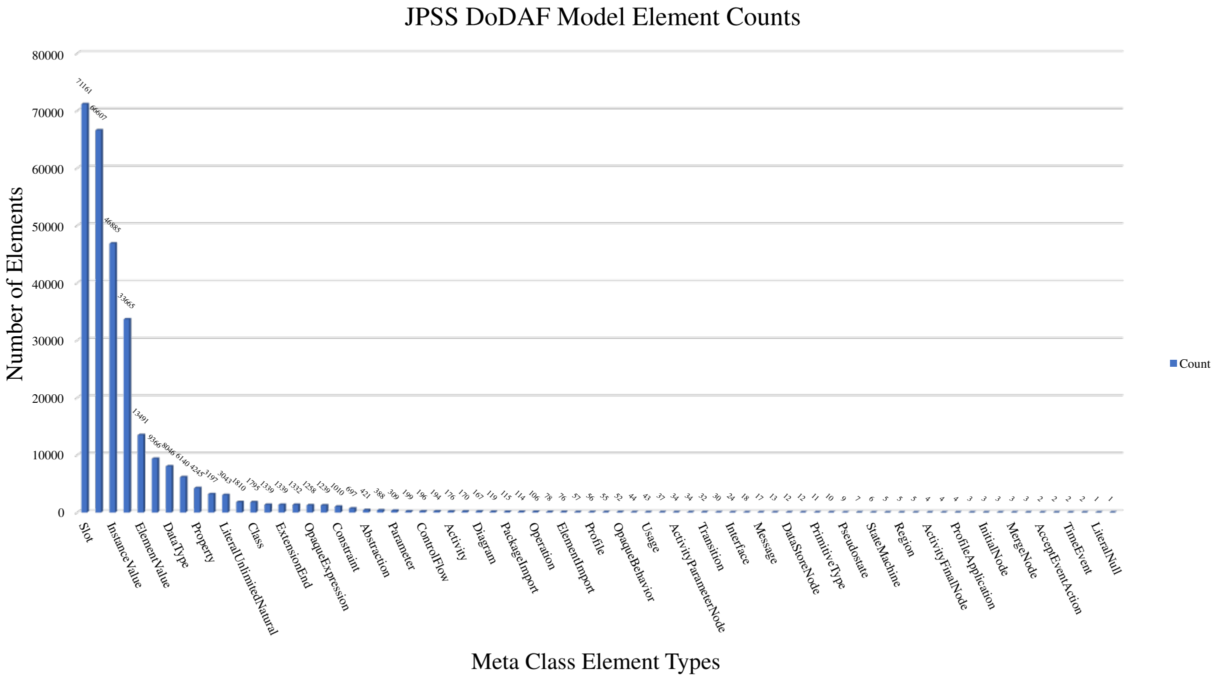

Figure B.3: Joint Polar Satellite System (JPSS) DoDAF CONOP Element Counts for Stored Mission Data (SMD)

