9-2022

# A Case Study of the Efficacy of Model-Based Requests for Information

Kyle J. Arruda

**A CASE STUDY ON THE EFFICACY OF MODEL-BASED REQUESTS FOR INFORMATION**

THESIS

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AFIT-ENV-MS-22-S-073

**DEPARTMENT OF THE AIR FORCE**
**AIR UNIVERSITY**

# AIR FORCE INSTITUTE OF TECHNOLOGY

**Wright-Patterson Air Force Base, Ohio**

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THESIS

Presented to the Faculty

Department of Systems Engineering and Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Engineering

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August 2022

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AFIT-ENV-MS-22-S-073

## Abstract

The Department of Defense (DoD) has encouraged the transition to digital engineering, yet there are limited guides for how to transition and there is limited data to show where an organization like a program office can reap the most benefit from the transition. To identify areas where potential benefits may be realized, this thesis compares two Requests for Information (RFIs), one document-based and one model-based, from generation to response. A survey was developed and administered to 7 members of a single program office to grade the RFI responses. The survey was based on the 43 benefit categories identified in the Systems Engineering Research Center's (SERC) previous study titled, "*Benchmarking the Benefits and Current Maturity of Model-Based Systems Engineering across the Enterprise.*" The study identified that model-based RFIs: 1) captured 100% more requirements, 2) doubled total RFI responses, 3) increased model-based RFI responses by 64%, 4) improved RFI responses across Quality, Velocity/Agility, User Engagement, and Knowledge Transfer, 5) increased responses that were pursued by 21%. Utlizing model-based RFIs is a simple first step for program offices to take on the transition to digital engineering, not only will it uncover overlooked requirements it will help improve responses allowing pursuit of better products.

**Acknowledgments**

I would like to thank my advisor, Lt Col Amy Cox, for her guidance and support throughout the course of this thesis effort. Your insight, experience, flexibility, and patience was greatly appreciated and vital to the completion of this research.

Kyle J.Arruda

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## A CASE STUDY ON THE EFFICACY OF MODEL-BASED REQUESTS FOR INFORMATION

## I. Introduction

### Background

The Department of Defense (DoD) Digital Engineering (DE) Strategy challenges the Department to "transform its engineering practices to digital engineering, incorporating technological innovations into an integrated, digital, model-based approach" (DoD, 2018). Traditionally, "acquisition engineering processes are document-intensive and stove-piped, leading to extended cycle times with systems that are cumbersome to change and sustain (DoD, 2018)". "The DoD's vision for digital engineering is to modernize how the Department designs, develops, delivers, operates, and sustains systems" (DoD, 2018). This will "allow…rapid response to changing threats, field advanced capabilities, and engineer dominant systems faster" (Jones, 2019).

To transition digital engineering, users need access to the correct tools, training, and digital environments. The Air Force, through its Digital Campaign, is working to provide access to Integrated Development Environments (IDEs), which is a compilation of data, models, and tools for collaboration, analysis, and visualization across functional domains.

While the DE Strategy establishes a desired end state, it understandably remains silent on the myriad ways to enact this transformation. At this writing, the Air Force is early in this adoption. This research captures data on the effort to transition an existing system of systems from document based to model-based processes. This research

contributes empirical data, processes and lessons learned, to aid others in their transition efforts.

**Problem Statement**

Program offices must transition from document-based engineering to digital engineering in order to meet the requirements and complexity of the DoD's future weapon systems. Through digital engineering the DoD may be able to answer emerging requirements at pace with or outpacing advancements by adversaries. Currently, there is no standard IDE or set of tools; it is on the program office to determine what they require. Additionally, there is no adequate guide to show a program office how they may realize the benefits of transitioning to model-based practices, such as the use of model-based systems engineering (MBSE). Lack of experience and exposure to digital engineering can make this transition an extremely daunting task. Without understanding the possible benefits of transitioning to digital engineering, the transition can also become difficult to sell to stakeholders.

Establishing and refining requirements is a fundamental phase of systems engineering processes, whether for a new system or modifications to a system in sustainment. The Request for Information (RFI) process provides insight to industry of the current requirements held by the government and allows industry the ability to demonstrate their solutions to meet those current or emerging needs. Requirements are at the foundation of RFIs. If there were no new requirements, there would be no need for an RFI; there would be no capability gap to trigger the search for a solution.

In their paper titled, "Modernizing DoD Requirements Enabling Speed, Agility, and Innovation", The MITRE Corporation describes the DoD's requirements system as

"stuck in the past…too slow to produce results…too inflexible…and too narrowly focused to satisfy joint warfighting needs across all domain operations" (MITRE, 2020). "Very few individuals are able to gain the proficiency needed to effectively capture and shape requirements" (MITRE, 2020). This is exacerbated by a lack of training (personnel only taking a few DAU courses) and warfighters serving in "ad-hoc roles working on requirements for 18–24 months" (MITRE, 2020). These top-level requirements problems can cause major issues for a program office. What happens if a program office spends their time and resources trying to solve for incorrect requirements? Most likely they will come to a solution that fails to meet the warfighters needs and wastes valuable time and resources that could have been better spent pursuing a better solution. Early investments in capturing requirements can reduce wasteful rework; they can lead to fielding the needed solution.

Traditional document-based engineering makes generating, expressing, and understanding requirements problematic for program offices. Document-based requirements often have 2 extremes, they either leave too much room for interpretation or leave no room at all. It is often difficult to describe why a requirement exists in a document within the context of the whole system, the requirement is often singular and does not illustrate its impact on the rest of the system. A digital approach to requirements could alleviate many of these problems, a model can give better context to each requirement and how they impact the larger system design. While digital engineering may address some of the DoD's current requirements system shortfalls, once it is implemented how do we even know if it is having an impact?

## Research Objectives

The goal of this research is to monitor and document how a single program office's requirements generation and management process is impacted as it transitions from traditional document-based to model-based. This research considers tool adoption, work force training, and model-based process adoption. This research provides side-by-side comparisons of document-based and model-based requirement development and RFI processes. Data and lessons learned for this transition are captured. The research objectives are as follows:

1. Identify strengths associated with a program office's transition to digital engineering with respect to the Request for Information (RFI) processes.
2. Identify limitations associated with a program office's transition to digital engineering with respect to the RFI processes.
3. Identify and validate a set of measures that can be utilized to gauge the effectiveness of MBSE on day-to-day processes that are currently used within a program office.

## Methodology

A case study was performed at the Tactical Air Control Party (TACP) Modernization program office, Hanscom AFB, MA. Two RFIs were developed utilizing five separate AF Form 1067s (requests for modification) as their basis for requirements. These five AF Form 1067s combined to create the "TACP Command and Control (C2) Weapon System". The first RFI was generated without the use of MBSE software, tools or methods, it was strictly document-based utilizing Microsoft Word. The second RFI was generated utilizing a MBSE software, called Cameo Enterprise Architect and

Microsoft Word. It included a requirements diagram, a use case diagram, and a system context diagram. The RFIs were given different titles, the document-based RFI was called the "Air Support Operations Center (ASOC) Modernization RFI", the model-based RFI was titled the "TACP C2 Weapon System RFI". Both RFIs were advertised on the System for Award Management (sam.gov), an official U.S Government website that advertises government RFIs and elicits responses from industry, for 30 days. The team responsible for identifying and developing the solutions for the AF Form 1067s then completed a survey grading each response as well as the quality of the product based on a 5-point Likert scale. Surveys were analyzed to measure the impact the modeling process had on the model-based RFI responses compared to the document-based RFI responses.

**Assumptions/Limitations**

This study was performed with a team of seven consisting of two engineers, two program managers, one acquisition support, one enlisted subject matter expert (SME), and one officer/program manager/engineer/SME. The study was performed with an ACAT III program. This is a relatively small sample size for survey results due to this smaller team size. The smaller sample size may reduce reliability of the study.

