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

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03/24/2022

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Introduction

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• Model Based System Engineering (MBSE) and Digital Engineering (DE) has become the standard tool for system engineering – MBSE and DE are considered by industry leader to be the 4th Industrial Revolution – MBSE and DE have become a primary focus of the Defense Department for the foreseeable future
• For the purpose of this study, the focus was placed on Department of Defense Architecture Framework (DoDAF) specifically to address quality of models – Standards like DoDAF, typically do not directly address quality – Quality is implied by simply stating “if we follow the standard, quality will be the inherited trait” – DoDAF is still in use today, and its system description methodologies continue to impact subsequent system description approaches [72] – DoDAF still leads both government and industry practice as the most widely mandated defense standard for U.S. government acquisition [77]
Problem Being Addressed

• The following are taken from the Hawaii International Conference on System Sciences conducted an analysis of papers **over a 15 year period**:
  
  – Key sub-problems are: Business View Presence and Alignment, Modeling Tool Availability, and **Quality**, Stakeholders Perspectives, Handling Dynamics [1].
  
  – Use of **practices and procedures – formal or otherwise** – to develop the Architecture. A 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, **Metrics**, Best Practices [1]
  
  – **Modeling Quality Attributes**: Modeling systems, including languages, are required to facilitate assessment of architecture according to **quality attributes**, [1]

• **Evaluation and measurement of methodological practice**[1]

• **Modeling assessment encompasses two key areas: quality attributes and metrics** [1]

What are good methods or practices to extract meaningful Quality Metrics to understand quality of the architectures?
Research
Research Objectives Literary Review

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 system engineering within the context of quality.

The Literary Review attempted 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 could be integrated into the dissertation.

- **Research Question 1:** How does DoDAF **relate to system engineering methods** of analysis for a quality-based design for a weapon system?
- **Research Question 2:** What are the **main factors in developing an MBSE conceptual framework that provides good system engineering** analysis?
- **Research Question 3:** What are the **metrics that are significant in assessing an approach that correlates quality** of design with an MBSE?
Literary Review High Points and Synopsis

- **Quality of Models**
  - MBSE methodologies being able to connect disparate data in a digital engineering environment has improved but, **quality understanding still needs to be addressed within academia and industry** [2]

- **MBSE Benefits That Drive Quality**
  - MBSE provides **struggles with quality within modeling paradigms** that needs to be addressed to meet the need of all stakeholders [3]

- **MBSE Quality in Defense**
  - The translation of architectural standards and **traditional system engineering documentation into the digital engineering model elements introduces ambiguity and programmatic risk to quality of the model** is not emphasized [4]

- **MBSE Architecture Frameworks and Quality**
  - **Quality is simply a byproduct and relies heavily on subjectivity, influence decisions in the application, or the expertise** of the team applying the standard [5] [7]

- **MBSE Quality Role In DoDAF Application**
  - Understanding the **quality competencies are required of system engineers and the MBSE implementation approach, without a quality design framework application of DoDAF architecture may lead to ambiguous data or lost context** [6]

- **MBSE Metrics and Quality**
  - Concepts of verification and validation approaches are not possible of MBSE descriptive models as **there is no output data to compare with actual data** [8]

- **MBSE Modularity Addressing Quality**
  - 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** [9]

- **MBSE Quality Architecture**
  - From functional to non-functional requirements, the MBSE approaches to **quality deal with the overall System of Systems approach to quality of MBSE models focusing on the SysML and less on parts of defense aspects** of the model quality [10]
  - While the **Quality Attribute Balancing (QAb) method addresses the quality of the SoS architecture, it fails to address the DoDAF specific framework and instead focuses on the SysML stereotypes** [11]

The Literary Review has shown that quality is difficult to address and is a ever growing problem within the DoDAF architecture
Why DoDAF Quality Conceptual Framework (DQCF)?

• Based on research and experience, the following observations have been noted through many different Societies:
  – 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. [2]
  – Further investigation or **research is needed to fully understand the implications of quality in the system engineering of model based approaches**. [3]
  – Even with standardization and simplification for model architecture development, the **translation from textual context of document in system engineering into digital engineering often introduces ambiguity and programmatic risk effecting quality of models developed**. [4]
  – Some methods exist that **address the quality of the SoS architecture, but fail to address the DoDAF specific framework** and instead focus on the SysML stereotypes

• The average cost of rework for increase of a project quality is around **2-20%** of the **total contract amount** [12]

• The Government Accountability Office (GAO) found that United States Defense Acquisition Programs are either **over budget or have schedule delays** [13]
  – 61 of 86 programs evaluated showed cost growth of **62.4% or $542.1 Billion and schedule overruns of 35 months** on an average [13]

“**DoD will implement rigorous processes to support cost-effective technology development and selection decisions**” - DoD Digital Engineering Strategy 2018

**Cost of Quality (CoQ) is usually around 15 - 20% of product development** [69]
Proposed Solution
By understanding the methodological gap and research questions, the author introduces the theory of "Quality by Design" in a re-contextualization mapping of terminology of quality of CONOPs in an MBSE DoDAF architecture. 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 [14].

Particular focus is given to the DoDAF architecture framework surrounding the CONOPs because of the mandated use across the defense industry in both private and public sectors [77]. A concept map of QbD theory allowed the author not only to generate spontaneous associative elements but also to outline key relationships between intentional terms from each area effectively completing the mapping re-contextualization of Juran's method [15].