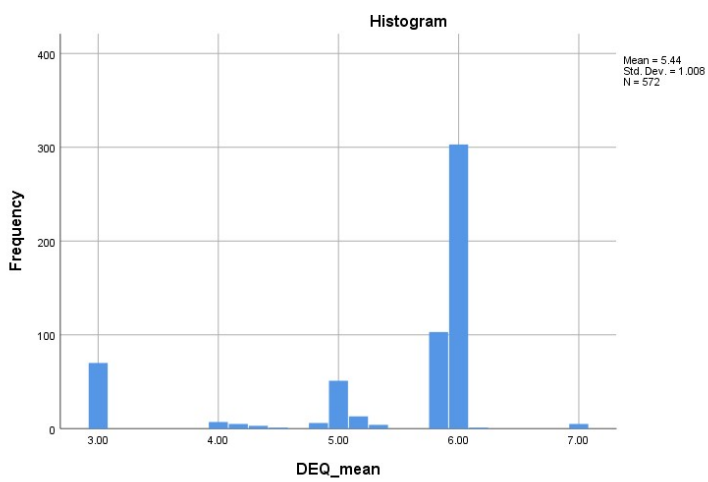

Figure B.4: JPSS DEQ Mean Histogram

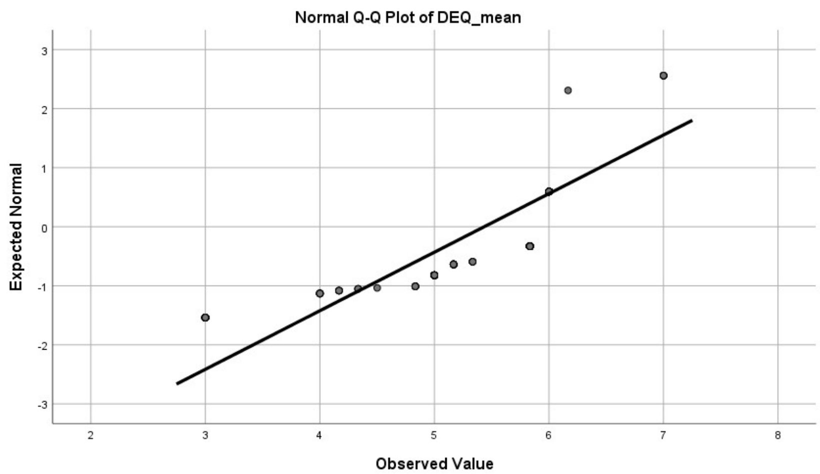

Figure B.5: JPSS Normal Q-Q Plot DEQ Mean

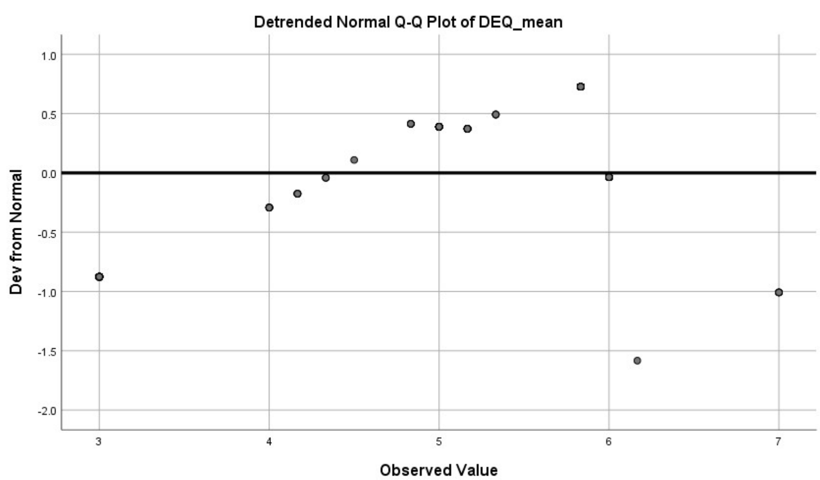

Figure B.6: JPSS Detrended Normal Q-Q Plot DEQ Mean

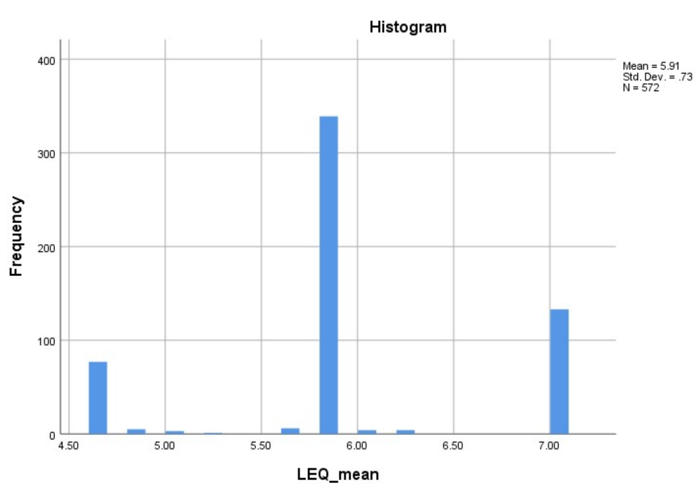

Figure B.7: JPSS LEQ Mean Histogram

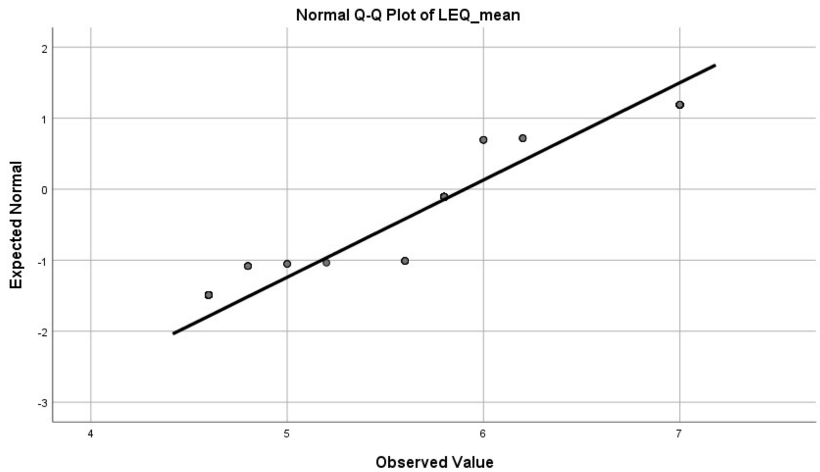

Figure B.8: JPSS Normal Q-Q Plot LEQ Mean

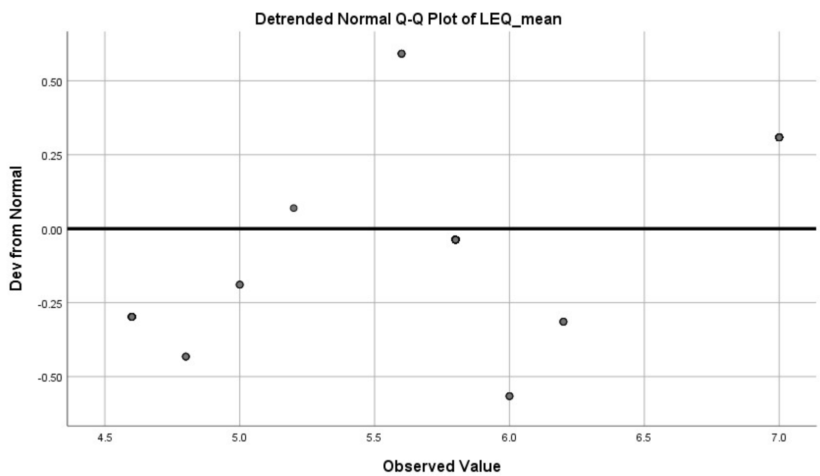

Figure B.9: JPSS Detrended Normal Q-Q Plot LEQ Mean

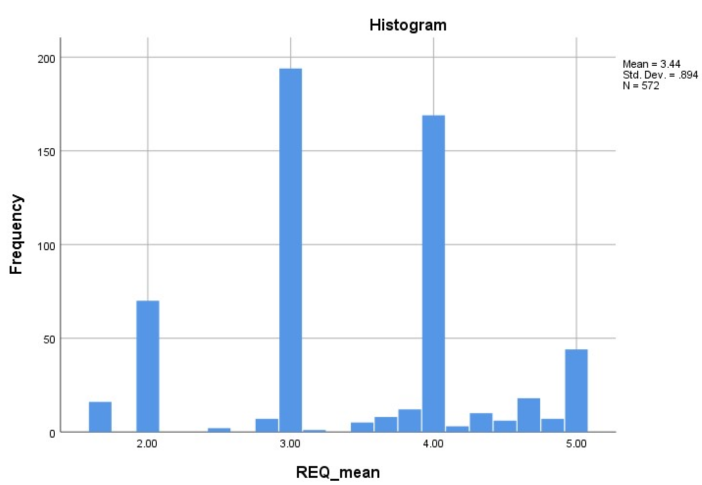

Figure B.10: JPSS REQ Mean Histogram

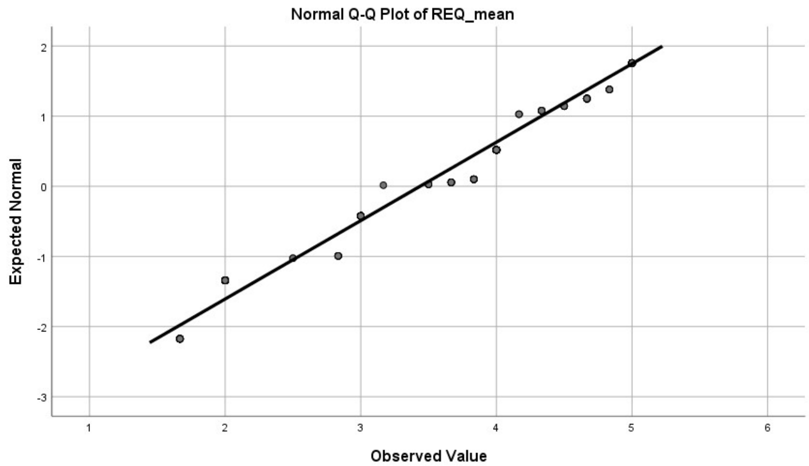

Figure B.11: JPSS Normal Q-Q Plot REQ Mean

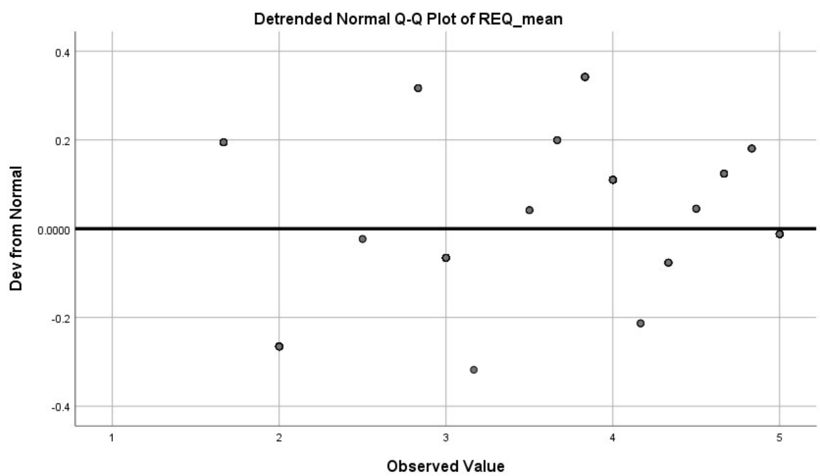

Figure B.12: JPSS Detrended Normal Q-Q Plot REQ Mean

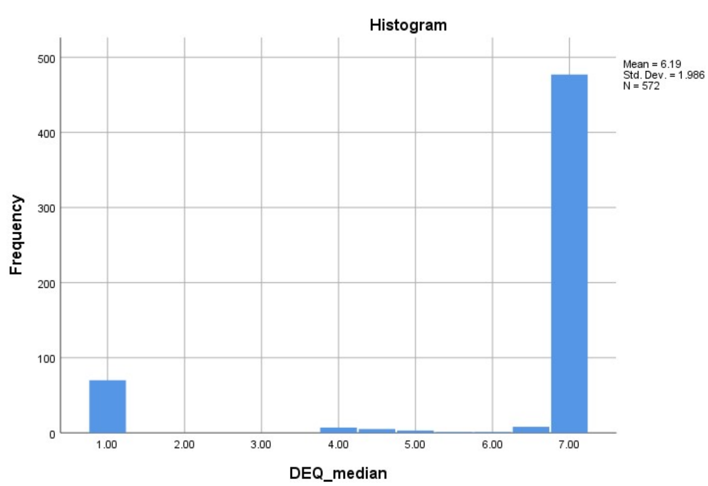

Figure B.13: JPSS DEQ Median Histogram

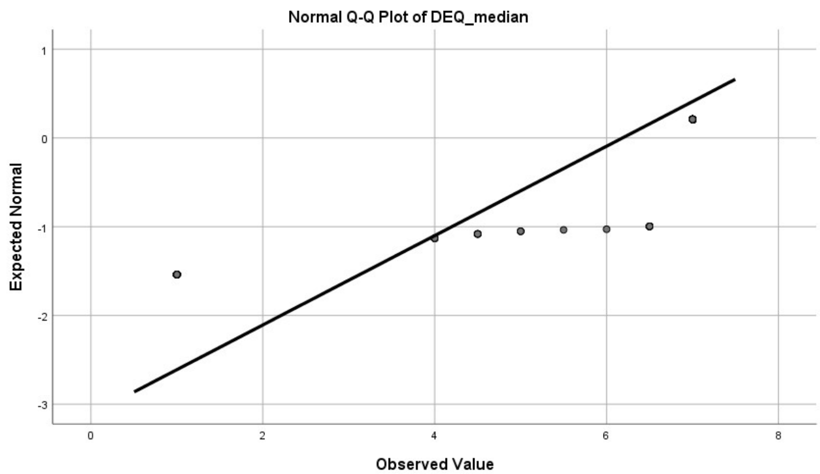

Figure B.14: JPSS Normal Q-Q Plot DEQ Median

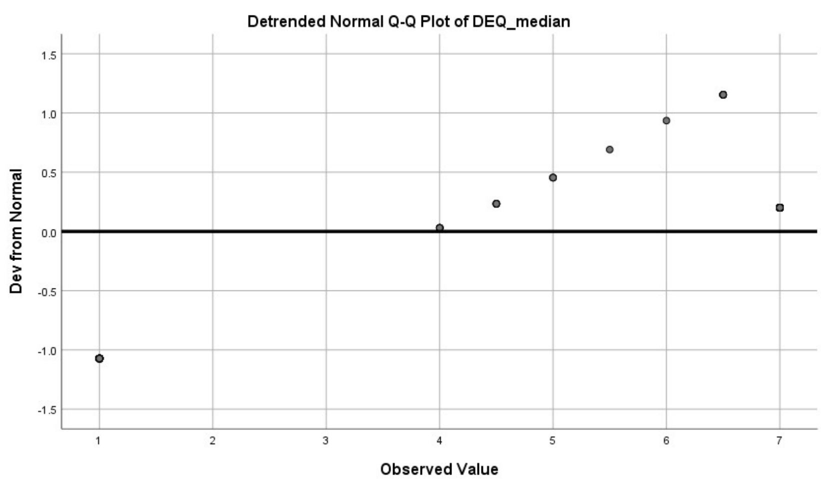

Figure B.15: JPSS Detrended Normal Q-Q Plot DEQ Median

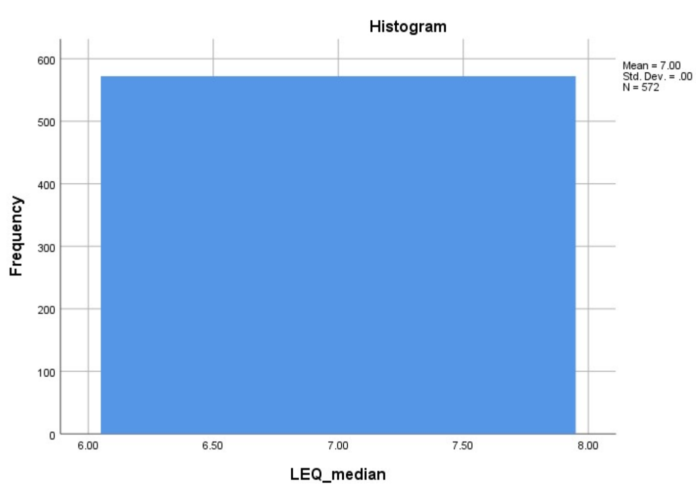

Figure B.16: JPSS LEQ Median Histogram

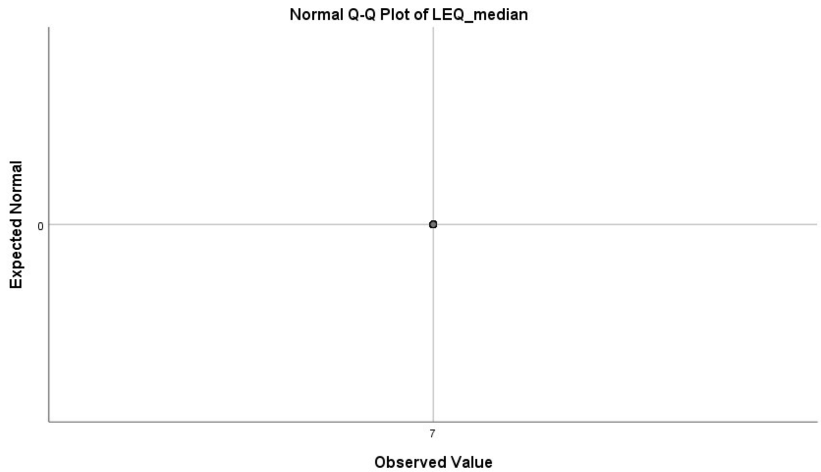

Figure B.17: JPSS Normal Q-Q Plot LEQ Median

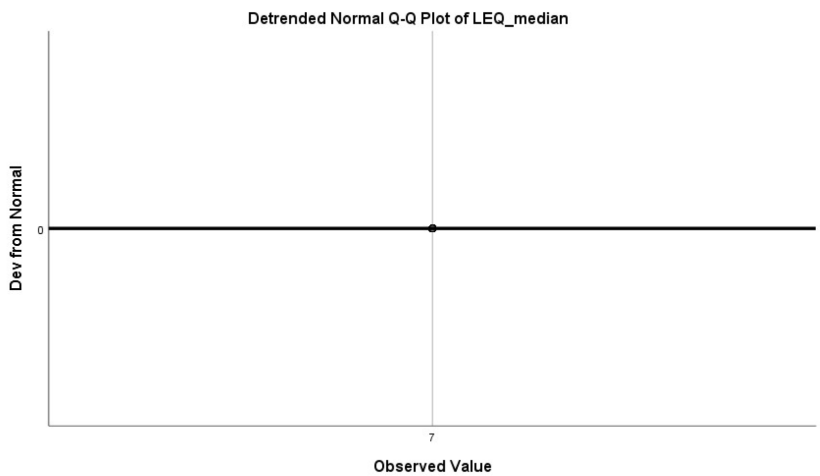

Figure B.18: JPSS Detrended Normal Q-Q Plot LEQ Median

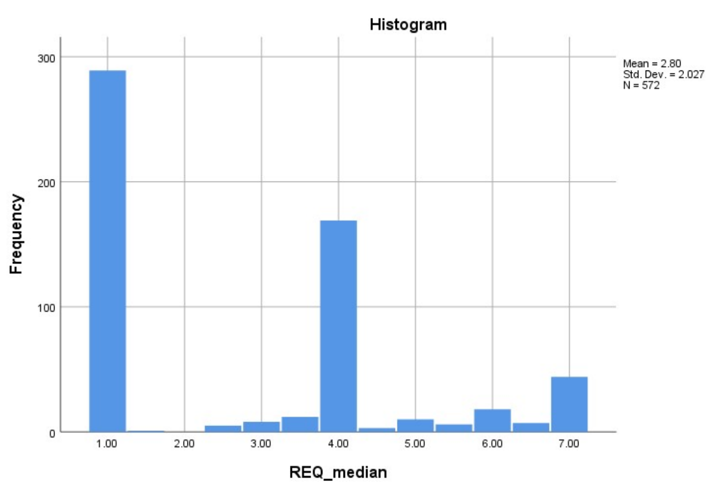

Figure B.19: JPSS REQ Median Histogram

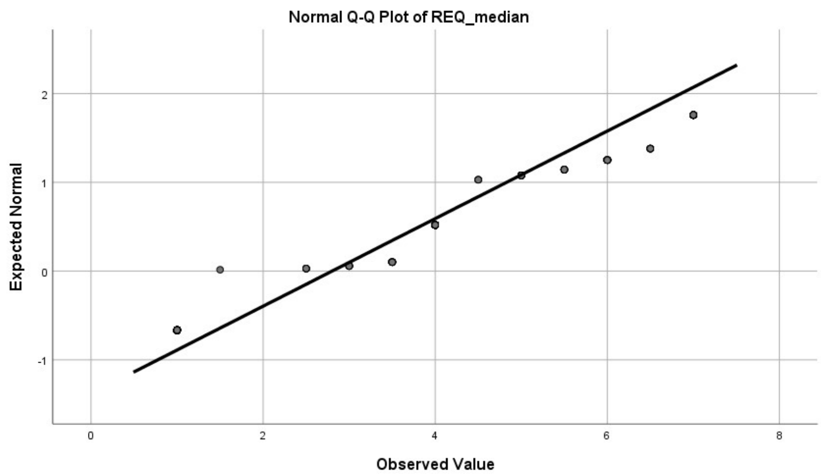

Figure B.20: JPSS Normal Q-Q Plot REQ Median

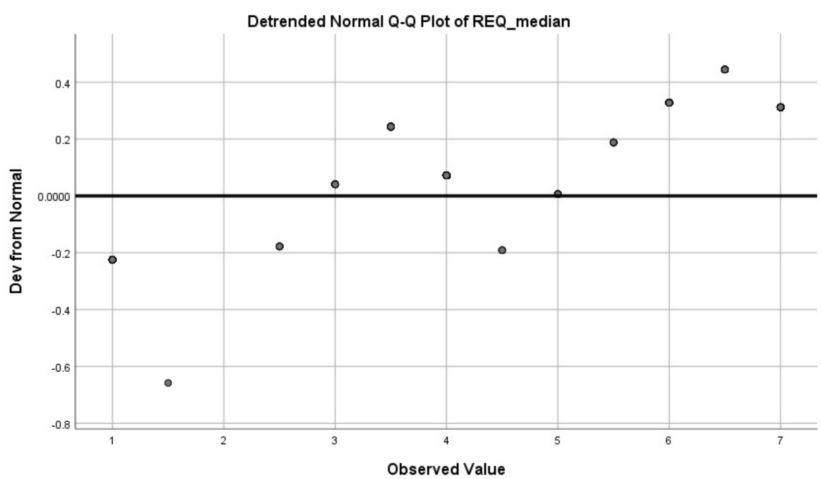

Figure B.21: JPSS Detrended Normal Q-Q Plot REQ Median

Table B.3: JPSS Component Matrix

Component Matrix					
	Component				
	1	2	3	4	5
DEQ3	-0.36	0.72	0.33	0.12	-0.01
DEQ4	0.84	-0.13	0.20	-0.14	0.16
LEQ1	0.25	0.74	-0.08	-0.46	-0.30
LEQ3	0.82	0.04	0.29	0.19	0.07
LEQ4	0.03	0.36	-0.72	0.22	0.49
REQ1	-0.11	0.27	0.51	-0.31	0.69
REQ2	0.77	0.16	-0.38	0.40	0.11
REQ3	0.50	0.36	-0.35	-0.56	-0.13
REQ4	-0.63	0.21	-0.13	-0.01	0.31
REQ5	-0.45	0.54	0.09	0.44	-0.28
REQ6	0.68	0.36	0.34	0.37	-0.03
Extraction Method: Principal Component Analysis.					
a. 5 components extracted.					

Table B.4: JPSS Total Variance Explained Adjusted 3 Factor

Total Variance Explained Adjusted						
Comp	**Initial Eigenvalues**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	3.5	31.8	31.8	3.2	28.6	28.6
2	1.9	17.3	49.1	1.9	17.0	45.7
3	1.4	12.8	61.9	1.8	16.3	61.9
4	1.2	11.1	73.0			
5	1.1	9.5	82.5			
6	0.8	7.6	90.13			
7	0.4	3.8	93.9			
8	0.3	2.7	96.6			
9	0.2	1.7	98.3			
10	0.1	0.9	99.2			
11	0.1	0.8	100.0			
Extraction Method: Principal Component Analysis.						
a. 3 components extracted.						