Both RFIs were posted at the same time. Since they had similar requirements, some responders chose to answer both with the same response, others answered a single response to one RFI. Submissions to both RFIs were categorized under the model-based RFI for analysis due to the assumption that the responder would have utilized the information given in the model-based RFI to generate both responses.

The model-based RFI generation process positively influenced the document-based process. The team that generated the document-based RFI determined that it was

missing too many requirements to publish after they had completed the model-based RFI. Higher level requirements from the model-based RFI were injected into the document-based RFI to improve quality. This was expected to have the effect of narrowing the difference in results between the two RFIs.

**Implications or Expected Contributions**

The results of this research are expected to identify improvements to the requirements generation and management process. Specifically, this research is expected to identify a path for program offices to introduce MBSE software and methods into their operations. It is expected to outline an improved method to generate RFIs as well as provide a set of measures that may be utilized to determine if MBSE is impacting specific operations within the acquisition process.

**Summary**

This study will analyze the impact the introduction model-based systems engineering has on a single program office's request for information and requirements processes. Two RFIs one document-based one model-based were published. Results were graded by a seven-member team using a survey based off the System Engineering Research Center's previously identified benefit categories. Results from the survey were analyzed to identify differences between the model-based RFI results and the document-based results. Overall, the model-based RFI was shown to receive a higher rate of responses and a higher rate of model-based responses. Model-based responses were graded higher in every category and improved the likely-hood of the program office pursuing that specific proposed solution or product.

# II. Literature Review

## Chapter Overview

The goal of this research is to evaluate a how a single program office's requirements generation and management process is impacted as it transitions from traditional document-based to model-based. This literature review will cover two distinct topics to support this research goal. First, it will provide background into the established requirement generation process for modifications to fielded systems. Next, since we are studying the transformation of a process, we will introduce measures of change.

## Air Force Form 1067

Air Force Instruction (AFI) 10-601 establishes the process for Operational Capability Requirements Documentation and Validation. This process is specific to the Air Force; however, it fits within a larger Department of Defense capability development system. The focus of this research is a fielded system that requires modifications. This specific aspect of requirements documentation and validation is described in AFI 10-601 and is documented with the Air Force (AF) Form 1067.

The AF Form 1067 is a document used to initiate modifications for fielded systems and equipment. A modification is an alteration to a configuration item (CI) that, as a minimum, changes its form, fit, function, or interface. A configuration item can be an individual hardware or software component of the overall system. As an example, the radio in a car could be a configuration item for the car system. In the Air Force model, modifying a radio would require an AF Form 1067

The AF Form 1067 also documents the submission, review and approval of requirements for permanent capability modifications. These capabilities can cover a diversity of modifications, examples include improvements identified by end-users (e.g. install a handle here) to those to capture shift in usage (e.g. change lighting to allow for night vision compatibility).

Since the intent of the AF Form 1067 is to support modifications to existing programs versus, the scope of the change supported by the AF Form 1067 is limited in cost. The limit is no more than ten percent of the minimum threshold dollar values for an Acquisition Category II (ACAT) program. The Department of Defense defines ACAT II programs as those requiring either a research and development budget of up to $200 million or a procurement budget of up to $920 million in fiscal year 2020 funds. While limited, the AF Form 1067 can support significant system changes.

The AF Form 1067s can be generated at any time and can be generated by any stakeholder (ex. maintainer, user, using command). The AF form 1067s typically are received throughout the year and validated during an annual requirement working group. Currently, within the Tactical Air Control Party Modernization (TACP-Mod) Program Office, the 1067 process is as follows:

1. Request For Action section is filled in by anyone (typically the end users or the using command, Air Combat Command (ACC) is the lead using command for the system). This is currently in the form of a written description of the "purpose", "impact", and "constraints/assumptions/proposed solutions". The AF Form 1067 is a fillable Portable Document Format (PDF) that could be submitted by itself or with accompanying documents or information. These

proposals are validated, disapproved, or returned to the initiator for additional information by the lead command functional responsible for operations.

2. The lead command functional responsible for plans and requirements validates or disapproves the request, categorizes the modification as temporary or permanent, and adds their additional written remarks (constraints or assumptions). The AF Form 1067 has fields for these remarks; however, additional documentation may be attached to expand beyond the space provided on the form (e.g. meeting minutes, attached e-mails, other documents).
3. The lead command functional responsible for plans and requirements then sends the AF Form 1067 to the Project Management Office (PMO) for cost estimates and engineering recommendations. This represents a transition of the requirement from the user to the acquirer. The PMO will typically publish a Request for Information (RFI) to industry to identify or develop possible solutions to the requirements in the AF Form 1067s. The PMO translates the information provided in the AF Form 1067 into a RFI document that is published to industry.
4. Interested firms submit responses to the RFI. These responses inform engineering recommendations and cost estimates from the PMO. This data informs the resource allocation decisions of the using command, balancing needs and resources available. The engineering recommendation and cost estimate is either approved or disapproved by the lead command for plans and requirements.

The AF Form 1067 process has several stakeholders: individual users, multiple functionals within the using command structure, the acquirer (including management and engineering functions), industry, and possibly others. Information is created, relayed and transformed through this process. Ultimately, this process begins with a user with a need and ends with that need deliberately not met or met in some manner. Inefficiencies and miscommunications often occur.

The form of the information passed in this process is changing. Information is passed among stakeholders and transformed. First information is relayed with the AF Form 1067, where information is either entered into the fields or attached to the form. Next, the information is converted to an RFI that is published to industry, this is typically in a narrative form. In turn, industry responds to the information request with product offerings in various formats. Finally, the RFI responses inform an engineering assessment and cost estimate that may be summarized on the AF Form 1067 and clarified with further attachments, documents or artifacts.

**Measuring The Effect of MBSE**

The existing modification process is document-based. This research is considering the effect of transitioning to a model-based modification process. First, a method to measure the effectiveness of MBSE needs to be identified. According to the Systems Engineering Research Center (SERC) report, “There is an imbalance between the expected benefits of MBSE and the implementation of MBSE metrics to measure the achievement of those benefits”. Most benefits described in research surrounding the use of MBSE are either perceived or observed versus explicitly measured through formal metrics (SERC, 2020). Therefore, the primary purpose of this section is to define the

formal metrics developed in order to measure the impact the introduction MBSE had on the RFI process.

For their report, “Benchmarking the Benefits and Current Maturity of MBSE”, the SERC administered the International Council on Systems Engineering’s (INCOSE) Model-Based Enterprise Capability Matrix to 240 participants, from government, industry, and academia, to assess the “maturity of system engineering’s digital transformation, identify specific benefits of MBSE and associated metrics, identify enablers and obstacles to DE and MBSE adoption across the enterprise, and understand evolving and necessary shifts in the systems engineering workforce” (SERC, 2020). The SERC’s metric research is heavily leveraged for the measures in this thesis.

The study was comprised of 23 rated questions and 12 free-text questions. To analyze the free text responses that related to MBSE benefits, value, and metrics, SERC developed a framework that organized responses into four general categories as seen in Figure 1. These categories “were developed from a literature review focused on digital enterprise transformation metrics, looking across similar digital enterprise transformation activities as well as agile software development activities and a previous SERC research report on digital engineering enabled transformation” (SERC, 2020).