Research into Approach Solution
Critical Theory Understanding

- System Engineering (SE)
  - Due to the **importance of the Concept Development Stage** in multiple System Engineering lifecycle models, focus was put on this stage and its quality
  - In the Concept Development stage, the **functional performance or operational requirements** analysis can be instantiated in an architecture
- Model Based System Engineering (MBSE)
  - The **extensible customization capability that MBSE brings** was used to develop a profile to capture criterion related to quality
- Department of Defense Architecture Framework (DoDAF)
  - Viewpoints and View
    - 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
  - CONOP Design Process
    - CONOP architecture development in conjunction with **operational performance requirements** 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 [16][17]
Quality Characteristic Categories (QCC)

- **DoDAF Element Quality (DEQ) – 6 Factors**
  - Deals with the aspect of the DoDAF element that meet standard and establishes elements in the architecture.

- **Language Element Quality (LEQ) – 5 Factors**
  - Deals with the aspect of the UML/SysML element that meet standards and establishes elements in the architecture.

- **Requirement Element Quality (REQ) – 6 Factors**
  - 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 attempts to provide an understanding of the functional coherent design for the system.

- DEQ, LEQ, and REQ constitute 17 category parameters to assess each element during the evaluation process.
- DEQ 2, 6 and REQ 1-6 deal with consistency and continuity for element data which are important considerations when addressing modularity within an architecture, and this part of assessment addresses these considerations.
- A neutral value is acceptable because some elements might not require a rating under specific category given contextual meaning of the element.
Addressing Subjectivity and Quality SME Engineer

- **Subjectivity**
  - When introducing a human making a multi-attributed choice, such as for the Likert scale evaluation of the QCC variables, introducing bias into the analysis is almost a certainty [23][24]
  - 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 [25] [26] [27]
  - Additionally, a Likert scale format may effectively reduce Acquiescence Bias meaning the agreement with research statements, without lowering quality of the data produced from the evaluation to determine the quality [28] [29] [30]
  - The reliability of the seven point Likert scale has been shown empirically to be approximately $\sim 90\%$ reliable and approximately $\sim 89\%$ valid [71]

- **Quality SME Engineer**
  - Role of **SME quality engineer is key** to effectively assessing the quality of model [70]
  - **INCOSE, NSAS, and MITRE Competencies evaluated** and arrived at these for Quality
  - **Skills and experience** are still essential [70]
Degree of Modularity

For purpose of modularity evaluation the DoDAF CONOP architecture specified mission threads in each of the case studies and was considered the end product [34][35][36].

The degree of modularity assessment is used in order to grasp functional reusability understanding of architecture aspects to support future development of system design.

The more modular a designed system is, the easier it is to upgrade, replace, or reuse design aspects [35][38].

A modified version of YuTian’s equation for Minimum Description Length (MDL) was used for describing the Degree of Modularity using human clustering [38][39].
Presentation Simple Execution Activity

- The Activity shows the **simple execution** of the key steps to application of the framework

- **DoDAF Element Section**
  - **Critical to the tailoring process** is what DoDAF Elements are selected in the Model
  - Helps to manage area of architecture **where quality is key for stakeholders**

- **DoDAF Quality Analysis Profile Applied** to Selected DoDAF Elements
  - The DoDAF architecture element is assessed using the 17 factors to support quality of architecture

- **DoDAF Element Assessment**
  - **Becomes data set** for analysis extracted from the model
  - **Automated** Evaluation From Model vs **Non-Automated** Evaluation

- Analysis of DoDAF Architecture
The Quality Target Product Profile (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).

The process can be tailored to what DoDAF Elements are selected using the QCA identification on the model architecture.

It is critical to identify what aspect of model is in need of evaluation:
- The QCA identification drives the focus area of quality understanding on critical areas of DoDAF architecture model.

The Case Studies focused on DoDAF CONOP Mission Thread to tailor the scope of what element were collected for evaluation.
Profile Application to Element

- The DQCF contains the **DoDAF Quality Analysis Profile (DQAP)** and was built using a built-in profiling capability.

- UML falls **under two approaches to development with profiles** [32].
  - 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 [32] [33].
  - The **second is based on particularization of a UML specializing elements or stereotypes with tag definitions** with respect to the UML base language [32].
Element Assessment Data

- The «DoDAF Quality View» icon appears at 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 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 QCC evaluation of the element.
Automation and Non-Automation Collection

- Both Case study models are contained in Cameo Enterprise Architecture 19.0 Service Pack 3 Model Based System Engineering (MBSE) tool
- The tool for automation is Cameo Enterprise Architecture 19.0 Service Pack 3 with Unified Profile for DoDAF/MODAF (UPDM) DoDAF profile
- The Java based plugin is designed specifically to work with Cameo Enterprise Architecture 19.0 Service Pack 3
- The Java base library for API calls is the jdk1.8.0_231 (64x) version
- Intellij IDEA ideaIC-2021.2.3 is the Java Integrated Development Environment (IDE) for automated data extraction
- Microsoft Office Excel 2013 or later is used for the template of data collection

API Development for this work has led to several Invention Disclosures, Technical Abstracts, Trainings
Analysis of DoDAF Arc

- Likert Scale Data Collection
  - Checks in place for data - Data Integrity
  - Mean Vs Median - Better Data Representation
  - Principal Component Analysis - Factor loading and Total Variance
  - Ordinal Logistic Regression - Factor Analysis

- Statistical Methods
  - To provide meaningful insight into data

The below Activity shows the execution of the key steps to application of the framework. The process can be both automated through the use of Cameo Developed Plugin or Manual through the use of Excel. The R code can be executed on both Cameo plugin Data and Manual created data. Manual process may take longer.