Table B.5: JPSS Component Matrix Adjusted 3 Factor

Component Matrix a.			
	Component		
	1	**2**	**3**
DEQ3	-0.36	0.72	0.33
DEQ4	0.84	-0.13	0.20
LEQ1	0.25	0.74	-0.08
LEQ3	0.82	0.04	0.29
LEQ4	0.03	0.36	-0.72
REQ1	-0.11	0.27	0.51
REQ2	0.77	0.16	-0.38
REQ3	0.50	0.36	-0.35
REQ4	-0.63	0.21	-0.13
REQ5	-0.45	0.54	0.09
REQ6	0.68	0.36	0.34
a. 3 components extracted.			

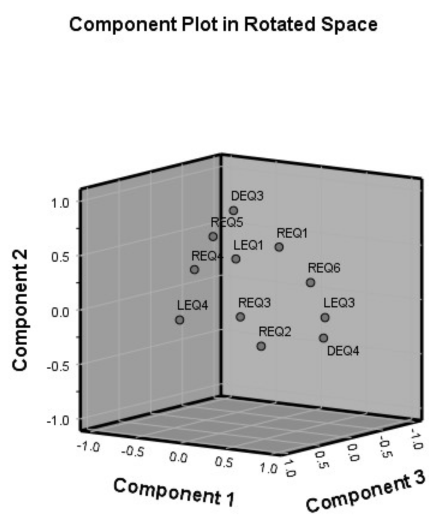

Figure B.22: Joint Polar Satellite System (JPSS) DoDAF QbD Three factor Loading Plot

Table B.6: JPSS Parameter Estimates

Parameter Estimates								
		Estimate	**Std. Error**	**Wald**	**df**	**Sig.**	**95% Confidence Interval**	
							Lower Bound	**Upper Bound**
Threshold	**[DEQ_mean = 3.00]**	55.98	6.72	69.45	1	0.00	42.81	69.14
	[DEQ_mean = 4.00]	59.08	6.94	72.54	1	0.00	45.48	72.67
	[DEQ_mean = 4.17]	61.48	7.05	76.13	1	0.00	47.67	75.29
	[DEQ_mean = 4.33]	63.47	7.23	77.12	1	0.00	49.31	77.64
	[DEQ_mean = 4.50]	64.26	7.33	76.96	1	0.00	49.90	78.61
	[DEQ_mean = 4.83]	67.38	7.47	81.47	1	0.00	52.75	82.01
	[DEQ_mean = 5.00]	77.64	7.82	98.50	1	0.00	62.30	92.97
	[DEQ_mean = 5.17]	80.28	8.00	100.74	1	0.00	64.60	95.96
	[DEQ_mean = 5.33]	80.95	8.05	101.24	1	0.00	65.18	96.72
	[DEQ_mean = 5.83]	87.46	8.33	110.23	1	0.00	71.14	103.79
	[DEQ_mean = 6.00]	98.11	8.60	130.28	1	0.00	81.26	114.96
	[DEQ_mean = 6.17]	100.67	9.23	118.98	1	0.00	82.58	118.76
Location	**DEQ3**	3.17	0.31	106.18	1	0.00	2.57	3.77
	DEQ4	2.75	0.22	150.32	1	0.00	2.31	3.19
	LEQ1	0.08	0.14	0.34	1	0.56	-0.20	0.36
	LEQ3	2.09	0.24	78.44	1	0.00	1.62	2.55
	LEQ4	7.21	0.93	59.85	1	0.00	5.38	9.03
	REQ1	0.95	0.59	2.55	1	0.11	-0.22	2.11
	REQ2	-0.10	0.16	0.37	1	0.54	-0.42	0.22
	REQ3	-0.08	0.11	0.54	1	0.46	-0.31	0.14
	REQ4	-1.26	0.14	83.41	1	0.00	-1.53	-0.99
	REQ5	0.27	0.13	4.15	1	0.04	0.01	0.53
	REQ6	0.79	0.23	11.73	1	0.00	0.34	1.25
Link function: Logit.								

Table B.7: Probability for JPSS Response

		Mean Represented Value Point												
		3	**4**	**4.17**	**4.33**	**4.5**	**4.83**	**5**	**5.17**	**5.33**	**5.83**	**6**	**6.17**	**7**
DEQ3														
S.Disagree	**Mean**	0.14	0.01	0.01	0.00	0.00	0.01	0.08	0.01	0.00	0.18	0.55	0.00	0.00
	N	524	524	524	524	524	524	524	524	524	524	524	524	524
	S.D	0.34	0.06	0.04	0.02	0.01	0.03	0.24	0.02	0.01	0.35	0.48	0.00	0.00
Disagree	**Mean**	0.01	0.06	0.05	0.01	0.00	0.01	0.38	0.20	0.04	0.14	0.05	0.01	0.01
	N	14	14	14	14	14	14	14	14	14	14	14	14	14
	S.D	0.03	0.14	0.13	0.03	0.00	0.01	0.23	0.12	0.02	0.09	0.19	0.04	0.03
SW.Agree	**Mean**	0.00	0.00	0.01	0.01	0.01	0.10	0.83	0.03	0.01	0.01	0.00	0.00	0.00
	N	1	1	1	1	1	1	1	1	1	1	1	1	1
	S.D													
Agree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.30	0.07	0.29	0.00	0.00	0.00
	N	2	2	2	2	2	2	2	2	2	2	2	2	2
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00
S.Agree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.05	0.01	0.22	0.40	0.00	0.16
	N	31	31	31	31	31	31	31	31	31	31	31	31	31
	S.D	0.00	0.00	0.00	0.00	0.00	0.01	0.25	0.09	0.03	0.20	0.40	0.00	0.37
Total	**Mean**	0.13	0.01	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.18	0.53	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.32	0.07	0.05	0.01	0.00	0.03	0.25	0.05	0.01	0.34	0.48	0.00	0.09
DEQ4														
S.Disagree	**Mean**	0.31	0.04	0.03	0.01	0.00	0.03	0.35	0.05	0.01	0.07	0.09	0.00	0.00
	N	150	150	150	150	150	150	150	150	150	150	150	150	150
	S.D	0.45	0.12	0.08	0.03	0.01	0.04	0.38	0.08	0.02	0.13	0.24	0.00	0.00
S.Agree	**Mean**	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.68	0.00	0.01
	N	422	422	422	422	422	422	422	422	422	422	422	422	422
	S.D	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.38	0.44	0.01	0.10
Total	**Mean**	0.13	0.01	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.18	0.53	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.32	0.07	0.05	0.01	0.00	0.03	0.25	0.05	0.01	0.34	0.48	0.00	0.09
LEQ1														
S.Disagree	**Mean**	0.17	0.01	0.00	0.00	0.00	0.01	0.11	0.01	0.01	0.23	0.43	0.00	0.00
	N	422	422	422	422	422	422	422	422	422	422	422	422	422
	S.D	0.37	0.07	0.04	0.02	0.01	0.02	0.26	0.04	0.00	0.38	0.48	0.01	0.01
Disagree	**Mean**	0.04	0.20	0.18	0.05	0.01	0.02	0.35	0.08	0.01	0.04	0.00	0.00	0.00

Continued on next page

Table B.7: Probability for JPSS Response (continued)

		Mean Represented Value Point												
		3	**4**	**4.17**	**4.33**	**4.5**	**4.83**	**5**	**5.17**	**5.33**	**5.83**	**6**	**6.17**	**7**
	N	4	4	4	4	4	4	4	4	4	4	4	4	4
	S.D	0.05	0.22	0.20	0.05	0.00	0.02	0.41	0.12	0.02	0.06	0.00	0.00	0.00
SW.Agree	**Mean**	0.00	0.00	0.01	0.01	0.01	0.09	0.82	0.03	0.01	0.01	0.00	0.00	0.00
	N	1	1	1	1	1	1	1	1	1	1	1	1	1
	S.D													
Agree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.30	0.07	0.29	0.00	0.00	0.00
	N	2	2	2	2	2	2	2	2	2	2	2	2	2
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00
S.Agree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.01	0.05	0.84	0.00	0.04
	N	143	143	143	143	143	143	143	143	143	143	143	143	143
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.06	0.01	0.13	0.34	0.00	0.18
Total	**Mean**	0.12	0.01	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.18	0.53	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.32	0.07	0.05	0.01	0.01	0.02	0.25	0.05	0.01	0.34	0.48	0.00	0.09
LEQ3														
S.Disagree	**Mean**	0.80	0.07	0.02	0.01	0.00	0.00	0.06	0.01	0.00	0.01	0.00	0.00	0.00
	N	58	58	58	58	58	58	58	58	58	58	58	58	58
	S.D	0.35	0.17	0.07	0.02	0.00	0.00	0.19	0.05	0.00	0.02	0.00	0.00	0.00
Disagree	**Mean**	0.07	0.26	0.19	0.05	0.00	0.03	0.23	0.06	0.02	0.06	0.00	0.00	0.00
	N	5	5	5	5	5	5	5	5	5	5	5	5	5
	S.D	0.06	0.23	0.17	0.03	0.01	0.03	0.36	0.13	0.04	0.13	0.00	0.00	0.00
SW. Disagree	**Mean**	0.00	0.06	0.13	0.06	0.01	0.03	0.11	0.13	0.04	0.37	0.00	0.00	0.00
	N	9	9	9	9	9	9	9	9	9	9	9	9	9
	S.D	0.02	0.09	0.20	0.10	0.02	0.05	0.12	0.11	0.03	0.32	0.00	0.00	0.00
Neutral	**Mean**	0.01	0.05	0.21	0.25	0.08	0.27	0.11	0.00	0.00	0.00	0.00	0.00	0.00
	N	1	1	1	1	1	1	1	1	1	1	1	1	1
	S.D													
Agree	**Mean**	0.00	0.00	0.01	0.02	0.01	0.15	0.76	0.03	0.00	0.00	0.00	0.00	0.00
	N	6	6	6	6	6	6	6	6	6	6	6	6	6
	S.D	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.02	0.00	0.01	0.00	0.00	0.00
S.Agree	**Mean**	0.05	0.00	0.00	0.00	0.00	0.00	0.08	0.01	0.00	0.20	0.61	0.00	0.01
	N	493	493	493	493	493	493	493	493	493	493	493	493	493
	S.D	0.22	0.00	0.00	0.00	0.00	0.01	0.24	0.04	0.01	0.36	0.46	0.01	0.09
Total	**Mean**	0.12	0.01	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.18	0.53	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572	572	572

Continued on next page

Table B.7: Probability for JPSS Response (continued)

		Mean Represented Value Point												
		3	**4**	**4.17**	**4.33**	**4.5**	**4.83**	**5**	**5.17**	**5.33**	**5.83**	**6**	**6.17**	**7**
	S.D	0.32	0.06	0.04	0.01	0.00	0.02	0.25	0.05	0.01	0.34	0.48	0.00	0.09
LEQ4														
S.Disagree	**Mean**	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	N	26	26	26	26	26	26	26	26	26	26	26	26	26
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S.Agree	**Mean**	0.08	0.01	0.00	0.00	0.00	0.00	0.10	0.02	0.00	0.19	0.56	0.00	0.01
	N	546	546	546	546	546	546	546	546	546	546	546	546	546
	S.D	0.27	0.07	0.05	0.02	0.00	0.02	0.25	0.05	0.01	0.34	0.48	0.00	0.09
Total	**Mean**	0.12	0.01	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.18	0.53	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.32	0.07	0.04	0.01	0.00	0.02	0.25	0.05	0.01	0.34	0.48	0.00	0.09
REQ1														
S.Disagree	**Mean**	0.12	0.01	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.18	0.53	0.00	0.00
	N	564	564	564	564	564	564	564	564	564	564	564	564	564
	S.D	0.32	0.06	0.04	0.02	0.00	0.02	0.24	0.05	0.01	0.34	0.48	0.00	0.01
S.Agree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.01	0.61
	N	8	8	8	8	8	8	8	8	8	8	8	8	8
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.51
Total	**Mean**	0.12	0.01	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.18	0.53	0.00	0.00
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.32	0.07	0.05	0.01	0.00	0.02	0.25	0.05	0.01	0.34	0.48	0.00	0.09
REQ2														
S.Disagree	**Mean**	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.06	0.07	0.00	0.05
	N	88	88	88	88	88	88	88	88	88	88	88	88	88
	S.D	0.40	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.21	0.24	0.00	0.23
Disagree	**Mean**	0.00	0.00	0.00	0.01	0.00	0.07	0.76	0.09	0.01	0.03	0.00	0.00	0.00
	N	3	3	3	3	3	3	3	3	3	3	3	3	3
	S.D	0.00	0.00	0.00	0.01	0.00	0.07	0.07	0.09	0.01	0.03	0.00	0.00	0.00
SW. Disagree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.01	0.20	0.02	0.00	0.17	0.58	0.00	0.00
	N	4	4	4	4	4	4	4	4	4	4	4	4	4
	S.D	0.00	0.00	0.00	0.00	0.00	0.02	0.41	0.03	0.00	0.10	0.39	0.00	0.00
Neutral	**Mean**	0.08	0.14	0.07	0.01	0.00	0.03	0.36	0.06	0.01	0.14	0.06	0.00	0.00
	N	16	16	16	16	16	16	16	16	16	16	16	16	16

Continued on next page

Table B.7: Probability for JPSS Response (continued)