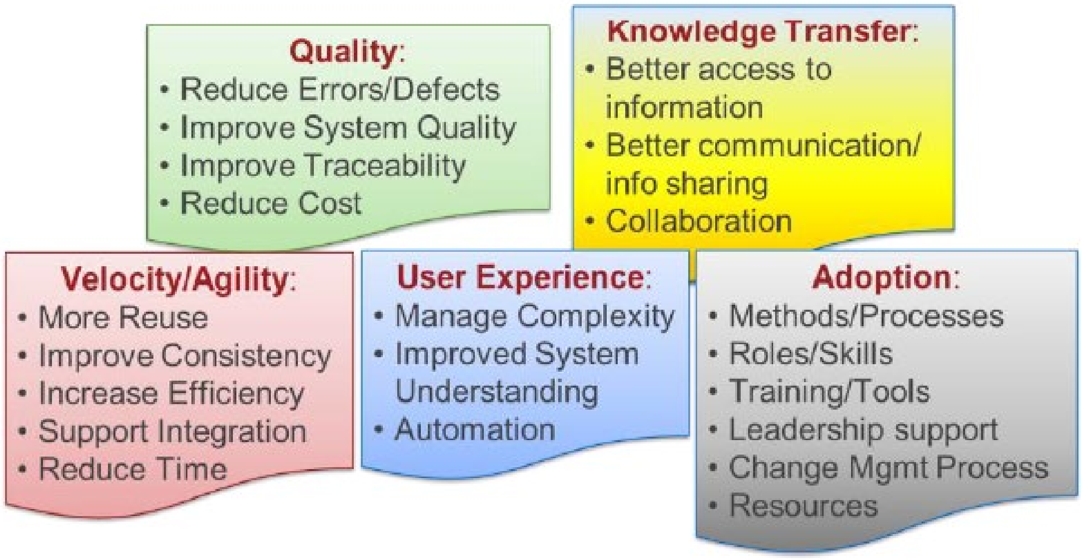


**Figure 1. Metrics Framework for the Survey Analysis (SERC, 2020)**

The SERC further refined the four general categories with the "Benefit Categories", seen in Table 1 through a literature review of 847 papers related to MBSE. The SERC study used the identification of specific phrases in the responses (seen in Table 1) to their survey to measure the impact MBSE was having on an organization. This paper will further utilize the "Benefit Categories" developed in SERC study to generate a survey to rate the RFI responses by specifically asking respondents if they have identified any of the benefits within each RFI response.

## Table 1. List of benefit categories used to analyze SERC study (SERC, 2020)

| Category | Benefit Category | Sample Phrases from Literature |
|---|---|---|
| Quality | Improve system quality | higher quality, quality of design, increased system quality, first time quality, improve SE quality, improve specification quality |
| | Increased rigor | rigorous model, rigorous formalisms, more rigorous data |
| | Increased traceability | requirements/ design/ information traceability |
| | Reduce errors | reduce error rate, earlier error detection, reduction of failure corrections, limit human errors, early detection of issues, detect defects earlier, early detection of errors and omissions, reduced specification defects, reduce defects, remove human sources of errors, reduce requirements defects |
| | Reduce cost | cost effective, cost savings, save money, optimize cost |
| | Reduce risk | reduce development risk, reduce project risk, lower risk, reduce technology risk, reduced programmatic risk, mitigate risk, reduce design risk, reduce schedule risk, reduce risk in early design decisions |
| | Improved risk analysis | earlier/ improved risk identification, identify risk |
| | Improved system design | improved design completeness, design process, design integrity, design accuracy, streamline design process, system design maturity, design performance, better design outcomes, clarity of design |
| | Increased effectiveness | effectively perform SE work, improved representation effectiveness, increased effectiveness of model, more effective processes |
| | Improved deliverable quality | improve product quality, better engineering products |
| | Better requirements generation | requirements definition, streamlining process of requirements generation, requirements elicitation, well-defined set of requirements, multiple methods for requirements characterization, more explicit requirements, improved requirements |
| | Increased accuracy of estimates | confident estimates of accuracy |
| | Improved predictive ability | better predict behavior of system, predict dynamic behavior, predictive analytics |
| | Better analysis capability | better analysis of system, tradespace analytics, Perform tradeoffs and comparisons between alternative designs, simulation |
| | Improved capability | greater system capability |
| | More stakeholder involvement | easy way to present view of system to stakeholders, better engage stakeholders, quick answers to stakeholder's questions, share knowledge of system with stakeholders, stakeholder engagement, satisfy stakeholder needs |
| | Strengthened testing | model based test and evaluation, increased testability, improved developmental testing |
| Velocity/ Agility | Reduce time | shorter design cycles, time savings, faster time to market, ability to meet schedule, reduce development time, time to search for info reduced, reduce product cycle time, delays reduced |
| | Improved consistency | consistency of info, consistency of model, mitigate inconsistencies, consistent documentation, project activities consistent, data consistency, consistent between system artifacts |
| | Increased capacity for reuse | reusability of models, reuse of info/ designs |
| | Easy to make changes | easier to make design changes, increased agility in making changes, changes automatically across all items, increased changeability |
| | Reduce rework | reduce rework |
| | Reduce waste | reduce waste, save resources |
| | Increased productivity | gains in productivity |
| | Increased efficiency | efficient system development, higher design efficiency, more efficient product development process |
| | Increased transparency | transparent design |
| | Increased confidence | higher confidence in system solution, increased confidence in system validity |
| | Increased flexibility | flexibility in design changes, increase flexibility in which design architectures are considered |
| | Better requirements management | better meet requirements, provide insight into requirements, requirements explicitly associated with components, coordinate changes to requirements |
| | Ease of design customization | ease of design customization |
| | Higher level of support for integration | integration of information, providing a foundation to integrate diverse models, system design integration, support for virtual enterprise/ supply chain integration, integration as you go |
| | Increased uniformity | uniformity |
| | Increased precision | design precision, more precise data, correctness, mitigate redundancies, accuracy |
| | Early V&V | early verification and/or validation |
| | Reduce ambiguity | less ambiguous system representation, clarity, streamline content, unambiguous |
| User Experience | Higher level support for automation | automation of design process, automatic generation of system documents, automated model configuration management |
| | Reduce burden of SE tasks | reduce complexity of engineering process |
| | Better manage complexity | simplify/ reduce complexity, understand/ specify complex systems, manage complex information/ design |
| | Improved system understanding | reduce misunderstanding, common understanding of system, increased understanding between stakeholders, understanding of domain/ behavior/ system design/ requirements, early model understanding, increased readability, better insight of the problem, coherent |
| | Reduce effort | reduce cognitive load, reduction in engineering effort, reduce formal analysis effort, streamline effort of system architecture, reduce work effort, reduce amount of human input in test scoping |
| | Better data management/ capture | representation of data, enhanced ability to capture system design data, manage data |
| | Better decision making | make early decisions, enables effective decision making, make better informed decisions |
| Knowledge Transfer | Better accessibility of info | Ease of info availability, single source of truth, centralized/ unique/ single source of info, simpler access to info, synthesize info, unified coherent model, one complete model |
| | Better knowledge management/ capture | knowledge capture of process, better information capture, early knowledge capture, more effective knowledge management |
| | Improved architecture | help develop unambiguous architecture, rapidly define system architecture, faster architecture maturity, accurate architecture design |
| | Multiple viewpoints of model | shared view of system, more holistic representation of system/ models, dynamically generated system views |
| | Better communication/ info sharing | communication with stakeholders/ team/ designers/ developers/ different engineering disciplines, information sharing, knowledge sharing, exchange of information, knowledge transfer |
| | Improved collaboration | simplify collaboration within team |

**Summary**

This literature review has provided a description of the Air Force's existing process for Operational Capability Requirements Documentation and Validation. Specifically, it has identified the aspects of the process that support modifications to fielded systems. The current process is document-based, leveraging multiple documents and artifacts across a diversity of stakeholders.

Chapter 3 will discuss the methods implemented to modify the process, and assess the effect of the modification. The measures implemented in Chapter 3 stem directly from the SERC study titled, "Benchmarking the Benefits and Current Maturity of MBSE", which identified "Benefit Categories" that will be used in this study to measure the impact of MBSE on the RFI process within a single program office.