Orange indicates Data Areas of Framework and Applicability to the Flow process.

Data Table Collection
Coded Extraction
Sample Understanding
Statistical Calculations
Statistical Resultant

The SME applies the DoDAF Quality Stereotype to Selected elements. The DoDAF architecture element is quantitatively and qualitatively assessed to support quality of architecture.

During the Assessment the elements are inspected along the criterion provided in the framework. Styles, patterns, and key aspects of the elements relating to the Views for the DoDAF Architecture.

The SME should verify each DoDAF Element is selected in the Model. The SME assesses if each aspect of model is needing evaluation.

Critical To tailor process to what DoDAF Elements are selected in the Model. SME should verify which aspect of model is needing evaluation. Helps to manage area of architecture where quality is key for stakeholders.

Excel DoDAF Quality Assessment Sheet Template.xls
Means to Analysis Data

Process analysis results with R Evaluator for Trend of data.
Final Quality and Degree of Modularity Determination

- The culmination of the analysis was to transform the final mean values for DEQ, LEQ, and REQ into an overall rating for quality of the model.

- The variables providing insight of the coherent design of the system model as well as application of standards.

- The variables rating can provide insight into sensitivities of the system design that could be used to identify risks to the system design.

- The degree of modularity assessment is used in order to grasp functional reusability understanding of architecture aspects to support future development of system design.

Overall Quality and Degree of Modularity

Overall Model Quality

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Degree of Modularity

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DQCF Conceptual Framework Execution

- DoDAF Quality Conceptual Framework (DQCF) to help assess the quality of DoDAF-based architectures
- **17 different quality factors are defined as assessed** using a Likert scale approach
- Variables providing 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 design
- The profile is exportable to XML 1.0 and can be imported to other tools making the profile usable in many other tools
- The degree of modularity assessment is used in order to grasp functional reusability understanding of architecture aspects to support future development of system design

Dissertation Flow Construct to Establish DoDAF Quality Conceptual Framework (DQCF)

- The figure to the right shows the DQCF Framework Development Model
  - The idea was that the Chapter developments drive the content to form the overall framework
- The green area represents the development area of the DQCF framework
  - The development area covers both the theory/approach and critical constraints on the development
- The blue area represents the application phase of the DQCF for generation of results
  - The blue is smaller but drives the activity execution in the case study model to perform analysis and generate results
  - The «activity» execution becomes the «operation» within the «block» Chapters case studies that must be performed
- The orange area is the conclusion analysis where 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»
Case Study Analysis Results
Joint Polar Satellite System (JPSS) Case Study One

- 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

- JPSS is a next generation earth observation program that collects and communicates global environmental data via polar-orbiting satellites [41]

- The primary mission of the JPSS system is to understand/predict changes in weather, climate, oceans, coasts, and space environment [41]

- The OV-1 shows the corresponding missions, activities, organizations, and high-level operations of the JPSS system [42]

- The JPSS CONOP contained all corresponding views for the SMD Mission Thread including the CV-1, CV-2, DIV-1, DIV-2, OV-1, OV-2, OV-5, SV-1, and SV-4
  - The OV-5 includes the OV-5a and OV-5b
  - Major system components and the interconnection among those components
  - Interfaces to external systems or procedures [43]
  - Capabilities, functions, and features of the current system [43]
  - 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 [43]
  - Performance characteristics, such as speed, throughput, volume, frequency
  - Provisions for safety, security, privacy, integrity, and continuity of operations in emergencies [43]
JPSS Element Sampling

- **572 elements of the JPSS model**, which represents the JPSS DoDAF CONOP, are roughly 5.46% of the total JPSS DoDAF CONOP architecture.
- Bulk of the elements are concentrated in the OV-2 ~18%, OV-5 ~12%, and SV-4 ~33% views for the CONOP.
- The DoDAF standard states that the **OV-2 is the backbone to which all other DoDAF elements**.
- **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**.
- 572 elements are evaluated against the **17 Quality Characteristic Categories (QCC)**, a total of **9,742 data points are present for the evaluation process**.
JPSS Statistical Analysis - Descriptives, Skewness, and Kurtosis

- Mean Vs Median
  - 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**
  - Standard errors are small for the mean values, **mean values are more representative of overall population** [45]

- Skewness and Kurtosis
  - Skewness and Kurtosis can provide **some interpretation about the model results** [46] [47]
  - More values are on the **right-handed for DEQ and LEQ on the right-hand side of graph with negative values**
  - For **REQ, this indicates a larger spread between values**, which reflect an **impact on the quality of the JPSS model**

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JPSS Statistical Analysis – Multicollinearity

- Multicollinearity is where two or more variables in the JPSS evaluation data set are highly linearly related.
- Each factor including a correlation coefficient and significance on for each observation was calculated to make a correlation determination [48].
- Multicollinearity needs to be addressed because the standard errors of the coefficients for variables could cause false indicators and become non-significant or significant [49].
- Analysis of the Variance Inflation Factors (VIF) values for each factor was used to determine elimination [49].
- Spearman’s rho can both be positive and negative, with the goal is to have a value between 0.1 and -0.1 [50].
- Statistical significance does not always imply the strength of Spearman’s correlation between variables [51].
- Statistically significant Spearman correlation indicates that there is less than a 5% chance that the strength of the association discovered occurred by coincidence [51].