		Mean Represented Value Point												
		3	**4**	**4.17**	**4.33**	**4.5**	**4.83**	**5**	**5.17**	**5.33**	**5.83**	**6**	**6.17**	**7**
	S.D	0.14	0.22	0.11	0.02	0.00	0.04	0.39	0.09	0.02	0.30	0.23	0.01	0.00
SW.Agree	**Mean**	0.00	0.01	0.02	0.01	0.01	0.05	0.55	0.05	0.01	0.23	0.04	0.00	0.00
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
	S.D	0.06	0.08	0.07	0.05	0.01	0.05	0.38	0.04	0.02	0.35	0.16	0.00	0.00
Agree	**Mean**	0.05	0.09	0.06	0.02	0.00	0.02	0.20	0.08	0.02	0.34	0.08	0.00	0.00
	N	32	32	32	32	32	32	32	32	32	32	32	32	32
	S.D	0.12	0.17	0.13	0.05	0.01	0.04	0.29	0.11	0.03	0.38	0.22	0.00	0.00
S.Agree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.19	0.75	0.00	0.00
	N	385	385	385	385	385	385	385	385	385	385	385	385	385
	S.D	0.00	0.00	0.00	0.00	0.00	0.01	0.15	0.04	0.01	0.36	0.41	0.01	0.01
Total	**Mean**	0.13	0.01	0.01	0.00	0.00	0.01	0.09	0.02	0.01	0.18	0.53	0.01	0.01
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.32	0.07	0.05	0.02	0.01	0.02	0.25	0.05	0.01	0.34	0.48	0.01	0.09
REQ3														
S.Disagree	**Mean**	0.18	0.02	0.01	0.00	0.00	0.01	0.13	0.03	0.01	0.12	0.48	0.00	0.01
	N	397	397	397	397	397	397	397	397	397	397	397	397	397
	S.D	0.38	0.08	0.05	0.02	0.01	0.03	0.28	0.06	0.01	0.27	0.48	0.01	0.11
Disagree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.89	0.05	0.00	0.00
	N	3	3	3	3	3	3	3	3	3	3	3	3	3
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.90	0.05	0.00	0.00
	N	2	2	2	2	2	2	2	2	2	2	2	2	2
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S.Agree	**Mean**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.31	0.67	0.00	0.00
	N	170	170	170	170	170	170	170	170	170	170	170	170	170
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.43	0.45	0.00	0.00
Total	**Mean**	0.13	0.01	0.01	0.00	0.00	0.01	0.09	0.02	0.01	0.18	0.53	0.00	0.01
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.33	0.07	0.05	0.02	0.01	0.02	0.25	0.05	0.01	0.34	0.48	0.01	0.09
REQ4														
S.Disagree	**Mean**	0.07	0.00	0.00	0.00	0.00	0.00	0.09	0.01	0.00	0.01	0.80	0.00	0.00
	N	356	356	356	356	356	356	356	356	356	356	356	356	356
	S.D	0.26	0.00	0.00	0.00	0.00	0.01	0.24	0.05	0.01	0.04	0.39	0.01	0.01
S.Agree	**Mean**	0.22	0.03	0.02	0.01	0.00	0.01	0.11	0.03	0.01	0.46	0.08	0.00	0.02

Continued on next page

Table B.7: Probability for JPSS Response (continued)

		Mean Represented Value Point												
		3	**4**	**4.17**	**4.33**	**4.5**	**4.83**	**5**	**5.17**	**5.33**	**5.83**	**6**	**6.17**	**7**
	N	216	216	216	216	216	216	216	216	216	216	216	216	216
	S.D	0.40	0.10	0.07	0.03	0.01	0.03	0.25	0.05	0.01	0.43	0.20	0.00	0.15
Total	**Mean**	0.13	0.01	0.01	0.00	0.00	0.01	0.09	0.02	0.01	0.18	0.53	0.00	0.01
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.33	0.07	0.05	0.02	0.01	0.02	0.25	0.05	0.01	0.34	0.48	0.01	0.09
REQ5														
S.Disagree	**Mean**	0.13	0.00	0.00	0.00	0.00	0.00	0.07	0.02	0.01	0.18	0.57	0.00	0.01
	N	520	520	520	520	520	520	520	520	520	520	520	520	520
	S.D	0.34	0.02	0.00	0.00	0.00	0.01	0.22	0.04	0.01	0.35	0.48	0.01	0.10
Disagree	**Mean**	0.05	0.09	0.08	0.05	0.01	0.06	0.35	0.04	0.01	0.09	0.17	0.00	0.00
	N	13	13	13	13	13	13	13	13	13	13	13	13	13
	S.D	0.12	0.17	0.14	0.08	0.02	0.08	0.39	0.08	0.02	0.12	0.32	0.00	0.00
SW. Disagree	**Mean**	0.01	0.06	0.14	0.07	0.02	0.07	0.57	0.04	0.01	0.01	0.00	0.00	0.00
	N	3	3	3	3	3	3	3	3	3	3	3	3	3
	S.D	0.02	0.11	0.23	0.11	0.02	0.02	0.47	0.03	0.00	0.01	0.00	0.00	0.00
Neutral	**Mean**	0.00	0.00	0.00	0.00	0.00	0.05	0.84	0.07	0.01	0.02	0.00	0.00	0.00
	N	2	2	2	2	2	2	2	2	2	2	2	2	2
	S.D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SW.Agree	**Mean**	0.02	0.10	0.09	0.02	0.00	0.02	0.21	0.02	0.00	0.12	0.38	0.00	0.00
	N	4	4	4	4	4	4	4	4	4	4	4	4	4
	S.D	0.05	0.20	0.18	0.04	0.01	0.02	0.42	0.032	0.00	0.13	0.44	0.00	0.00
Agree	**Mean**	0.09	0.16	0.10	0.04	0.01	0.03	0.22	0.10	0.03	0.16	0.08	0.00	0.00
	N	10	10	10	10	10	10	10	10	10	10	10	10	10
	S.D	0.15	0.22	0.15	0.07	0.01	0.06	0.29	0.13	0.04	0.22	0.24	0.00	0.00
S.Agree	**Mean**	0.06	0.11	0.05	0.02	0.00	0.03	0.24	0.04	0.01	0.1	0.24	0.00	0.00
	N	20	20	20	20	20	20	20	20	20	20	20	20	20
	S.D	0.13	0.20	0.11	0.03	0.01	0.06	0.35	0.07	0.03	0.24	0.37	0.00	0.00
Total	**Mean**	0.13	0.01	0.01	0.00	0.00	0.01	0.09	0.02	0.01	0.18	0.53	0.00	0.01
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.32	0.06	0.05	0.02	0.01	0.02	0.25	0.05	0.01	0.34	0.48	0.01	0.09
REQ6														
S.Disagree	**Mean**	0.73	0.00	0.00	0.00	0.00	0.02	0.22	0.01	0.00	0.00	0.00	0.00	0.00
	N	60	60	60	60	60	60	60	60	60	60	60	60	60
	S.D	0.44	0.00	0.00	0.00	0.00	0.03	0.38	0.02	0.00	0.01	0.00	0.00	0.00

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Table B.7: Probability for JPSS Response (continued)

		Mean Represented Value Point												
		3	**4**	**4.17**	**4.33**	**4.5**	**4.83**	**5**	**5.17**	**5.33**	**5.83**	**6**	**6.17**	**7**
S.Agree	**Mean**	0.06	0.01	0.01	0.00	0.00	0.01	0.07	0.02	0.01	0.20	0.59	0.00	0.01
	N	512	512	512	512	512	512	512	512	512	512	512	512	512
	S.D	0.22	0.07	0.05	0.02	0.01	0.02	0.22	0.05	0.01	0.36	0.47	0.01	0.10
Total	**Mean**	0.13	0.01	0.01	0.00	0.00	0.01	0.09	0.02	0.01	0.18	0.53	0.00	0.01
	N	572	572	572	572	572	572	572	572	572	572	572	572	572
	S.D	0.33	0.07	0.05	0.02	0.01	0.02	0.25	0.05	0.01	0.34	0.48	0.01	0.09

Appendix C

Search and Rescue Case Study Additional Data

Table C.1: SAR Abbrevations

Abbreviations	Description
AAIB	Air Accident Investigation Board
ACC	Assistant Chief Constable
ACCOLC	Access Overload Control Scheme
ACPO	Association of Chief Police Officers
ACPO(TAM)	Association of Chief Police Officers (Terrorism and Allied Matters)
ACPO(S)	Association of Chief Police Officers in Scotland
AIO	Ambulance Incident Officer
AJP	Allied Joint Publication
APA	Association of Police Authorities
APCM	Aircraft Post Crash Management
ARAD	Agriculture and Rural Affairs Department (Welsh Assembly)
ARCC	Aeronautical Rescue Coordination Centre
ASA	Ambulance Services Association
ATCC	Air Traffic Control Centre
AWE	Atomic Weapons Establishment
Bde	Brigade
BCRC	British Cave Rescue Council
BCU	Basic Command Unit
BFL	British Fishery Limits
BHA	Body Holding Area
BNFL	British Nuclear Fuels Ltd

BRT	Brigade Reinforcement Team
BSFO	British Sea Fishery Officer
BTP	British Transport Police
CBRN	Chemical, Biological, Radiological and Nuclear
CB	Casualty Bureau
CCA	Civil Contingencies Act
CCC	Civil Contingencies Committee
CCRF	Civil Contingency Reaction Force
CCS	Civil Contingencies Secretariat
CDM	Chief of Defence Materiel
Cdrs	Commanders
CDS	Chief of the Defence Staff
CEMG	Central Emergency Management Group
CEPU	Central Emergency Planning Unit
CESO	Chief Environment and Safety Officer
CFOA	Chief Fire Officers' Association
CINCAIR	Commander in Chief Air Command
CINCLAND	Commander in Chief Land Command
CINCFLEET	Commander in Chief Fleet Command
CMD	Conventional Munitions Disposal
CMG	Crisis Management Group
CNC	Civil Nuclear Constabulary
COBR	Cabinet Office Briefing Room
COMAH	Control of Major Accident Hazards
CPRB	Counter Pollution and Response Branch
CPSO	Counter Pollution and Salvage Officer

CPT	Contingency Planning Team
CRF	Commander Regional Forces
CSIA	Central Sponsor for Information Assurance (Cabinet Office)
CST	Command Support Team
CT	Counter Terrorism
C&W	Cable and Wireless
C2	Command & Control
D & D	Distress and Diversion
DA	Devolved Administration
DAFNI	Department of Agriculture and Fisheries Northern Ireland
DARDNI	Department of Agriculture and Rural Development Northern Ireland
DBERR	Department of Business, Enterprise and Regulatory Reform
DCA	Defence Critical Asset
DCDS(C)	Deputy Chief of the Defence Staff (Commitments)
DCLG	Department for Communities and Local Government
DCMO	Defence Crisis Management Organisation
DCMS	Department of Culture, Media and Sport
D CT & UK Ops	Directorate Counter Terrorism and UK Operations
Defra	Department for Environment, Food and Rural Affairs
DEPC	Department for Environment, Planning and Countryside (WAG)
DfES	Department for Education and Science
DFID	Department for International Development
DfT	Department for Transport
DoH	Department of Health
DSTL	Defence Science and technology Laboratory
DWP	Department for Work and Pensions

EA	Environment Agency
ECN	Emergency Communications Network
EM	Emergency Mortuary
EOD	Explosive Ordnance Disposal
EP	Emergency Planning
EPIC	Emergency Procedures Information Centre
ETV	Emergency Towing Vessel
FCO	Foreign and Commonwealth Office
FCP	Forward Control Point
FLC	Front Line Command
FOSNNI	Flag Officer Scotland Northern England and Northern Ireland
FRAGO	Fragmentary Order
FSA	Food Standards Agency
FTRS	Full Time Reserve Service
GCHQ	Government Communications Headquarters
GDS	Government Decontamination Service
GLA	Greater London Authority
GLO	Government Liaison Officer
GLT	Government Liaison Team
GMDSS	Global Maritime Distress and Safety System
GNN	Government News Network
GO	Government Office
GOBCP	Government Office Business Continuity Plan
GOR	Government Office for the Regions
GTPS	Government Telephone Preference Scheme
HAZMAT	Hazardous Material

HAC	Humanitarian Assistance Centre
HEMS	Helicopter Emergency Medical Service
HMG	Her Majesty's Government
HMIC	Her Majesty's Inspector of Constabulary
HMICS	HM Inspectorate of Constabulary for Scotland
HMRC	HM Revenue and Customs
HO	Home Office
HPA	Health Protection Agency
HPS	Health Protection Scotland
HQ	Headquarters
HQ AIR	Headquarters Air Command
HQ LAND	Headquarters Land Command
HSE	Health and Safety Executive
ICP	Incident Control Point
IED	Improvised Explosive Device
IEDD	Improvised Explosive Device Disposal
IEM	Integrated Emergency Management
IMO	International Maritime Organisation
ISDN	Integrated Services Digital Networkr
JESCC	Joint Emergency Services Control Centre
JCP	Joint Contingency Plan
JIG	Joint Intelligence Group
JLP	Joint Logistic Plan
JOA	Joint Operations Area
JOP	Joint Operational Plan
JPG	Joint Planning Guide

JRLO	Joint Regional Liaison Officer
JSCG	Joint Service Coordination Group
JSEODOC	Joint Service EOD Operations Centre
JTAC	Joint Terrorism Analysis Centre
LESLP	London Emergency Services Liaison Panel
LFEPA	London Fire and Emergency Planning Authority
LGD	Lead Government Department
LO	Liaison Officer
LRA	Local resilience Area
LRAG	Local Risk Assessment Guidance
LRF	Local Resilience Forum
MACA	Military Aid to the Civil Authorities
MACC	Military Aid to the Civil Community
MACP	Military Aid to the Civil Power
MAGD	Military Aid to other Government Departments
MAIB	Marine Accident Investigation Board
MCA	Maritime and Coastguard Agency
MCT	Maritime Counter Terrorism
MDAT	Major Disaster Advisory Team
MDP	Ministry of Defence Police
MEDEVAC	Medical Evacuation
MEF	Media Emergency Forum
MHD	Military Home Defence
MIO	Medical Incident Officer
MIRG	Maritime Incident Response Group
MOD	Ministry of Defence

MPS	Metropolitan Police Service
MRC	Mountain Rescue Council of England and Wales
MRCC	Maritime Rescue Coordination Centre
MRC	of S Mountain Rescue Committee of Scotland
MRSC	Maritime Rescue Sub-Centre
MRT	Mountain Rescue Team
MSMO	Military Support to the Mounting of Operations
MT	Military Task
NARO	Nuclear Accident Response Organisation
NAW	National Assembly for Wales
NBC	Naval Base Commander
NCIS	National Criminal Intelligence Service
NCS	National Crime Squad
NHS	National Health Service
NIAS	Northern Ireland Ambulance Service
NIFRS	Northern Ireland Fire and Rescue Service
NIO	Northern Ireland Office
NIOBR	Northern Ireland Briefing Room
NISCC	National Infrastructure Security Coordination Centre
NPIA	National Policing Improvement Agency
NRC	Naval Regional Commander
NRO	Naval regional Officer
NRPB	National Radiological Protection Board
NSID	National Security International Development.
NSID	(PSR) NSID Sub-committee Protective Security Resilience
NVASEC	National Voluntary Aid Society Emergency Committee