# III. Methodology

## Chapter Overview

This chapter details the process used to analyze the impact MBSE had on the RFI process within a single program office. The RFI development and publication process for both document and model-based RFIs will be discussed. Survey design will be outlined as well as the processes used to validate raters, questions, and subscales. Finally, analysis methods from the survey results will be detailed.

## Overview of System/Case Study

The program office under study is the TACP-Mod program office. It has been chosen for multiple reasons to include the ability to introduce MBSE, ability to control how MBSE is used in the RFI generation process, the ability to author and publish RFIs, and access to validated AF Form 1067s (requirements).

An experiment was conducted in the course of accomplishing PMO activities, one that involved generating two similar RFIs. The first leveraged traditional document-based approach typically employed by the PMO. The second RFI was generated using a model-based approach, providing models to accompany the RFI.

Responses for the RFIs were assessed by the team of seven reviewers in the PMO. The team members assessed each industry response based on the factors identified by the SERC. A score was assigned for each SERC factor using a five-point Likert scale (strongly disagree to strongly agree). The numerical values of the population of responses (e.g. those to a model-based RFI versus document-based) were then compared to determine categorical differences between the methods.

**RFI Development**

Two RFIs were developed and published to sam.gov. The proposals were open for responses for 30 days. The first RFI, titled "Air Support Operations Center Modernization (ASOC-Mod) RFI", was limited to written text. The RFI was generated using Microsoft Word and will be referred to throughout the rest of this paper as the document-based RFI. No diagrams were included in this RFI.

The first RFI was generated prior to development of the second RFI, titled "TACP C2 Weapon System RFI." This ordering or RFI generation was chosen to control for influence between the new process (model-based) and the legacy process (document-based) so that the use of modeling wouldn't influence the legacy process currently used by the program office. The TACP C2 Weapon System RFI will be referred to throughout the rest of this paper as the model-based RFI.

One observation in regards to the introduction of MBSE was that after using the modeling software to generate the model-based RFI, engineers determined that the document-based RFI was inadequate and missing key requirements. High level requirements were added into the document-based RFI after the model-based RFI was complete. While the initial intent was to avoid influence/contamination of the legacy process, the omissions were too significant to support an effective RFI. It is assumed that this change will have the effect of limiting the difference between document-based and model-based responses.

**Model-based RFI Development**

Before the model was developed, the PMO required tools and workforce development to support this effort. The model-based RFI was generated using MBSE

software called Cameo Enterprise Architect. The program office procured this software through the Naval Systems Engineering Resource Center (NSERC). The TACP Mod Program Office also received a 16-hour Air Force Institute of Technology introduction to MBSE workshop titled, "Applied Model-Based Systems Engineering Using SysML". This workshop introduced the office, and the members generating these RFIs, to the Object-Oriented Systems Engineering Method (OOSEM).

Three SysML diagrams were generated to support the model-based RFI: a requirements diagram, a use case diagram and a block definition diagram portraying high level system components. The first was the TACP C2 Weapon System Requirements Diagram (Figure 7 - Figure **7**). The program office expanded requirements to the first 4 levels for a major sub-system. This was done as it was viewed as the minimal amount to organize the requirements in a way that made sense to the team. The program office did not want to make requirements so specific they constrained responses or prescribed solutions and left the remaining lower levels open to contractor input. This limitation drove dialogue among the program team and had the effect of ensuring that the program team thought through every requirement to ensure its validity and necessity on the diagram. This deliberation process resulted in the consolidation of many lower-level requirements into one higher-level requirement, this helped the team understand the intent or reasoning for the lower-level requirements, some of which were not necessary and were only copied from previous RFIs because "that is what we always put in the RFIs."