\[
VIF_i = \frac{1}{1 - R_i^2}
\]

Table: Factors Eliminated due to VIF

<table>
<thead>
<tr>
<th>QCC Factor</th>
<th>VIF Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEQ1</td>
<td>11.684</td>
</tr>
<tr>
<td>DEQ2</td>
<td>21.112</td>
</tr>
<tr>
<td>DEQ5</td>
<td>18.235</td>
</tr>
<tr>
<td>DEQ6</td>
<td>13.521</td>
</tr>
<tr>
<td>LEQ1</td>
<td>11.442</td>
</tr>
<tr>
<td>LEQ5</td>
<td>16.348</td>
</tr>
</tbody>
</table>

Table: Collinearity Statistics Tolerance

<table>
<thead>
<tr>
<th>Collinearity Statistics Tolerance</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEQ3 0.388</td>
<td>2.576</td>
</tr>
<tr>
<td>DEQ4 0.298</td>
<td>3.354</td>
</tr>
<tr>
<td>LEQ1 0.247</td>
<td>4.043</td>
</tr>
<tr>
<td>LEQ3 0.338</td>
<td>2.962</td>
</tr>
<tr>
<td>LEQ4 0.309</td>
<td>3.232</td>
</tr>
<tr>
<td>REQ1 0.581</td>
<td>1.721</td>
</tr>
<tr>
<td>REQ2 0.159</td>
<td>6.303</td>
</tr>
<tr>
<td>REQ3 0.274</td>
<td>3.652</td>
</tr>
<tr>
<td>REQ4 0.339</td>
<td>2.949</td>
</tr>
<tr>
<td>REQ5 0.479</td>
<td>2.088</td>
</tr>
<tr>
<td>REQ6 0.244</td>
<td>4.096</td>
</tr>
</tbody>
</table>

\[
\rho = 1 - \frac{6 \sum d_i^2}{n (n^2 - 1)}
\]
JPSS Statistical Analysis - Principal Component Analysis (PCA)

- Accurately of the evaluation data set represents the purposeful sampling adequacy for the JPSS DoDAF CONOP architecture.

- 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 [53] [54]

- Bartlett’s Test of Sphericity showed that the correlation matrix formed is not an identity matrix.
- Indicates that the total variance is achieved between 72.986% and 82.507% for a total of four to five factors.
- 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 [57]; because of this, the JPSS needed additional factor reduction.
- Adjusting for the 50% to 60% of the variance, the total variation for two to three components between 45.659% to 61.920% for two to three components.
- Oblique rotation or varimax rotation due to the more realistic representation for the data [55] [56].
- Simplicity of analysis only two factors are used for the eigenvalues giving a maximum of 49.077% of the total variance, which is still acceptable for the 50% to 60% of the variance.
- Evaluation of the loadings aid in the identification of each component’s characteristics in terms of the variables [52].
JPSS Statistical Analysis – Ordinal Logistic Regression (OLR)

- **DEQ3**: Missing description to understand what element is representing for the architecture were common place in the JPSS architecture.

- **DEQ4**: Element types were used in the architecture were missing «ActualMeasurementTypes» as well as «ValueProperties» to explain the data selection.

- **LEQ3**: 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".

- **LEQ4**: The JPSS model contained orphaned elements existed that often did not have relationships to parts of the DoDAF architecture.

- **REQ4**: 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.

- **REQ5**: 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.

- **REQ6**: 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.

![Identify the Strength of effects](image)
JPSS Degree of Modularity Determination

- **DEQ2, 6** and **REQ1-6**: All of the elements evaluated had some form of relationship to the JPSS DoDAF architecture being direct or indirect.
  - This means that **some degree of modularity is present**
  - **DEQ6**: VIF calculated showed a value of 13.521
  - **REQ1-6**: PCA and OLR analysis found key significance in the REQ criteria from the QCC for the JPSS architecture

- The **pairwise weighting each item** with the rest of the group and give a preferential level to the item

- If the **model description is simple, the model description is short** [39]
  - Many data mismatches would exist, and the mismatched data description would become longer [39]
  - A **complicated model reduces the description of mismatched data, but the model description would be longer** [39]
JPSS Overall Results

• 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 element 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.
  – Analysis **found key significance in the REQ criteria from the QCC for the JPSS architecture**.

JPSS Rating was “Acceptable” to “Good” with sensitivity to **REQ factors**

• DEQ was yellow to green but 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 JPSS Overall score is a 3.62 or "Acceptable" to "Good" rating

<table>
<thead>
<tr>
<th>Overall Model Quality</th>
<th>Mean Value</th>
<th>Quality Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEQ</td>
<td>5.435</td>
<td>3.96</td>
</tr>
<tr>
<td>LEQ</td>
<td>5.9056</td>
<td>4.27</td>
</tr>
<tr>
<td>REQ</td>
<td>3.437</td>
<td>2.62</td>
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<tr>
<td>Total</td>
<td>3.62</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Degree of Modularity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>Type I</td>
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</tr>
<tr>
<td>Type II</td>
<td>1827.04</td>
</tr>
<tr>
<td>Total MDL</td>
<td>34374.17</td>
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</table>
Search and Rescue (SAR) Case Study Two