ODSec	Defence & Overseas Secretariat
OEI	Offshore Energy Installation
OFMDFM	Office of the First Minister and Deputy First Minister
OGD	Other Government Department(s)
OSCT	Office of Security and Counter Terrorism
PCB	Police Casualty Bureau
PCT	Primary Care Trust
PJHQ	Permanent Joint Headquarters
PMLO	Police Military Liaison Officer
PNICC	Police National Information and Coordination Centre
POL	Petrol, Oil and Lubricants
PPE	Personal Protective Equipment
PSNI	Police Service of Northern Ireland
PSTN	Public Switch Telephone Network
PSU	Police Support Unit
RAFRLO	RAF Regional Liaison Officer
RAMP	Reception Arrangements for Military Patients
RAYNET	Radio Amateurs Emergency Network
RCC	Rescue Coordination Centre
RCCC	Regional Civil Contingencies Committee
RCDM	Royal Centre for Defence Medicine
RCU	Regional Coordination Unit
RDS	Radio Data System
REPPIR	Radiation Emergency Preparedness and Public Information Regulations
RMEF	Regional Media Emergency Forum
RIMNET	Radioactive Incident Monitoring Network

RNC	Regional Nominated Coordinator
RNLI	Royal National Lifeboat Institution
RNRLO	Royal Navy Regional Liaison Officer
ROE	Rules of Engagement
RRF	Regional Resilience Forum
RRT	Regional Resilience Team
SACP	Scene Access Control Point
SAG	Safety Advisory Group
SAR	Search and Rescue
SARDA	Search and Rescue Dog Association
SCG	Strategic-Coordinating Group
SE	Scottish Executive
SECC	Scottish Emergency Coordinating Committee
SEDD	Scottish Executive Development Department
SEEAT	Scottish Executive Emergency Action Team
SEETLLD	Scottish Executive, Enterprise, Transport and Lifelong Learning Department
SEER	Scottish Executive Emergency Room
SEERAD	Scottish Executive Environment and Rural Affairs Department
SEFCSD	Scottish Executive Finance and Central Services Department
SEJD	Scottish Executive Justice Department
SEPA	Scottish Environment Protection Agency
SFPA	Scottish Fishery Protection Agency
SHA	Strategic Health Authority
SIO	Senior Investigating Officer
SJC(UK)	Standing Joint Commander (UK)

SME	Subject Matter Expert
SOCA	Serious Organised Crime Agency
SOSREP	Secretary of State's Representative
SPICC	Scottish Police Information and Coordination Centre
SRR	Search and Rescue Region
STAC	Science Technical Advisory Cell
SUA	Suppression of Unlawful Acts
TLACP	Training and Logistics Assistance to the Civil Police
UKAEA	United Kingdom Atomic Energy Authority
UKAEAC	United Kingdom Atomic Energy Authority Constabulary
UKFSSART	United Kingdom Fire Service Search and Rescue Team
UNCLOS	United Nations Convention on Law of the Sea
US&R	Urban Search and Rescue
USAF	United States Air Force
VAS	Voluntary Aid Societies
VSCPF	Voluntary Sector Civil Protection Forum
WAG	Welsh Assembly Government
WBRG	Welsh Borders Resilience Group
WCCC	Wales Civil Contingencies Committee
WMEF	Welsh Media Emergency Forum
WRAG	Wales Risk Assessment Group
WRF	Wales Resilience Forum
WRVS	Women's Royal Voluntary Service

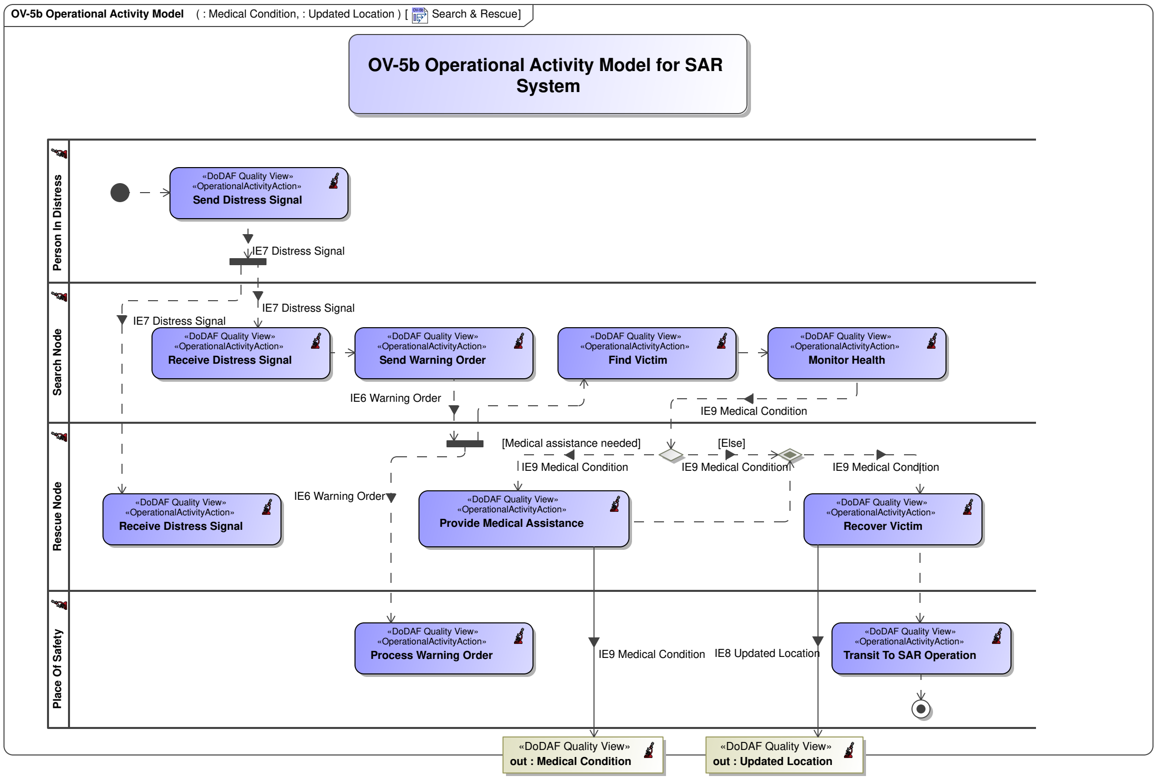

Figure C.1: Search and Rescue (SAR) DoDAF OV-5b Sample Diagram View

Table C.2: SAR Correlations Matrix

Correlations							
			DEQ1	**DEQ3**	**DEQ5**	**LEQ1**	**REQ5**
Spearman's rho	**DEQ1**	**Correlation Coefficient**	1.00	0.06	0.78	0.20	0.22
		Sig. (2-tailed)		0.13	0.00	0.00	0.00
		N	590	590	590	590	590
	DEQ3	**Correlation Coefficient**	0.06	1.00	0.02	0.23	0.12
		Sig. (2-tailed)	0.13		0.64	0.00	0.00
		N	590	590	590	590	590
	DEQ5	**Correlation Coefficient**	0.78	0.02	1.00	0.12	0.16
		Sig. (2-tailed)	0.00	0.64		0.00	0.00
		N	590	590	590	590	590
	LEQ1	**Correlation Coefficient**	0.20	0.23	0.12	1.00	0.70
		Sig. (2-tailed)	0.00	0.00	0.00		0.00
		N	590	590	590	590	590
	REQ5	**Correlation Coefficient**	0.22	0.12	0.16	0.69	1.00
		Sig. (2-tailed)	0.00	0.00	0.00	0.00	
		N	590	590	590	590	590

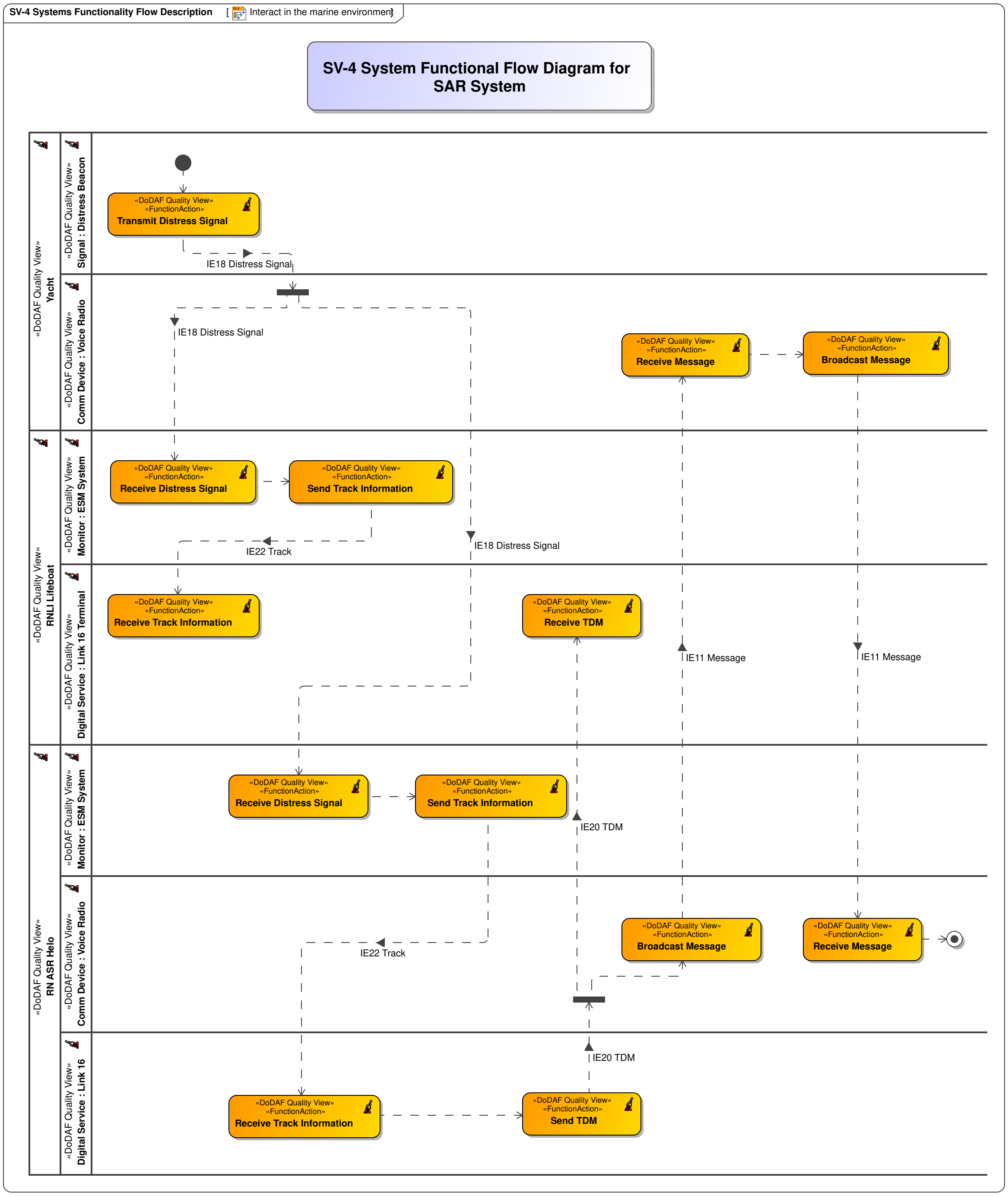

Figure C.2: Search and Rescue (SAR) DoDAF SV-4 Sample Diagram View

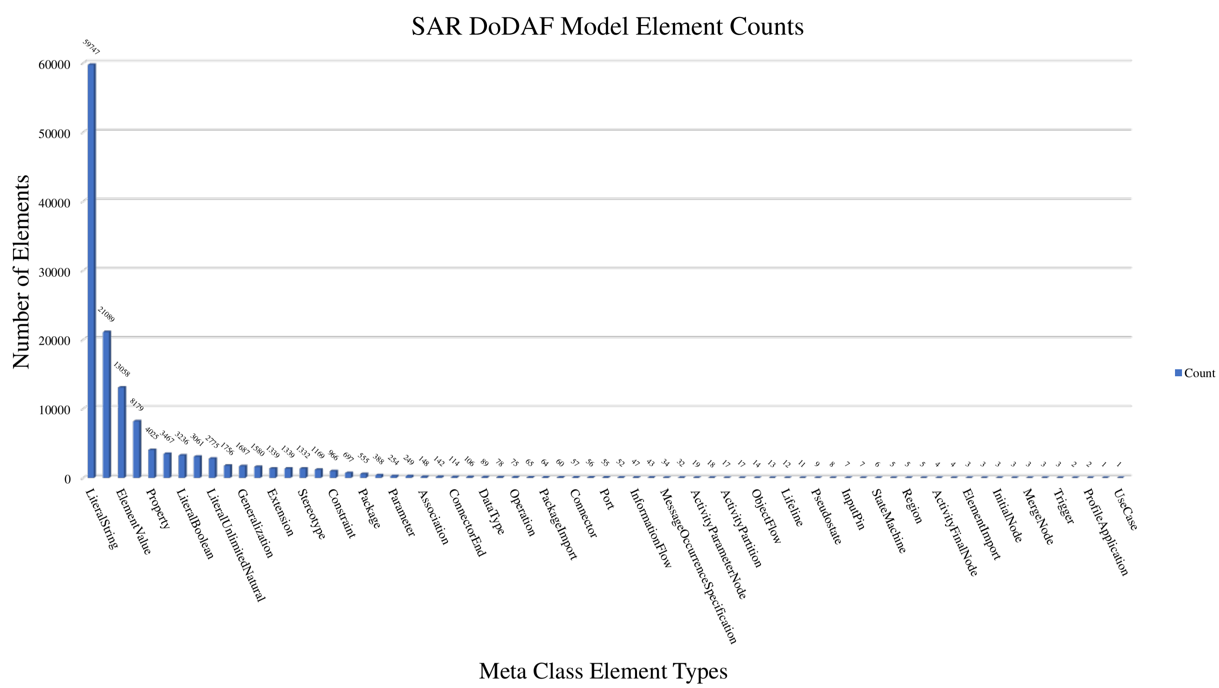

Figure C.3: Search and Rescue (SAR) DoDAF CONOP Element Counts for Command and Control Signal