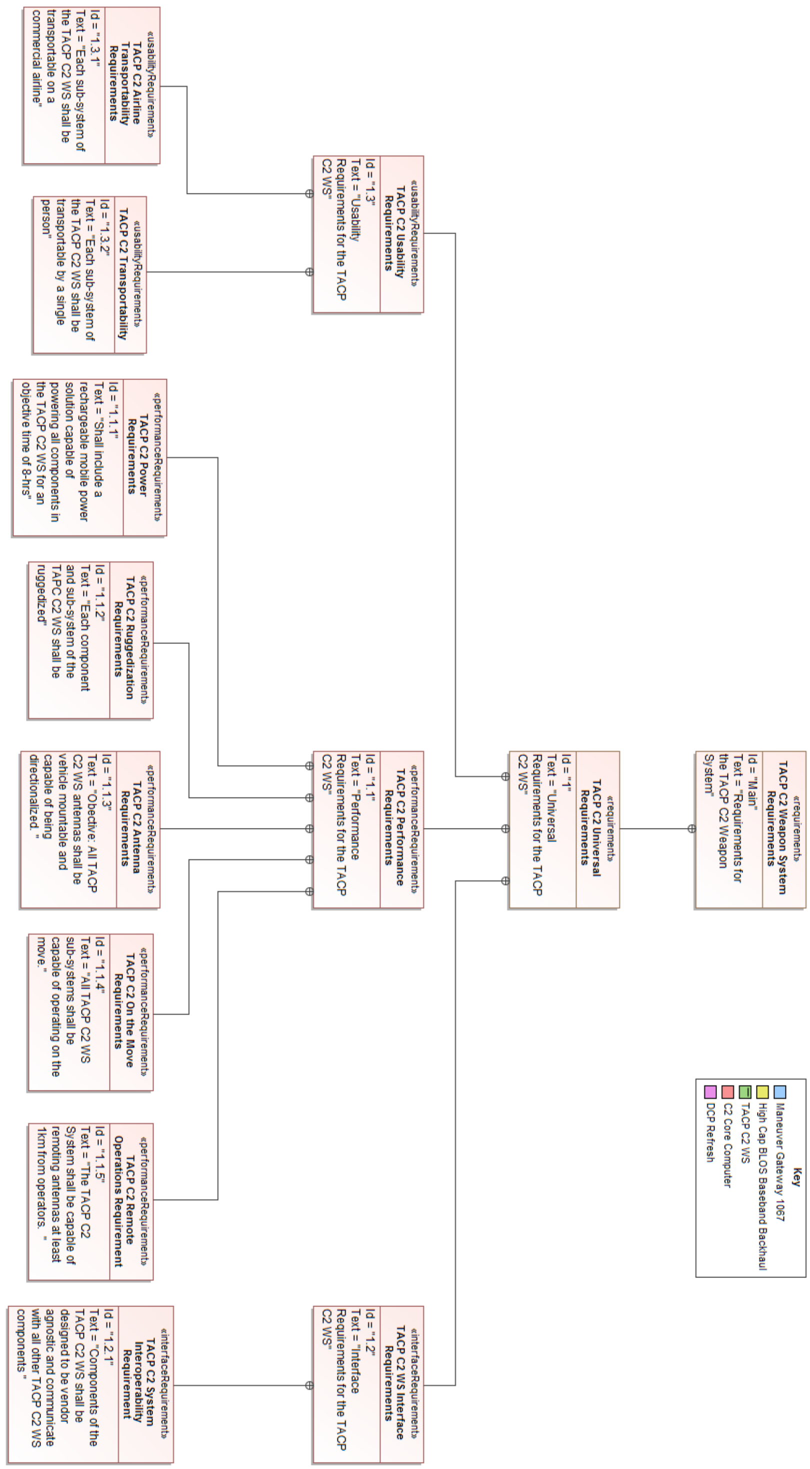


**Figure 2. Requirements Diagram - Universal Subsection**

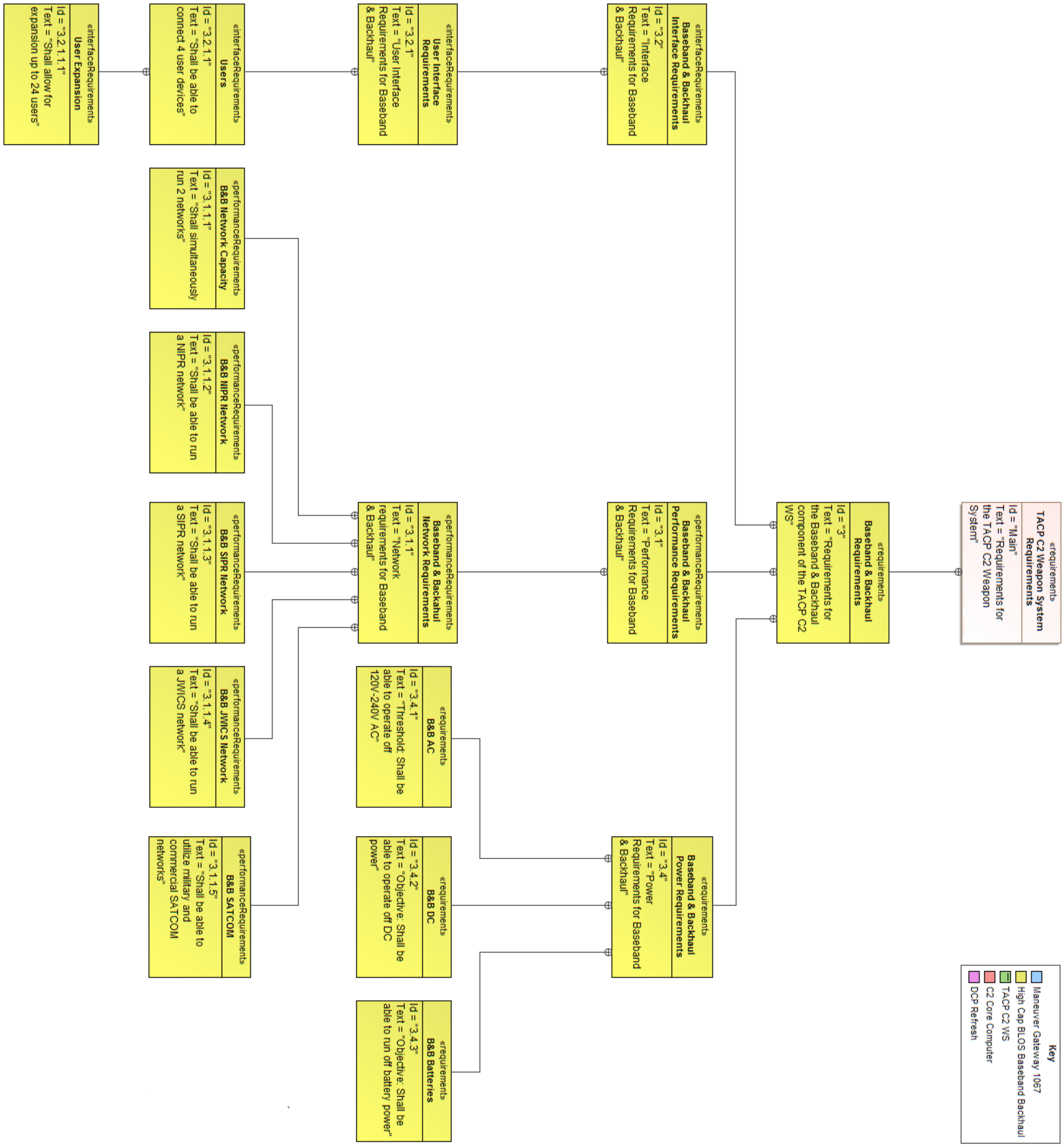


**Figure 3. Requirements Diagram - Baseband & Backhaul Subsection**

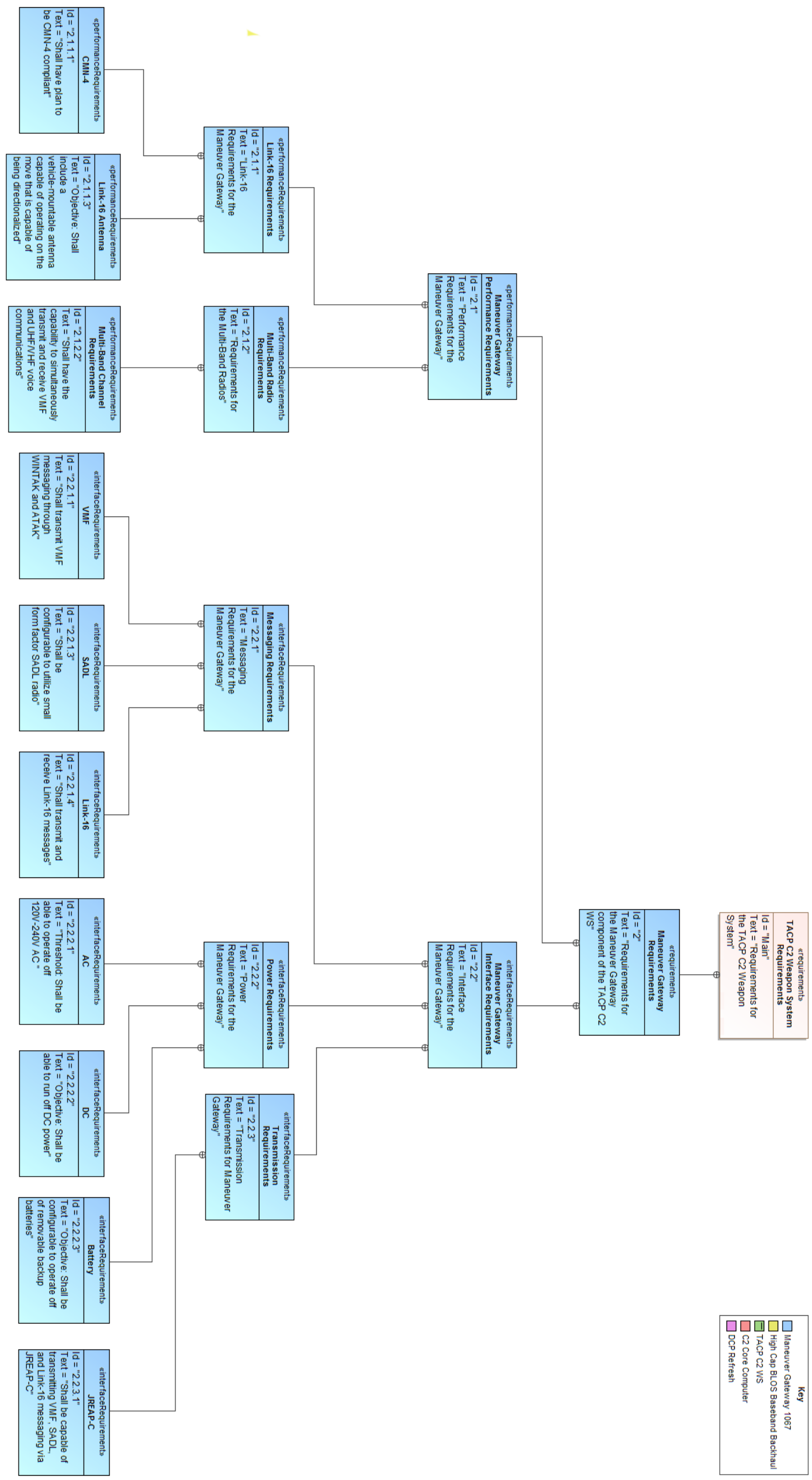


**Figure 4. Requirements Diagram - Maneuver Gateway Subsection**

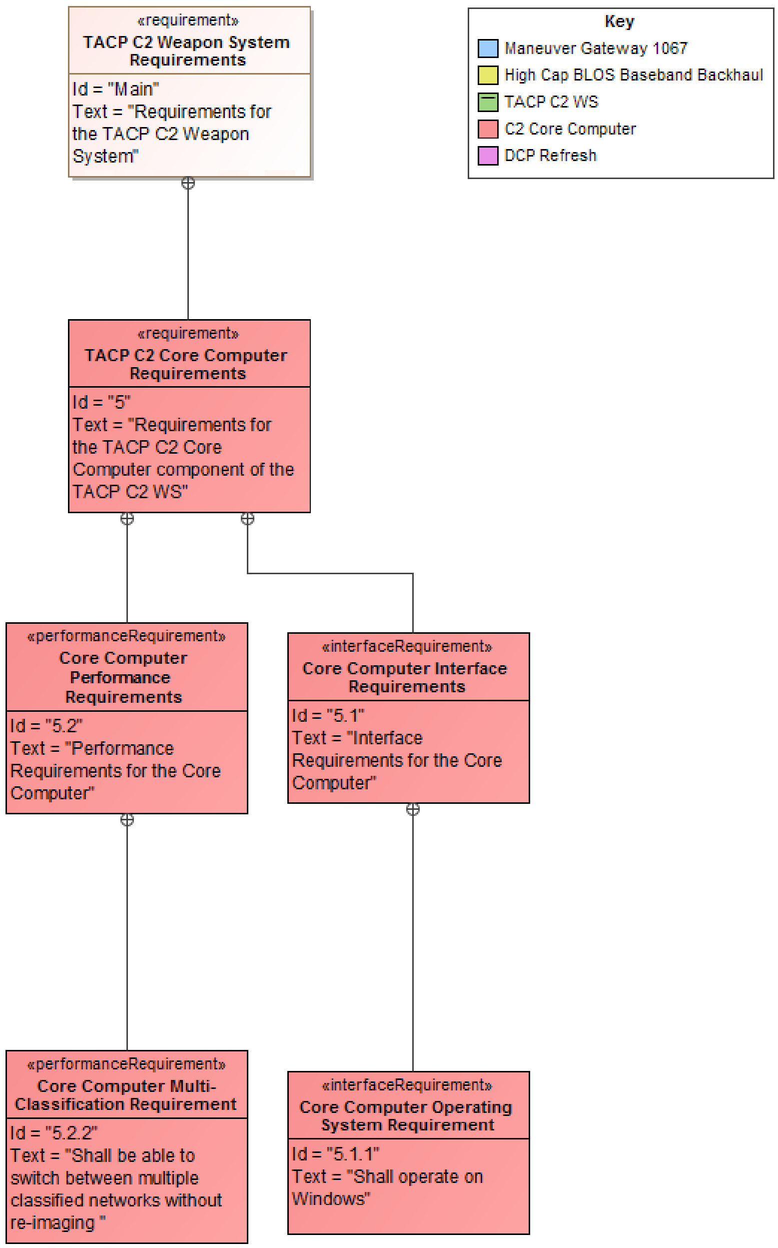


**Figure 5. Requirements Diagram - Core Computer Subsection**

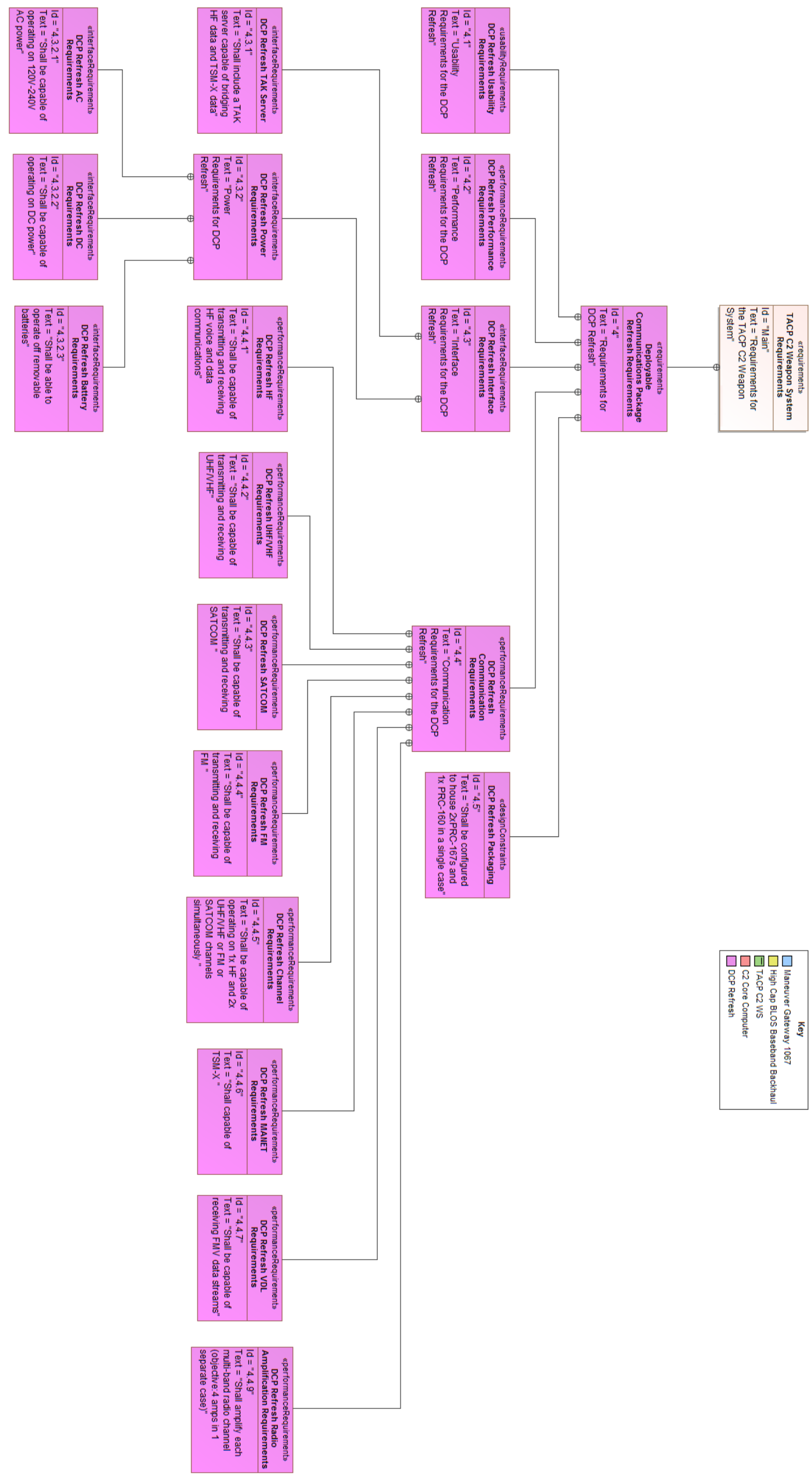


**Figure 6. Requirements Diagram - DCP Subsection**

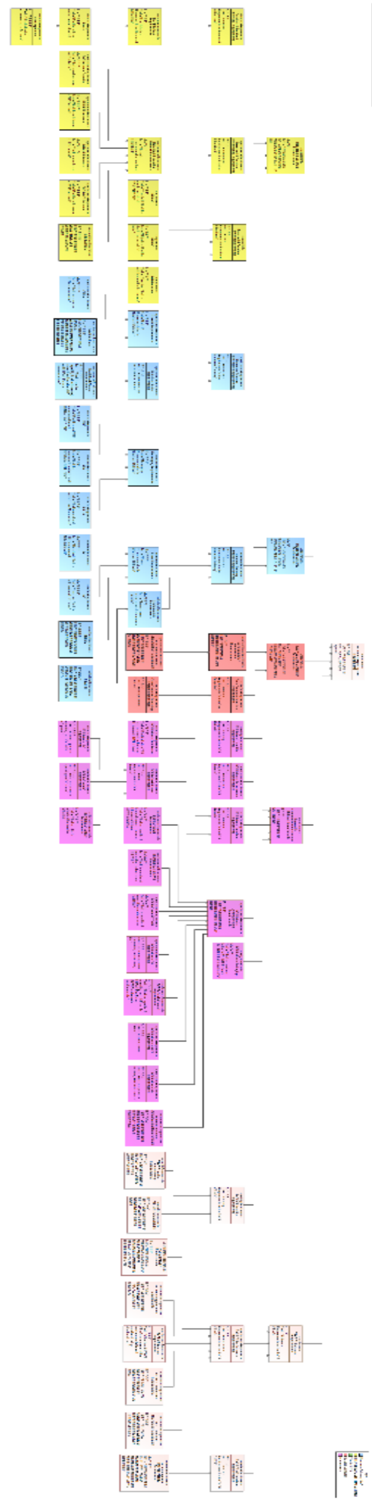

**Figure 7. TACP C2 WS Complete Requirements Diagram**

The second diagram generated for the model-based RFI was the “TACP C2 WS Use Case Diagram” (Figure 8). The use case diagram served to