- **Search and Rescue (SAR) DoDAF CONOP architecture with focus on the Command and Control (C2) signaling mission thread**
  - 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 [64]
  - 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 [65] [66]
- The OV-1 shows the corresponding missions, activities, organizations, and high-level operations of the SAR system
- The SAR CONOP contained all corresponding views for the Command and Control signaling mission thread the CV-1, CV-2, DIV-1, DIV-2, OV-1, OV-2, OV-5, SV-1, and SV-4
  - The **OV-5 includes the OV-5a and OV-5b**
  - Major system components and the interconnection among those components
  - Interfaces to external systems or procedures [43]
  - Capabilities, functions, and features of the current system [43]
  - 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 [43]
  - Performance characteristics, such as speed, throughput, volume, frequency
  - Provisions for safety, security, privacy, integrity, and continuity of operations in emergencies [43]
SAR Element Sampling

- **590 elements of the SAR model**, which represents the SAR DoDAF CONOP, are roughly 6.34% of the total SAR DoDAF CONOP architecture.

- Bulk of the elements are concentrated in the **DIV-2 ~19%, OV-2 ~27%, OV-5 ~8%, SV-1 ~23%, and SV-4 ~15%** views for the CONOP.

- The DoDAF standard states that the **OV-2 is the backbone to which all other DoDAF elements**.

- **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**.

- 590 elements are evaluated against the **17 Quality Characteristic Categories (QCC)**, a total of **10,030 data points are present for the evaluation process**.

<table>
<thead>
<tr>
<th>Cameo Project Statistics</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Diagrams</td>
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<tr>
<td>All Diagrams</td>
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</tr>
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<td>All Elements</td>
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<td>Project Symbol Styles</td>
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</table>

<table>
<thead>
<tr>
<th>DoDAF CONOP View</th>
<th>Element Count</th>
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<tr>
<td>CV-1</td>
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<td>CV-2</td>
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</tr>
<tr>
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<tr>
<td>DIV-2</td>
<td>111</td>
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<td>OV-1</td>
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<td>SV-1</td>
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<tr>
<td>SV-4</td>
<td>89</td>
</tr>
<tr>
<td>Total</td>
<td>590</td>
</tr>
</tbody>
</table>
**SAR Statistical Analysis - Descriptives, Skewness, and Kurtosis**

- **Mean Vs Median**
  - 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 present.
  - Standard errors are small for the mean values, mean values are more representative of overall population.
  - 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.

- **Skewness and Kurtosis**
  - Skewness and Kurtosis can provide some interpretation about the model results.
  - More values are on the right-handed for DEQ and LEQ on the right-hand side of graph.

**SAR Descriptives**

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Std. Error</th>
<th>Median</th>
<th>Std. Error</th>
</tr>
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</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>DEQ</td>
<td>7.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEQ</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DEQ</td>
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<tr>
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<tr>
<td>DEQ</td>
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<td></td>
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<tr>
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<tr>
<td>DEQ</td>
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<td>DEQ</td>
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<tr>
<td>DEQ</td>
<td>-1.101</td>
<td>0.201</td>
<td></td>
</tr>
</tbody>
</table>

Mean = 5.10, Std. Dev. = 1.69, N = 390
SAR Statistical Analysis – Multicollinearity

- Multicollinearity is where two or more variables in the **SAR evaluation data set are highly linearly related**
- Each factor including a correlation coefficient and significance on for each observation was calculated to make a correlation determination [48]
- Multicollinearity needs to be addressed because the **standard errors of the coefficients for variables could cause false indicators and become non-significant or significant** [49]
- Analysis of the Variance Inflation Factors (VIF) values for each factor was used to determine elimination [49]
- Spearman’s rho can both be positive and negative, with **the goal is to have a value between 0.1 and -0.1** [50]
- **Statistical significance does not always imply the strength of Spearman’s correlation** between variables [51]
- Statistically significant Spearman correlation **indicates that there is less than a 5% chance that the strength of the association discovered occurred by coincidence** [51]

\[
VIF_i = \frac{1}{1 - R^2_i}
\]

<table>
<thead>
<tr>
<th>Collinearity Statistics</th>
<th>Tolerance</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEQ1</td>
<td>0.401</td>
<td>2.496</td>
</tr>
<tr>
<td>DEQ3</td>
<td>0.971</td>
<td>1.029</td>
</tr>
<tr>
<td>DEQ5</td>
<td>0.403</td>
<td>2.482</td>
</tr>
<tr>
<td>LEQ1</td>
<td>0.485</td>
<td>2.063</td>
</tr>
<tr>
<td>REQ5</td>
<td>0.485</td>
<td>2.061</td>
</tr>
</tbody>
</table>

**Factors Eliminated due to VIF**

<table>
<thead>
<tr>
<th>QCC Factor</th>
<th>VIF Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEQ2</td>
<td>17.143</td>
</tr>
<tr>
<td>DEQ4</td>
<td>11.052</td>
</tr>
<tr>
<td>DEQ6</td>
<td>16.504</td>
</tr>
<tr>
<td>LEQ2</td>
<td>38.105</td>
</tr>
<tr>
<td>LEQ3</td>
<td>39.008</td>
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<td>LEQ4</td>
<td>54.958</td>
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<td>REQ2</td>
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<tr>
<td>REQ3</td>
<td>24.886</td>
</tr>
<tr>
<td>REQ4</td>
<td>22.476</td>
</tr>
<tr>
<td>REQ6</td>
<td>14.314</td>
</tr>
</tbody>
</table>

**Spearman’s Rho**

\[
\rho = 1 - \frac{6 \sum d_i^2}{n (n^2 - 1)}
\]
SAR Statistical Analysis - Principal Component Analysis (PCA)

- Accurate evaluation of the data set represents the **purposeful sampling adequacy** for the SAR DoDAF CONOP architecture.
- **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 [53] [54].