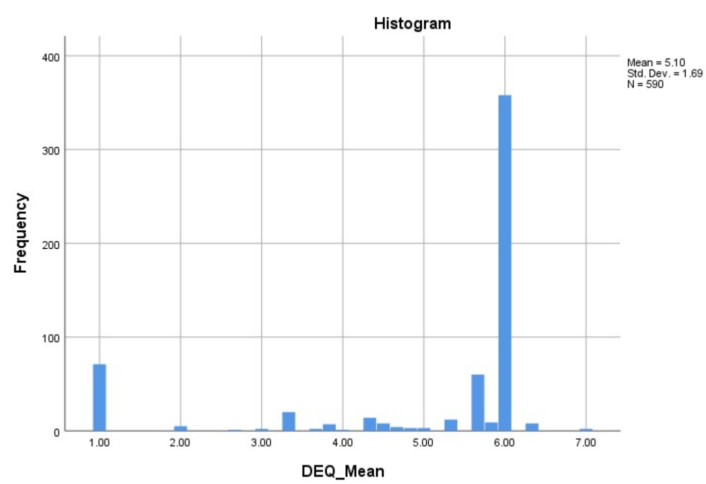

Figure C.4: SAR DEQ Mean Histogram

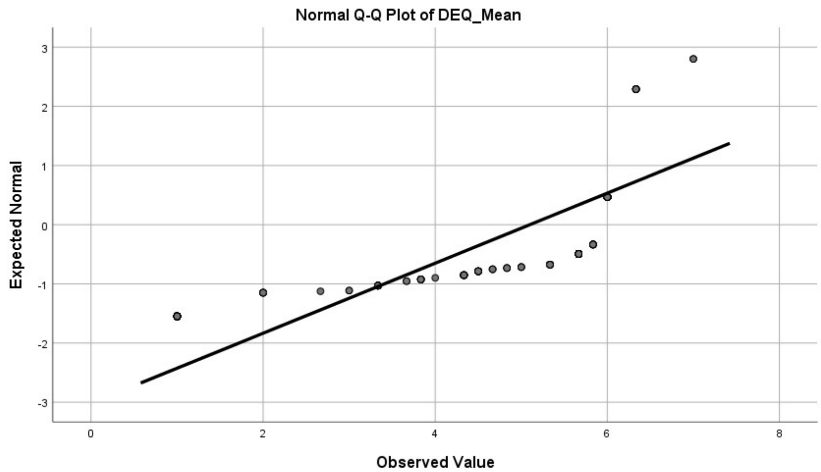

Figure C.5: SAR Normal Q-Q Plot DEQ Mean

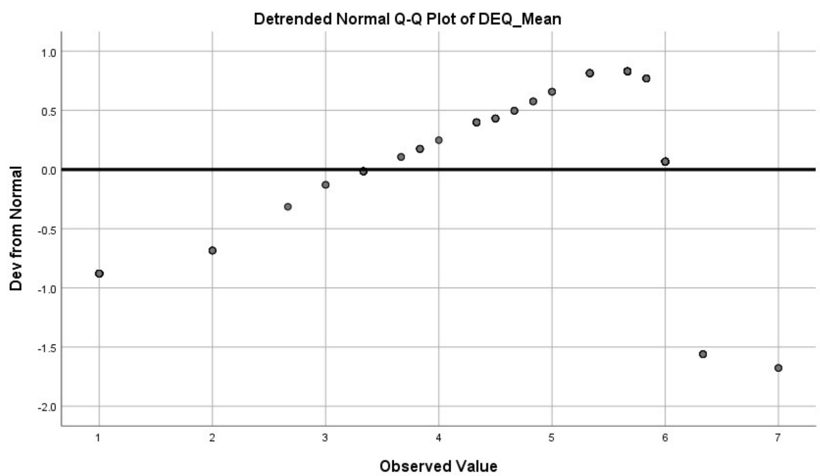

Figure C.6: SAR Detrended Normal Q-Q Plot DEQ Mean

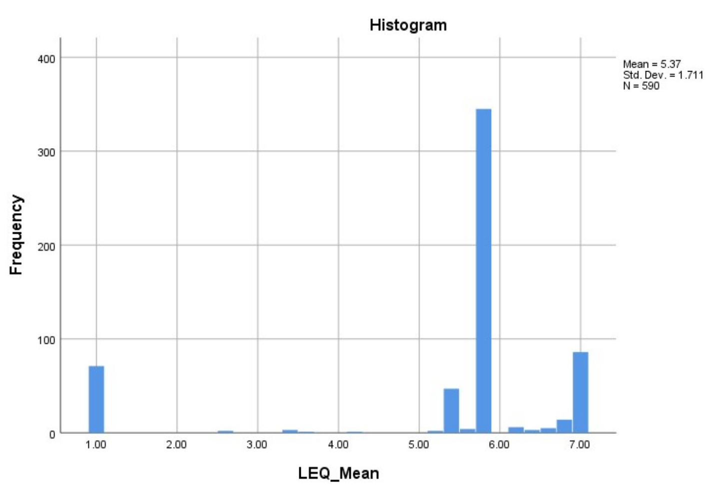

Figure C.7: SAR LEQ Mean Histogram

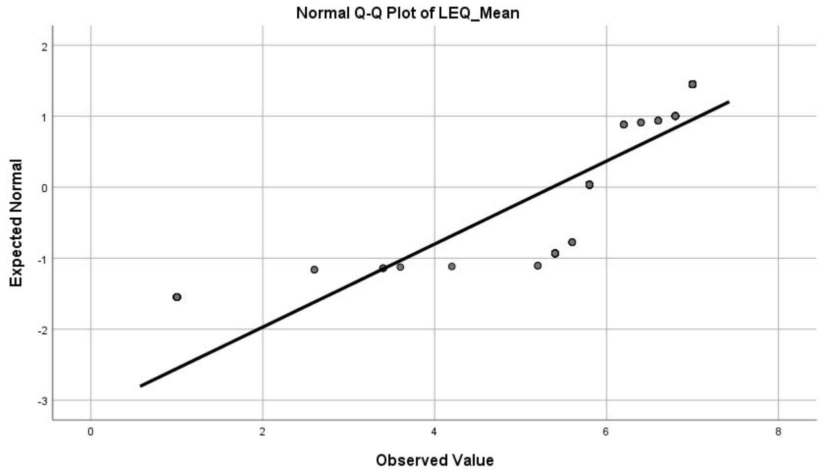

Figure C.8: SAR Normal Q-Q Plot LEQ Mean

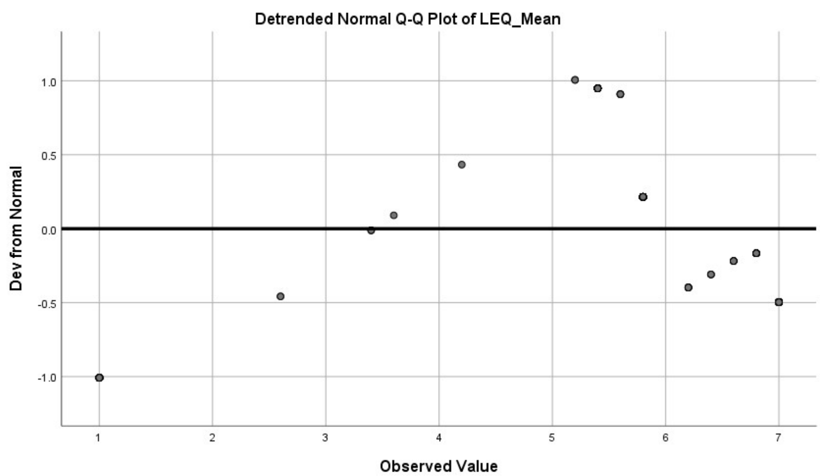

Figure C.9: SAR Detrended Normal Q-Q Plot LEQ Mean

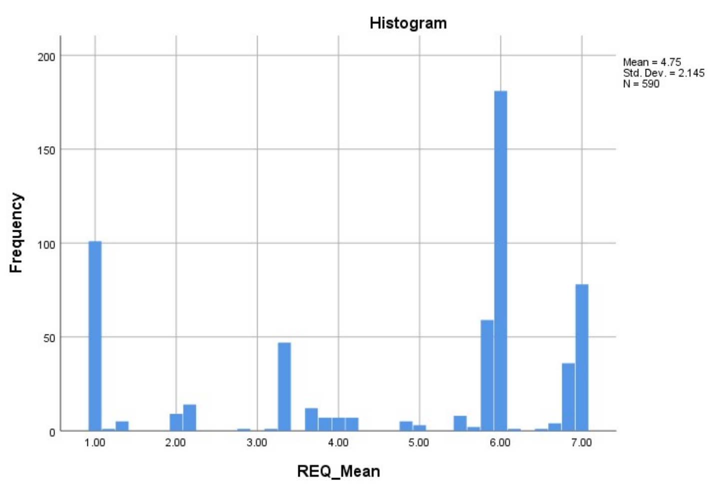

Figure C.10: SAR REQ Mean Histogram

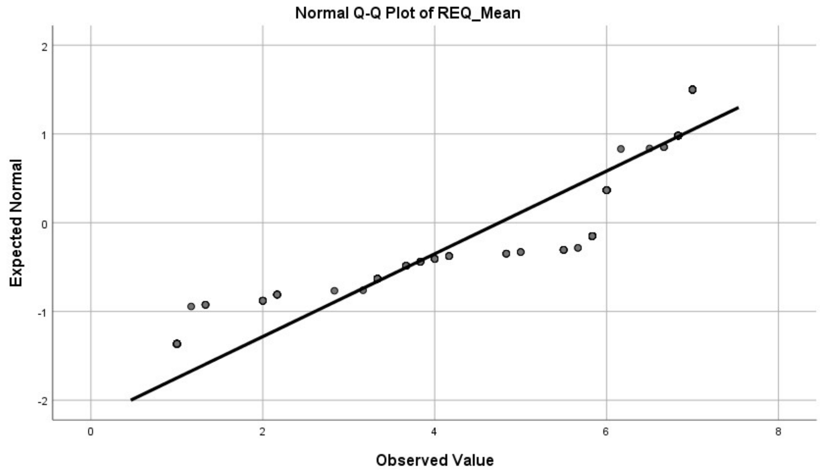

Figure C.11: SAR Normal Q-Q Plot REQ Mean

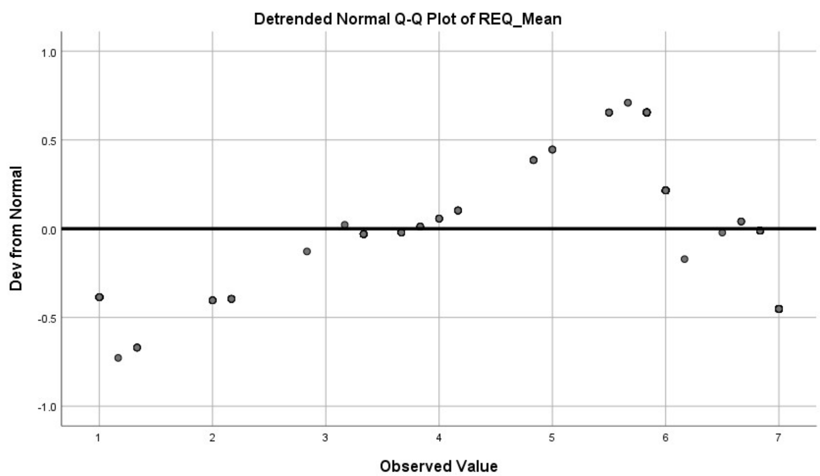

Figure C.12: SAR Detrended Normal Q-Q Plot REQ Mean

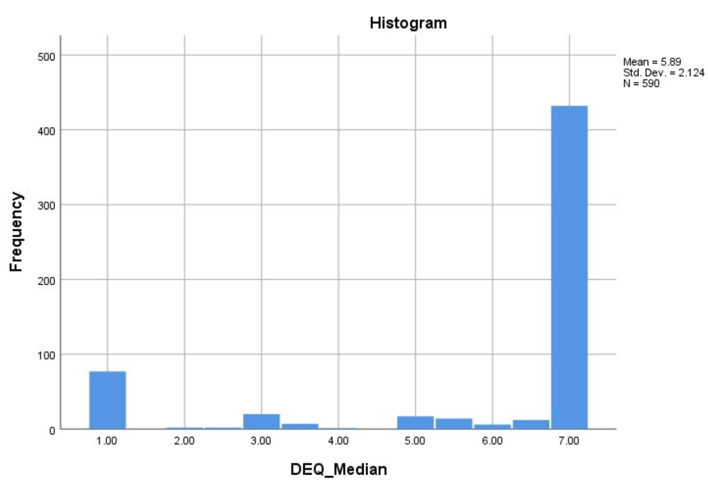

Figure C.13: SAR DEQ Median Histogram

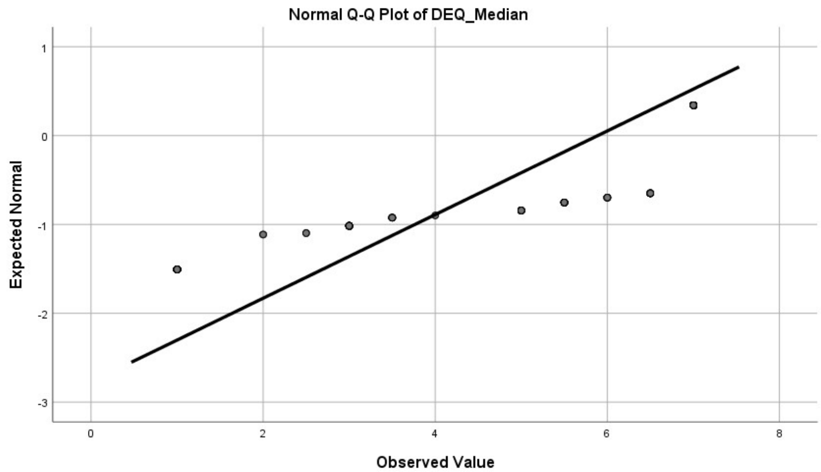

Figure C.14: SAR Normal Q-Q Plot DEQ Median

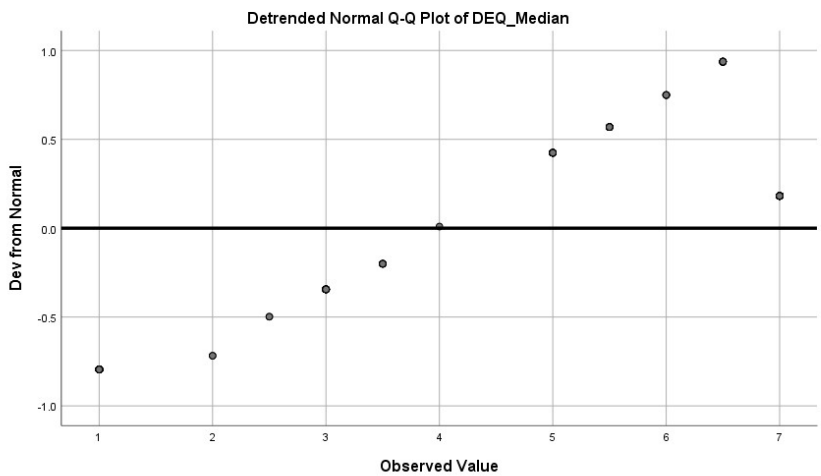

Figure C.15: SAR Detrended Normal Q-Q Plot DEQ Median

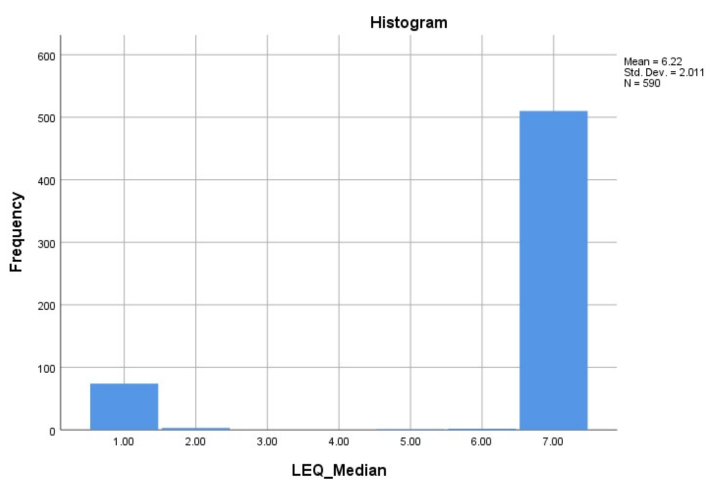

Figure C.16: SAR LEQ Median Histogram

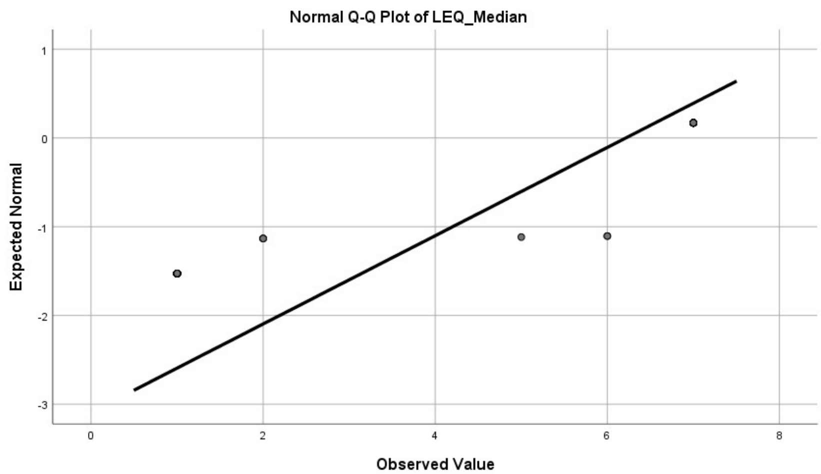

Figure C.17: SAR Normal Q-Q Plot LEQ Median

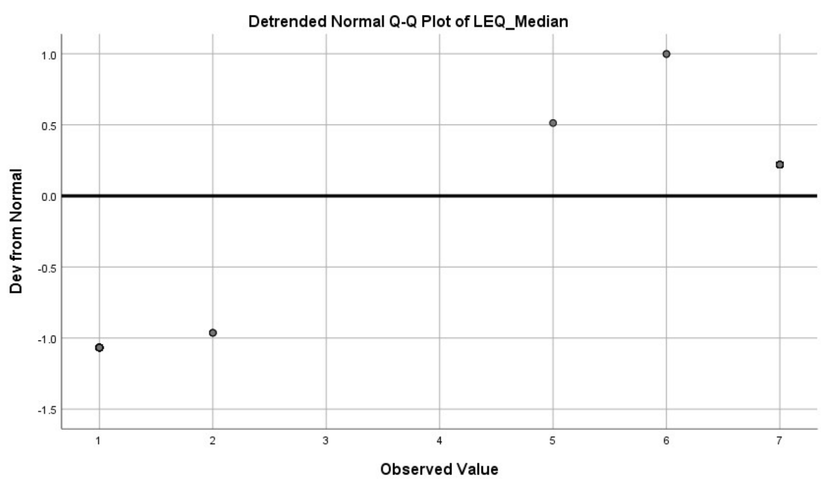

Figure C.18: SAR Detrended Normal Q-Q Plot LEQ Median

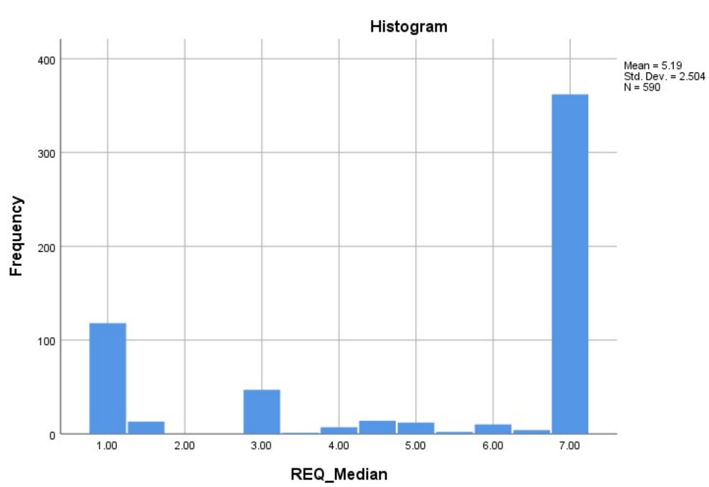

Figure C.19: SAR REQ Median Histogram

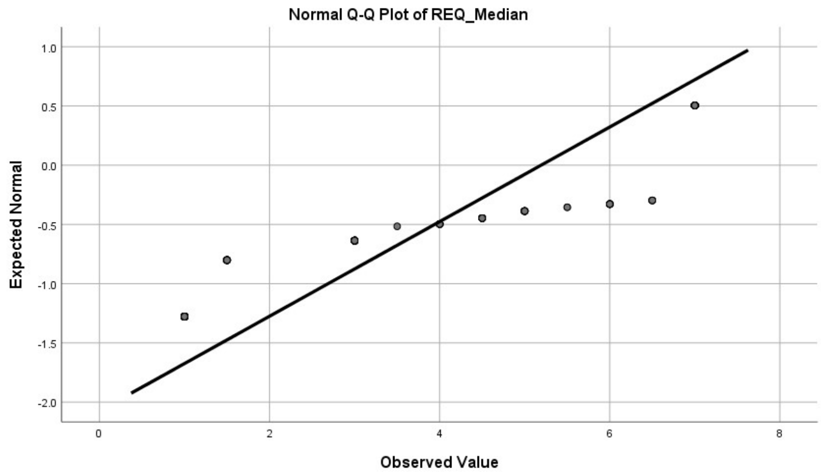

Figure C.20: SAR Normal Q-Q Plot REQ Median

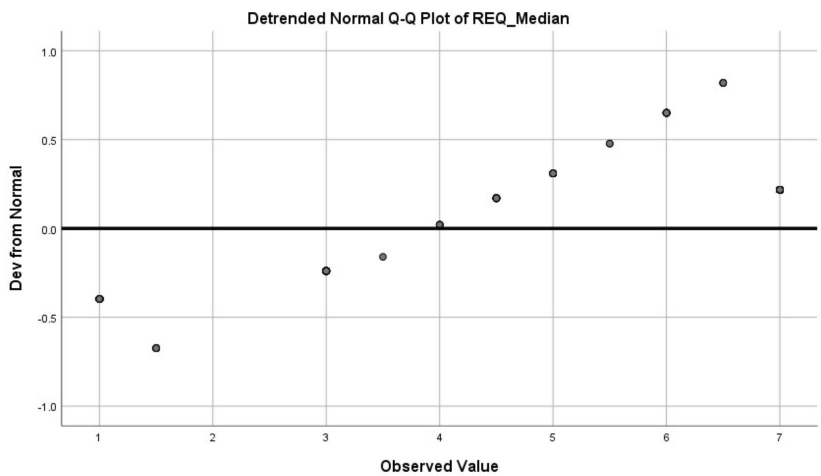