illustrate to potential RFI responders how the systems were intended to be used as well as clarify the intended uses of the systems with the end users. The diagram was again limited to 4 levels to only include the most important use cases. Generating the use case diagram forced the program office to go back to the personnel who generated the AF Form 1067 and clarify what they intended to do with the systems they were asking for. Since all parties were looking at the same diagram there was less room for misinterpretations.

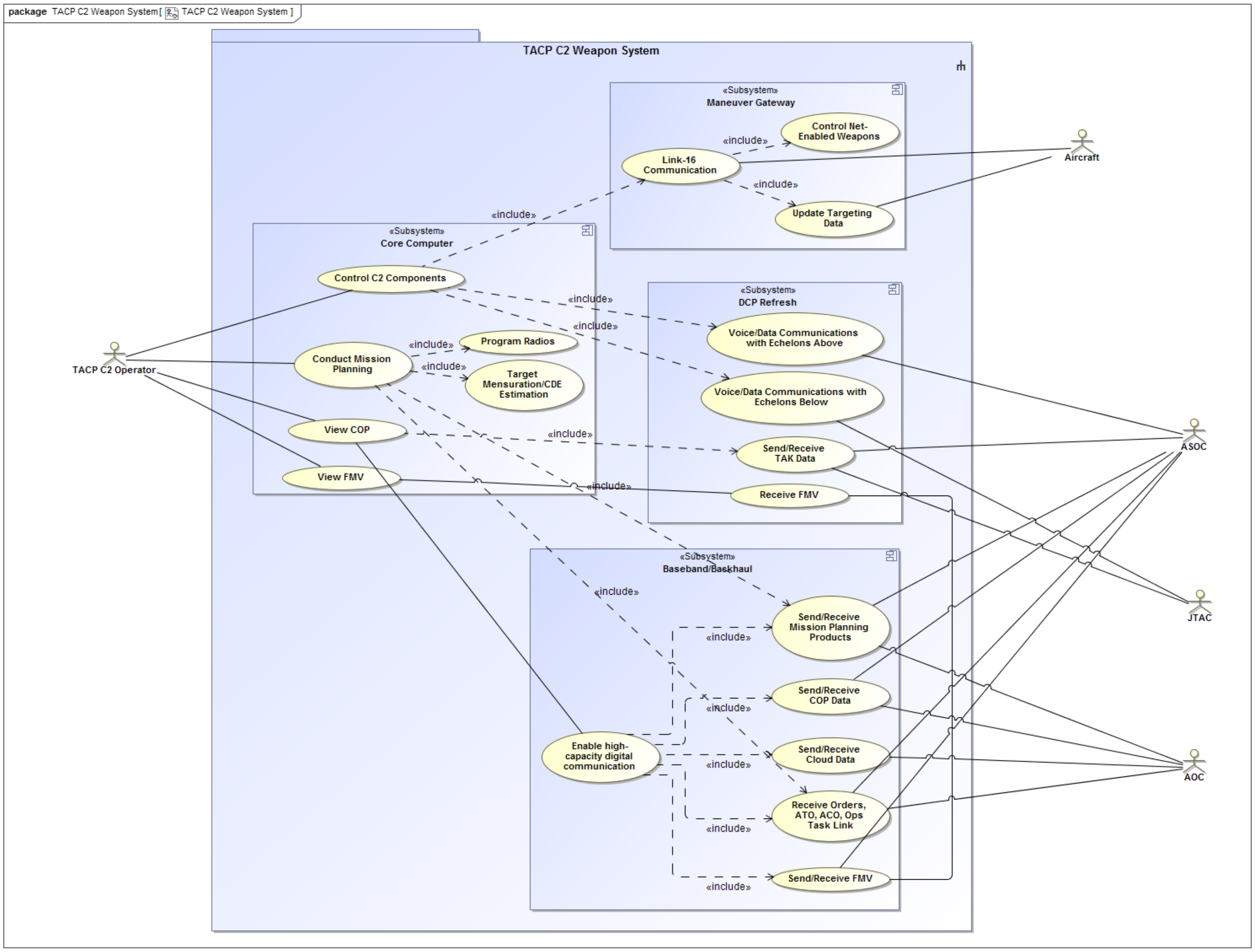


**Figure 8. TACP C2 WS Use Case Diagram**

The third, and final, diagram that was generated for the model-based RFI was a Block Definition Diagram entitled “TACP C2 WS System Context Diagram” (Figure 9). The context diagram illustrated what other systems the proposed solutions would need to interact or integrate with. The diagram is similar in content to a Department of Defense Architecture Framework System View 1 (SV-1) Diagram, Systems Interface Description. The diagram indicates the performers that the overall system is composed of (systems,

people) and the flows of resources (primarily information/data) between those performers. The diagram was only built to the level needed to identify other systems that would be directly affected by the proposed solutions. This system context diagram could be compared to a DoD Architecture Framework (DoDAF) systems interface description (SV-1) that depicts resource structures and interactions.