- Bartlett’s Test of Sphericity showed that the **correlation matrix formed is not an identity matrix**.
- 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** [57].
- No real adjustment is needed for the 50% to 60% of the variance, when the **total variance is achieved at 70.685% for a total of two factors**.
- Oblique rotation or varimax rotation due to the **more realistic representation** for the data [55] [56].
- Evaluation of the **loadings aid in the identification of each component’s characteristics in terms of the variables** [52].
SAR Statistical Analysis – Ordinal Logistic Regression (OLR)

- **DEQ1:** The SAR model execution did not have a SysML termination to some of the «ControlFlow» functions.
  - Name 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".

- **DEQ3:** 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.

- **DEQ5:** Several elements did not have instantiation for need in the architecture, this was consist ratings presented “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.

- **LEQ1:** 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.

- **REQ5:** were 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, What the data contained, structure, or measurement was not present.

---

**Identify the Strength of effects**

<table>
<thead>
<tr>
<th>Location</th>
<th>DEQ1</th>
<th>DEQ3</th>
<th>DEQ5</th>
<th>LEQ1</th>
<th>REQ5</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEQ1</td>
<td>1.014</td>
<td>3.663</td>
<td>1.315</td>
<td>0.235</td>
<td>-0.292</td>
</tr>
<tr>
<td>DEQ3</td>
<td>0.093</td>
<td>0.499</td>
<td>0.099</td>
<td>0.062</td>
<td>0.055</td>
</tr>
<tr>
<td>DEQ5</td>
<td>118.118</td>
<td>53.866</td>
<td>175.668</td>
<td>14.322</td>
<td>28.025</td>
</tr>
<tr>
<td>LEQ1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>REQ5</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Link function: Logit.
SAR Degree of Modularity Determination

- **DEQ2.6** and **REQ1-6**: All of the elements evaluated had some form of relationship to the SAR DoDAF architecture being direct or indirect.
  - This means that **some degree of modularity is present**.
  - **DEQ6**: VIF calculated showed a value of 16.504.
  - **REQ1-6**: PCA and OLR analysis found key significance in the REQ criteria from the QCC for the SAR architecture.

- The **pairwise weighting each item** with the rest of the group and give a preferential level to the item.

- **If the model description is simple, the model description is short** [39]
  - Many data mismatches would exist, and the mismatched data description would become longer [39]
  - A **complicated model reduces the description of mismatched data, but the model description would be longer** [39]
SAR Overall Results

• DEQ Findings:
  – **DEQ2 and DEQ6 Showed some degree of modularity** is present in the architecture.
  – **Unrelated elements on DoDAF Views**
  – 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.
  – Several DEQ values the **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 felt during** compiled execution of a model activity.

• REQ Findings: Many of the element in the SAR 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.
  – Analysis **found key significance in the REQ criteria from the QCC for the SAR architecture**

SAR Rating was “Acceptable” to “Good” with sensitivity to **REQ factors**

• DEQ was yellow to green but very close to a value of 3.73 or "Good" rating
• The LEQ was a green score of a value of 3.91 but still a "Good" rating
• The REQ was a red score of 3.50 in a "Poor" to "Acceptable" rating
• The SAR Overall score is a 3.72 or "Acceptable" to "Good" rating
Recommendations and Reviews
Summary and Recommendations

- **DQCF presents an advantage to the industry and DoD in a new methodical approach** to quality within MBSE environment.

- However, despite the fact that there is no ideal technique for quality evaluation, the suggested approach demonstrated **promising ability to detect quality and model sensitivities to quality analysis**.

- In truth, basic scoring techniques have increased in favor primarily because they **are quick and straightforward to utilize** [68]

- By providing a **renewed focus on a quality-based system engineering process** when applying DoDAF, **improved trust in the system and data architecture** of the completed models can be achieved

---

**The technical approach using the DQCF presents a unique opportunity** for baseline understanding to be set for development with respect to quality and save money on development of DoD programs

**Cost of Quality (CoQ) savings could be at minimum 15% or 81.315 Billion ~2576 years, 9 months, 7 days, and 20 hours**


References Cont.


42. J. L. Hayden and A. Jeffries, “On using sysml, dodaf 2.0 and updm to model the architecture for the noaa’s joint polar satellite system (jpss) ground system (gs),” in NASA Technical Reports Server, 2012.


References Cont.