Figure C.21: SAR Detrended Normal Q-Q Plot REQ Median

Table C.3: SAR Parameter Estimates

Parameter Estimates								
		Estimate	**Std. Error**	**Wald**	**df**	**Sig.**	**95% Confidence Interval**	
							Lower Bound	**Upper Bound**
Threshold	**[DEQ_Mean = 1.00]**	9.11	0.78	136.60	1	0.00	7.58	10.63
	[DEQ_Mean = 2.00]	10.17	0.82	154.92	1	0.00	8.57	11.77
	[DEQ_Mean = 2.67]	10.31	0.82	157.88	1	0.00	8.70	11.91
	[DEQ_Mean = 3.00]	10.54	0.83	162.97	1	0.00	8.92	12.15
	[DEQ_Mean = 3.33]	12.60	0.91	191.67	1	0.00	10.82	14.39
	[DEQ_Mean = 3.67]	12.86	0.93	191.67	1	0.00	11.04	14.68
	[DEQ_Mean = 3.83]	13.44	0.98	187.59	1	0.00	11.52	15.37
	[DEQ_Mean = 4.00]	13.51	0.99	186.93	1	0.00	11.57	15.44
	[DEQ_Mean = 4.33]	14.45	1.09	174.41	1	0.00	12.30	16.59
	[DEQ_Mean = 4.50]	15.16	1.16	171.10	1	0.00	12.89	17.44
	[DEQ_Mean = 4.67]	15.57	1.19	172.44	1	0.00	13.25	17.90
	[DEQ_Mean = 4.83]	15.80	1.20	173.99	1	0.00	13.45	18.15
	[DEQ_Mean = 5.00]	16.00	1.21	175.71	1	0.00	13.63	18.36
	[DEQ_Mean = 5.33]	16.61	1.23	182.75	1	0.00	14.20	19.01
	[DEQ_Mean = 5.67]	18.20	1.26	207.02	1	0.00	15.65	20.59
	[DEQ_Mean = 5.83]	18.27	1.26	209.91	1	0.00	15.80	20.74
	[DEQ_Mean = 6.00]	25.28	1.60	248.88	1	0.00	22.14	28.42
	[DEQ_Mean = 6.33]	35.25	15.95	4.89	1	0.03	4.00	66.52
Location	**DEQ1**	1.01	0.09	118.12	1	0.00	0.83	1.20
	DEQ3	3.66	0.50	53.87	1	0.00	2.68	4.64
	DEQ5	1.32	0.10	175.68	1	0.00	1.12	1.51
	LEQ1	0.24	0.06	14.32	1	0.00	0.11	0.36
	REQ5	-0.29	0.05	28.03	1	0.00	-0.40	-0.18
Link function: Logit.								

Table C.4: Probability for SAR Response

		Mean Represented Value Point																		
		1	**2**	**2.67**	**3**	**3.33**	**3.67**	**3.83**	**4**	**4.33**	**4.5**	**4.67**	**4.83**	**5**	**5.33**	**5.67**	**5.83**	**6**	**6.33**	**7**
DEQ1																				
S. Disagree	Mean	0.76	0.05	0.01	0.01	0.11	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	N	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
	S.D.	0.36	0.05	0.01	0.02	0.19	0.02	0.03	0.01	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S. Agree	Mean	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.13	0.02	0.73	0.02	0.00
	N	498	498	498	498	498	498	498	498	498	498	498	498	498	498	498	498	498	498	498
	S.D.	0.01	0.02	0.01	0.01	0.09	0.01	0.02	0.00	0.03	0.02	0.01	0.01	0.01	0.02	0.07	0.01	0.23	0.10	0.06
Total	Mean	0.12	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.11	0.02	0.62	0.01	0.00
	N	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590
	S.D.	0.31	0.03	0.01	0.01	0.12	0.01	0.02	0.00	0.03	0.02	0.01	0.01	0.01	0.02	0.08	0.01	0.34	0.09	0.06
DEQ3																				
S. Disagree	Mean	0.13	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.11	0.02	0.62	0.00	0.00
	N	578	578	578	578	578	578	578	578	578	578	578	578	578	578	578	578	578	578	578
	S.D.	0.31	0.03	0.01	0.01	0.12	0.01	0.02	0.00	0.03	0.02	0.01	0.01	0.01	0.02	0.08	0.01	0.34	0.00	0.00
SW. Disagree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.37	0.60	0.00
	N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	S.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.01	0.29	0.34	0.00
S. Agree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
	N	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	S.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	Mean	0.12	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.02	0.11	0.02	0.62	0.01	0.00
	N	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590
	S.D.	0.31	0.03	0.01	0.01	0.11	0.01	0.02	0.00	0.03	0.02	0.01	0.01	0.01	0.02	0.08	0.01	0.34	0.09	0.06
DEQ5																				
S. Disagree	Mean	0.73	0.04	0.01	0.01	0.11	0.01	0.03	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00
	N	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95
	S.D.	0.40	0.03	0.01	0.01	0.19	0.02	0.05	0.01	0.05	0.02	0.01	0.00	0.00	0.00	0.01	0.00	0.13	0.00	0.00
SW. Disagree	Mean	0.01	0.01	0.00	0.00	0.09	0.03	0.09	0.01	0.21	0.18	0.09	0.04	0.03	0.08	0.09	0.00	0.03	0.00	0.00
	N	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	S.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SW. Agree	Mean	0.06	0.09	0.02	0.03	0.28	0.02	0.04	0.00	0.05	0.04	0.03	0.02	0.02	0.06	0.14	0.01	0.09	0.00	0.00
	N	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
	S.D.	0.05	0.08	0.01	0.02	0.22	0.02	0.03	0.00	0.02	0.03	0.03	0.02	0.02	0.07	0.17	0.01	0.11	0.00	0.00
Agree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.03	0.03	0.02	0.02	0.08	0.31	0.04	0.45	0.00	0.00
	N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	S.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.03	0.01	0.01	0.11	0.00	0.00
S. Agree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.12	0.02	0.79	0.02	0.00
	N	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451
	S.D.	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.14	0.10	0.07
Total	Mean	0.12	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.11	0.011	0.62	0.01	0.00
	N	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590
	S.D.	0.31	0.03	0.01	0.01	0.12	0.01	0.02	0.00	0.03	0.02	0.01	0.01	0.01	0.02	0.08	0.01	0.34	0.09	0.06
LEQ1																				
S. Disagree	Mean	0.15	0.01	0.00	0.00	0.04	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.02	0.10	0.02	0.60	0.00	0.00
	N	475	475	475	475	475	475	475	475	475	475	475	475	475	475	475	475	475	475	475
	S.D.	0.34	0.04	0.01	0.01	0.13	0.01	0.03	0.00	0.03	0.02	0.01	0.00	0.01	0.02	0.08	0.01	0.35	0.03	0.00
SW. Disagree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.33	0.64	0.00
	N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	S.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.01	0.27	0.33	0.00
Agree	Mean	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.00	0.04	0.04	0.03	0.02	0.02	0.06	0.19	0.02	0.47	0.06	0.00
	N	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	S.D.	0.00	0.00	0.00	0.00	0.08	0.02	0.04	0.00	0.06	0.04	0.03	0.02	0.02	0.06	0.13	0.01	0.35	0.22	0.00
S. Agree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.14	0.02	0.73	0.01	0.02
	N	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
	S.D.	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.02	0.02	0.01	0.01	0.01	0.03	0.08	0.01	0.21	0.08	0.14
Total	Mean	0.12	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.11	0.02	0.62	0.01	0.00
	N	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590
	S.D.	0.31	0.03	0.01	0.01	0.12	0.01	0.02	0.00	0.03	0.02	0.01	0.01	0.01	0.02	0.08	0.01	0.34	0.09	0.06
REQ5																				
S. Disagree	Mean	0.16	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.08	0.01	0.62	0.01	0.00
	N	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453
	S.D.	0.35	0.035	0.01	0.01	0.13	0.01	0.02	0.00	0.03	0.02	0.01	0.00	0.00	0.01	0.05	0.01	0.37	0.06	0.05
SW. Disagree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.17	0.03	0.74	0.00	0.00
	N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	S.D.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SW. Agree	Mean	0.14	0.18	0.03	0.05	0.43	0.03	0.05	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	N	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	S.D.																			
Agree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.01	0.06	0.28	0.04	0.54	0.00	0.00
	N	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	S.D.																			
S. Agree	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.01	0.04	0.19	0.03	0.61	0.04	0.01
	N	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
	S.D.	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.03	0.02	0.02	0.01	0.01	0.04	0.10	0.01	0.22	0.15	0.09
Total	Mean	0.12	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.11	0.02	0.62	0.01	0.00
	N	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590	590
	S.D.	0.31	0.03	0.01	0.01	0.12	0.01	0.02	0.00	0.03	0.02	0.01	0.01	0.01	0.02	0.08	0.01	0.34	0.09	0.06

Glossary

Acquiescence Bias a tendency to agree rather than disagree, in human factor decision making [242] *on page(s):* 47

Architecture Framework defines the structure and minimal required content of architecture descriptions as well as the range of activities that go into creating and using an architecture description. Architectural frameworks incorporate a broad consensus on best practices for system modeling [243] *on page(s):* 20

Bus architecture is one where the modules are not connected to one another, but rather all independently to a single module [171] *on page(s):* 137, 181

Data-Centric refers to an architecture where data is the primary and permanent asset, and applications come and go [244] [72] *on page(s):* 36

diagrammatics A plan, sketch, drawing, or outline designed to demonstrate or explain how something works or to clarify the relationship between the parts of a whole [245] *on page(s):* 161, 201

MBE is a software and systems development paradigm that emphasizes the application of visual modeling principles and best practices throughout the System Development Life Cycle [246] *on page(s):* ii

MBSE is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases [246] *on page(s):* ii

mission thread A sequence of end-to-end actions and events that are presented as a series of stages and that are used to execute one or more capabilities that are supported by the architectural design [158] *on page(s):* 71

Model Model is a approximation representation, or idealization of selected aspects of the structure, behavior, operation or other characteristics of a real-world process, concept, or system [247] *on page(s):* 8

Multicollinerarity The term occurs when high intercorrelations among two or more independent variables in a regression model [128] *on page(s):* 61

Multiple-Domain Matrix A multiple-domain matrix allows whole systems consisting of multiple domains, each having multiple elements, connected by various relationship types [228] *on page(s):* 136, 180

Psychometric refers to the study of physiological analysis associated with human factor decision trait and understanding mental measurements [248] [249] *on page(s):* 47

Quality Management The term quality management is conceptually established as practices, principles and techniques facilitating customer focus, continuous improvement and teamwork and product quality [250] [251] *on page(s):* 48

Realized The term means to become fully aware of or understand clearly what the system is to perform in the model [73] *on page(s):* 112, 155

SysML is a general-purpose architecture modeling language for Systems Engineering applications [73] *on page(s):* 1

System A system can for example include hardware, software, personnel and activities [252] *on page(s):* ii

System Architecture or System Model A system architecture is the composite of the design architectures for products and their lifecycle processes. A design system Model is defined as an arrangement of design elements that provides the design solution for a product or a life cycle process [253] *on page(s):* 13

System of Systems is viewed as a complex large-scale system which entails interdisciplinary problems [254] *on page(s):* 19

Systems Engineering Systems engineering is defined by the International Council on Systems Engineering (INCOSE) as an interdisciplinary approach and means to enable the realization of successful systems. Systems engineering is both a technical and a management process. [255] *on page(s):* 11

View A view is a representation of a whole system from the perspective of related concerns [243] *on page(s):* 13

Viewpoint template, pattern or specification for constructing a view [243] *on page(s):* 33

Acronyms

AIAA American Institute of Aeronautics and Astronautics *on page(s):* 4

API Application Programming Interface *on page(s):* 50, 51, 84, 86

BDD Block Definition Diagram *on page(s):* 16, 103, 146

BPMN Business Process Modeling Notation *on page(s):* 81

C4ISR Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance *on page(s):* 34

CDR Critical Design Review *on page(s):* 80

CONOP Concept of Operations *on page(s):* iii, x, xi, 6, 24, 26, 27, 33, 36, 38, 39, 43–47, 49–51, 57, 69–73, 75, 77, 78, 80, 81, 84, 86, 94, 95, 97, 98, 103–106, 108–113, 117, 121, 122, 124–127, 129, 130, 133–141, 145, 149–156, 160, 161, 164, 166, 168–171, 173–194, 196, 211, 239

DAS Defense Acquisition System *on page(s):* 35

DoD Department of Defense *on page(s):* 5, 6, 21, 28, 34–36, 195, 197

DoDAF Department of Defense Architecture Framework *on page(s):* ii, iii, x, xi, 1–8, 12–15, 17–21, 24–27, 33–36, 38, 39, 42–51, 53, 55–57, 66, 69–73, 75–79, 81–84, 86, 94, 95, 97–106, 108–113, 117, 118, 121, 122, 124–127, 129–156, 160, 161, 163–166, 168–171, 173–194, 196, 197, 199, 200, 202, 203, 209–211, 219, 237–239

DQAP DoDAF Quality Analysis Profile *on page(s):* 44, 45, 53, 55, 70, 81, 82, 92

DQCF DoDAF Quality Conceptual Framework *on page(s):* iii, x, 25, 28, 32, 39–43, 49–53, 70, 76, 81, 82, 86, 87, 93–95, 97, 98, 108, 109, 115, 117, 121, 133, 134, 136, 140, 141, 151, 154, 157, 160, 165, 178, 180, 184–187, 189, 191, 195–198

DQV DoDAF Quality View *on page(s):* 52

DSL Domain Specific Language *on page(s):* 71, 82

DSM Design Structure Matrix *on page(s):* 75–77, 198

EPL Extensible Programming Languages *on page(s):* 84

GAO Government Accountability Office *on page(s):* 5, 9, 133, 189

GBSD Ground Based Strategic Deterrent *on page(s):* 195

GPS Global Positioning System *on page(s):* 108

GUID Globally Unique Identifier *on page(s):* 93, 111, 154

HCR High-Performance Computing Resources *on page(s):* 198

IBD Internal Block Diagram *on page(s):* 16, 103, 146

IDE Integrated Development Environment *on page(s):* 34, 51

IEEE Institute of Electrical and Electronics Engineers *on page(s):* 4

INCOSE International Council on Systems Engineering *on page(s):* 4, 48, 72, 80, 250

JCIDS Joint Capabilities Integration and Development System *on page(s):* 35, 49

JPSS Joint Polar Satellite System *on page(s):* iii, x, xi, 50, 98–118, 120–129, 131–140, 177, 186–190, 194, 196, 209–217, 219

KMO Kaizer-Meyer-Olkin *on page(s):* 54, 58, 63, 64, 113, 121, 156, 166, 187, 192

KPP Key Performance Parameters *on page(s):* 106, 107

MB Model-Based *on page(s):* 5

MBSE Model-Based Systems Engineering *on page(s):* ii, iii, 1–5, 7–12, 14–17, 19–22, 24–27, 29, 30, 32, 33, 35, 42, 44, 45, 48, 50, 51, 70, 82, 84–86, 104, 106, 186, 195, 197, 198

MDL Minimum Description Length *on page(s):* 75–77, 139, 183, 186, 190, 194

MDS Modularity Design Structure *on page(s):* 77, 78, 134, 136–139, 178, 180–183, 190, 194

MLR Multinomial Logistic Regression *on page(s):* 66, 127, 170

NASA National Aeronautics and Space Administration *on page(s):* iii, 15, 19, 24, 29, 48, 98, 186, 198

NDIA National Defense Industrial Association *on page(s):* 79, 80, 197

NOAA National Oceanic and Atmospheric Administration *on page(s):* iii, 98, 107, 186

NPOESS National Polar-orbiting Operational Environmental Satellite System *on page(s):* 98

OLR Ordinal Logistic Regression *on page(s):* 57, 62, 64, 66–68, 127–130, 133, 135, 170, 172–175, 177, 179, 188, 189, 193, 196

OMG Object Management Group *on page(s):* 35, 71, 82, 84

PCA Principal Components Analysis *on page(s):* 57, 63, 64, 66, 114, 116–119, 121, 135, 159–161, 165, 166, 179, 188, 192

PDR Preliminary Design Review *on page(s):* 80

PPBE Planning, Programming, Budgeting, and Execution *on page(s):* 35

QbD Quality By Design *on page(s):* ii, iii, x, xi, 2, 24, 27, 39, 43, 44, 51, 56, 70, 73, 95, 97, 108, 109, 140, 151, 152, 184–186, 219

QCA Quality Control Attribute *on page(s):* 44, 45, 51, 53, 73

QCC Quality Characteristic Categories *on page(s):* 46, 47, 52, 53, 57, 71, 73, 75, 81, 83, 94, 108, 109, 112, 114, 117, 119, 120, 124, 130–136, 151, 156, 157, 160, 168, 175, 178–180, 185–189, 191, 197, 199

QTPP Quality Target Product Profile *on page(s):* 44

RKV Redesigned Kill Vehicle *on page(s):* 33

S-NPP Suomi National Polar-orbiting Partnership *on page(s):* 98

SAR Search and Rescue *on page(s):* iii, x–xii, 50, 130, 141–164, 166–184, 191–194, 196, 237–245

SFR System Functional Review *on page(s):* 80

SMD Stored Mission Data *on page(s):* iii, xi, 50, 98, 101, 103–105, 108, 110, 112, 113, 118, 125, 133, 135, 137, 140, 181, 186, 187, 189–191, 211

SME Subject Matter Expert *on page(s):* 15, 18, 47, 49, 53, 72, 83, 84

SoS System of Systems *on page(s):* iii, 12, 19, 20

SPSS Statistical Package for the Social Sciences *on page(s):* 94, 127, 170

SRR System Requirements Review *on page(s):* 80

SysML Systems Modeling Language *on page(s):* iii, x, 13, 16, 19, 30, 32–34, 36, 44–46, 49, 51, 56, 57, 70, 71, 81, 82, 98, 106, 117, 119, 124, 131, 133, 134, 141, 161–163, 168, 169, 175–177, 185, 189, 193, 196, 200–202

TOGAF The Open Group Architecture Framework *on page(s):* 81

TPM Technical Performance Measurements *on page(s):* 106

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