Additional Publications and Efforts
Ph.D. Candidate Accomplishments

• Accomplishments
  – Certified Project Management Professional (PMP) (2020)
  – National Defense Industrial Association (NDIA) Modular Open System Architecture (MOSA) Architecture Committee
  – National Defense Industrial Association (NDIA) Systems Engineering Education and Training Committee
  – System Engineering Research Center (SERC) Contributing Author
  – Aerospace Industrial Association (AIA) Digital Engineering Acquisition Metrics Committee
  – Boeing MBSE Metric Community of Practice (CoP) Committee Chair

• Conferences and Publications
  – 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 Sr. Digital Engineering Lead

• Professional Accomplishments (2001 to present)
  – Current: Lead Digital Engineer MWS Product Security, The Boeing Company
    • Lead Ground Based Mid-Course Defense (GMD) Cyber Architecture, System Integration and Test Readiness (SITR), and many others
  – Sr. System Engineer, Cummings Aerospace
  – Lead Threat Modeling Engineering, Allpoints LLC.
  – Sr. System Engineer, Modern Technology Solutions Inc. (MTSI)
  – General Engineer, Department of Defense (DoD) Missile Defense Agency (MDA)

• Orcid ID: https://orcid.org/0000-0001-6866-9024, LinkedIn www.linkedin.com/in/andrew-miller-8b75648b
Acknowledgments

• Special Thanks
  – Mrs. Ashley L. Miller, PMP.
    • Mrs. Miller serves as the Director of Missile Defense Agency (MDA) Programs TEAMS Next Contract for the Modern Technologies Solutions Inc. (MTSI) Company
    • Mrs. Miller provided motivation and technical engineering evaluation of this works methodology application.
  – Mr. Russell F. Miller
    • Mr. Miller serves as Sr. Engineering Technical Advisor to MDA for the Parson Corporation, and provided technical guidance and motivational support to complete this work
  – Mr. Kirk Moen
    • Mr. Moen serves as Sr. System Engineering Team Lead/Architecture Lead at the Boeing Company and helped provided case studies and technical guidance for the analysis within this work.
  – Mr. Brian Rosa
    • Mr. Rosa serves as Sr. Manager for Ground Based Midcourse Defense (GMD) program at the Boeing Company, without his early approval, embarking on this journey would not have been possible.
  – Dr. George Collins Ph. D.
    • For giving me the opportunity to achieve this goal of completing my Ph.D.
  – Dr. Daniel R. Herber Ph. D.
    • Picking up where Dr. Collins left off and providing technical guidance allowing the author to complete this work
  – Committee Members: Dr. Thomas Bradley, Ph. D., Dr. Erika Miller, Ph. D., Dr. Steve Simske, Ph. D., Dr. Azer P. Yalin, Ph. D.
  – Staff of System Engineering Department Colorado State University
Questions?
Thank you
Reviewer Comments of Material - 3 Ph. D. Level Reviewers

- All comments have been addressed and submitted to Wiley System Engineering Journal

- Overall Comments
  - This is very well written and well referenced manuscript (Reviewer 1)
  - Overall, very thorough treatment of architectural assessment (Reviewer 1)
  - The methodology discussed is logically clear with sufficient technical details, especially the elements on quality factors and measurement reflected the authors’ contribution (Reviewer 2)
  - Overall this is a great piece of work in the area of operational research (Reviewer 2)
  - The literature review conducted is comprehensive (Reviewer 2)

1. Is the rating how well a particular framework (now superseded by UAF) is implemented (Reviewer 3)
   - DoDAF, while still used, has been greatly deemphasized in policy as it once was when originally released (Reviewer 1)
   - While advancements have been made in the field of architecture development standards, DoDAF still leads both government and industry practice as the most widely mandated defense standard for U.S. government acquisition and continues to impact system descriptions. DoDAF was mandated in 2013 and has not been superseded [72].

2. ‘Good’ rating after applying the process, does this mean the design is solid or does it mean the model did not express a coherent design in terms of the DoDAF structure? What does it tell you about design risks? (Reviewer 3)
   - So one concern is the DQAP’s assessment and linkage to “requirements”, depending on the purpose of the architectural effort (Reviewer 1)
   - The REQ variable takes into account the SE methods of the DoDAF CONOP architecture and relates the element to requirement instantiation of the architecture in the model to understand how well requirements are met in the system solution [4]
   - 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 [76]. Ultimately, the goal is to identify and address the sensitivity through possible mitigations presented with the variable quantifications.
3. You state “Assess the degree of modularity based on these results—is the system considered more modular/less integrated or less modular/more integrated?” Please provide more context. (Reviewer 1)
   – Are you defining a new definition for modularity which is generally a structural attribute of a system? (Reviewer 1)
   – The degree of modularity assessment was used in order to grasp the functional reusability of the views and understand the complexity of the DoDAF architecture. In contrast, many data mismatches would exist, and the mismatched data description would become longer. A complicated model reduces the description of mismatched data, but the model description would be longer.

4. Can one get a full picture of the quality of design for a mere 5% of the depictions? (Reviewer 1)
   – The Kaizer-Meyer-Olkin (KMO) addresses partial correlation between the variables [73]. 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[73][74].

5. Attempting to find precision on crude Likert assessments (low accuracy) correct? (Reviewer 1)
   – The reliability of the seven-point Likert scale has been shown empirically to have 90% approximate reliability and 89% approximate validity[75].
1= Strongly Disagree, 2=Disagree, 3=Somewhat Disagree, 4=Neutral, 5=Somewhat Agree, 6=Agree, 7=Strongly Agree

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Mean: 5.31
Std Dev: 1.5
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### Total Variance Explained

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### Component Matrix - a

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</table>

**Extraction Method:** Principal Component Analysis.
**Rotation Method:** Varimax

a. Rotation converged in 3 iterations.
1= Strongly Disagree, 2=Disagree, 3=Somewhat Disagree, 4=Neutral, 5=Somewhat Agree, 6=Agree, 7=Strongly Agree
1= Strongly Disagree, 2=Disagree, 3=Somewhat Disagree, 4=Neutral, 5=Somewhat Agree, 6=Agree, 7=Strongly Agree
1= Strongly Disagree, 2=Disagree, 3=Somewhat Disagree, 4=Neutral, 5=Somewhat Agree, 6=Agree, 7=Strongly Agree
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Component Plot in Rotated Space

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Extraction Method: Principal Component Analysis.
Rotation Method: Varimax
a. Rotation converged in 3 iterations.
DoDAF Quality Framework Execution activity

The below Activity shows the execution of the key step to application of the framework. The process can be both automated through the use of Cameo Developed Plugin or Manual through the use of Excel. The R code can be executed on both Cameo plugin Data and Manual created data. Manual process may take longer.

Orange indicates Data Areas of Framework and Applicability to the Flow process.

- Quality Logical Model for DoDAF
- SME Quality Assessment Method
- DoDAF Quality Analysis Profile
- DoDAF Quality Analysis Data Tables
- Means to Analyze Data

The decision is based on the output data of the model. The SME is not satisfied with the result and it is necessary to establish why or if it is necessary to understand justification for rating.

- [Yes] Final Assessment
- [No] Continue with Process

Excel DoDAF Quality Assessment Data Linear Model

The SME applies the DoDAF Quality Assessment Data Linear Model to the selected elements. The DoDAF architectural elements are evaluated and appropriately categorized to support quality of architecture.

During the assessment the elements are inspected along the dataset provided in the framework. Status, pattern, and key aspects of the element regarding to the SME for the architectural elements.

Process analysis results with R Evaluation for Trend of Data

Even with Evaluation complete. This is expected to follow the development Trend to be reviewed by the program.
Element Assessment Data

- DoDAF Quality View Stereotype Applied Stereotype Indicator
- DoDAF Quality View Stereotype Applied Icon Indicator
- Orange Block indicate instruction about Applied DoDAF Quality View Stereotype
- Likert Applied Data for Evaluation
- Identified Applied Stereotype from DQAP

Unique ID for Element | Name of Element | Qualified Path | Likert Evaluation of Element
---|---|---|---
1 | _16_Sbeta_18F40297_1232816548301_796562_6555 | Find Victim | 4 2 3 5 5 5
Quality System Engineering Competency Understanding to Apply DoDAF Quality Analysis Profile For Model Assessment
Quality systems engineers recommend establishing a quality assurance in the systems architecture development. They conduct quality process and product architecture reviews and influence the resolution through evaluation actions to ensure adherence to quality standard processes. They help develop a measurement capability used within the architecture for evaluation purpose and to report architecture progress.
The DoDAF Quality Analysis Profile is a profile that contains stereotypes that are applied to DoDAF Model Elements. The DoDAF Model Elements are evaluated based on the DoDAF Quality Framework and scored accordingly. The scoring data is extracted and analyzed to provide a robust picture of Model-desired aspect quality.
Juran Quality By Design Application to DoDAF Framework

Juran Quality By Design Taxonomy
- Quality by Design (QBD)
  - Contains QTP
- Quality Target Product Profile (QTPP)
  - Quality Attributes to Control
  - Within SAR Model Identified QTPP Area
- Quality Control Attribute (QCA)
  - Desired
  - Necessary

DoDAF Sample Model
- Contains DoDAF Framework
- Stereotypes
  - Break out Views from Architecture

What CONOP Consists of In Model
- OV_1
- OV_2
- DV_1
- SV_1
- CV_1
- OV_5 Structural
- DV_2
- SV_4 Structure
- CV_2

Direct Connection
- Attribute of DoDAF for Quality Control Analysis
- View in DoDAF
- Could be Both
- Necessary Data toPull from model could be UML or SysML
- Stereotypes applied to DoDAF elements that populate these diagrams

Through the Application of the DoDAF Quality Analysis Profile the Desired and Necessary aspects of the QCA are collected and analyzed.

Legend
- Quality By Design Element
- DoDAF Element
- UML
- SysML
- Quality By Design Concept
**MDS Model Relation Clustering examples**

**Non-Clustered Model Relations**
- DoDAF Element
- Relations Drive Clustering to understand Modularity
- Blacked out Same element relation

**Clustered Model Relations**
- Clusters were considered as weighted DSMs
- S1 Mismatch
- S2 Mismatch

**Clustered Model Weight Relations**
- Weighted Relation indicators added to Cluster

**DoDAF Elements**
- OV-1
- OV-2

**DoDAF Viewpoint**

**Table: Length**

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<th>$3\log n_n$</th>
<th>$\log n_n$</th>
<th>$4\log n_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>B,D,G</td>
<td>3</td>
<td>9</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>A,C,E,H</td>
<td>4</td>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Formula: Type 1 Mismatch**

$S_1 = \sum_{d_{ij}=0} p_{ij}$

**Formula: Type 2 Mismatch**

$S_2 = \sum_{d_{ij}=1} (1 - p_{ij})$

**Execution of Step for Data of Dependency Matrix**

<table>
<thead>
<tr>
<th>Scale</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weak Relation</td>
</tr>
<tr>
<td>2</td>
<td>Good Relation</td>
</tr>
<tr>
<td>3</td>
<td>Strong Relation</td>
</tr>
</tbody>
</table>
Using the QCC each quality aspect of an element or model can be evaluated and scored.