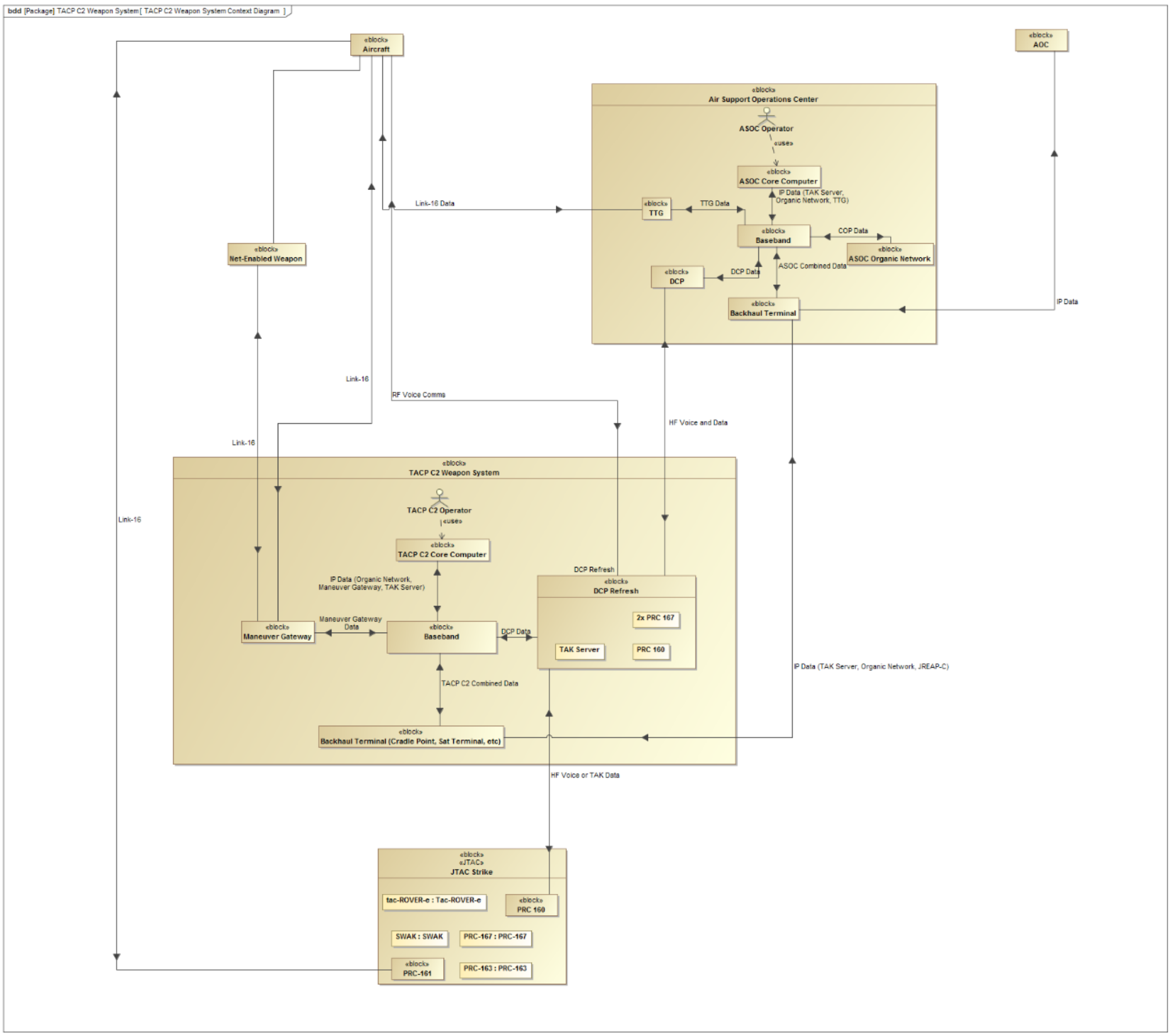


**Figure 9. TACP C2 WS System Context Diagram**

**Survey Design**

The survey was generated using 43 of the benefit categories identified in the SERC report in Table **1** to analyze the responses. Statements that were removed were:

1. Better Requirements Generation (Companies responding to the RFI weren't generating requirements)
2. Strengthened testing (Test was not involved with the RFI)
3. Higher level support for automation (Automation was not a factor due to the low level of MBSE implementation within the program office)
4. Better accessibility of info (The RFIs were the full responses, no additional data was accessible)
5. Better knowledge management/ capture (Since this statement was related to processes, it was deemed irrelevant to the RFI responses)

The questionnaire was completed by seven members of the program office's ASOC team as they reviewed the RFI responses. Each member of the team who was involved in the evaluation of responses had worked on ASOC related projects for over a year. Each member was familiar with the five specific AF Form 1067s related to the TACP C2 Weapon System, the requirements, and the current state of the TACP Weapon System. For each statement, participants were asked to rate their agreement on a 5-point Likert scale (3-Strongly Agree, 1- Agree, 0- Neutral, -1-Disagree, -3-Strongly Disagree). The numerical values used were picked simply for ease of converting the data into charts and graphs. Team members were also given the opportunity to add a free text response to each question as well as a free text response to the entire RFI response.

RFI responses were identified as either having responded to the model-based RFI or the document-based RFI, either "included a diagram in response" or "did not include a diagram in response," this included responses that reused the diagrams that were included in the model-based RFI. A second set of questions (Table 2) were used to analyze the quality of the product. Table **1**Table 2 identifies the Quality of Product Survey statements utilized to determine if a product was deemed useful to pursue.

**Table 2: Quality of Product Survey**

<table>
<tr><td rowspan="12">Quality of Product</td><td rowspan="3">Maneuver Gateway</td><td>Responded to this sub-section</td></tr>
<tr><td>Currently fieldable</td></tr>
<tr><td>Recommend use in WS</td></tr>
<tr><td rowspan="3">Baseband Backhaul</td><td>Responded to this sub-section</td></tr>
<tr><td>Currently fieldable</td></tr>
<tr><td>Recommend use in WS</td></tr>
<tr><td rowspan="3">Core Computer</td><td>Responded to this sub-section</td></tr>
<tr><td>Currently fieldable</td></tr>
<tr><td>Recommend use in WS</td></tr>
<tr><td rowspan="3">Deployable Communications Package</td><td>Responded to this sub-section</td></tr>
<tr><td>Currently fieldable</td></tr>
<tr><td>Recommend use in WS</td></tr>
</table>

The results of the survey were then analyzed to determine the impact MBSE had on the RFI responses.

### Validating Raters Reliability

The reliability of the raters was evaluated utilizing IBM SPSS Statistics software. Larger correlation between two variables (raters) would indicate reliability. One way to measure the correlation within a set of data is using the Cronbach Alpha value, which can be computed using SPSS. A Cronbach Alpha value of 0.7 or greater is generally considered reliable (Field 2009). A scale reliability test was performed to determine the

Cronbach Alpha value for the group of raters. This method would identify if the raters were grading consistently with respect to each other. A correlation matrix was also generated to identify how types of raters (engineer, acquisition support, officer, enlisted, and program manager) interpreted responses with respect to each other.

**Validating Questions and Subscales**

The individual questions as well as subscales (Quality, Velocity/Agility, User Experience, Knowledge Transfer) were also evaluated utilizing a scale-reliability test in IBM SPSS. This produced Cronbach Alpha values for each question and each subscale. This process identified if a specific question or subscale was not being answered reliably between the 7 raters. It also served to develop a rank structure for reliability of the questions and subscales.

**Analyzing the Survey**

The survey responses were gathered and analyzed to compare the model-based RFI results to the document-based RFI results. The median response value for each question was calculated as well as a percentage-based score for each subscale. Responses for the over-all model-based RFI and document-based RFI were analyzed (model-based and document-based RFI responses combined), as well as separate results for model-based and document-based responses (responses included a model or did not include a model). A ranking system was applied to rank the 4 categories of RFIs (model-based RFI with model-based response, model-based RFI with document-based response, document-based RFI with model-based response, and document-based RFI with document-based response). Additionally, principal component analysis was performed on the model-

based response questions to determine if the survey questions were aligning to the four subscales outlined by the SERC study. A new set of subscales was identified and reliability of the new and old subscales was compared utilizing the reliability data obtained from the question validation method. The results may help program offices narrow down focus areas as they generate RFIs in the future.

**Summary**

This chapter detailed how the methodology of the RFIs were developed, including examples of the diagrams that were used in the model-based RFIs. It also explained how the survey was developed, how rater, question, and subscale reliability would be validated, and how survey data would be analyzed. Chapter IV will explain the results of the study and show how the introduction of MBSE helped improve the RFI process for the program office.

# IV. Analysis and Results

## Chapter Overview

This chapter provides details on the data collected in the survey as well general observations that were noted throughout the process of the study. First, impacts observed by implementing MBSE software during the RFI generation process are discussed. Next, rater reliability, question subscale reliability, and individual question reliability are validated. Results from the document-based RFI responses and model-based RFI responses are then compared to identify how the implementation of MBSE impacted the RFI response quality. Finally, results from the principal component analysis are discussed with recommendations for possible updates to subscales.

## RFI Generation

The document-based RFI took less time to develop than the model-based RFI. The document-based RFI was developed in five business days, while the model-based RFI took ten business days to complete. The document-based RFI included 21 requirements compared to the model-based RFI's 44 requirements; the MBSE method of generating the RFI identified more than double the requirements compared to the document-based method. Eight (8) of the document-based RFI's requirements were identified during the development of the model-based RFI and introduced after the model-based RFI was complete.

The increased number of requirements can be attributed to the use of Cameo. The software has built in stereotypes for requirements, allowing for categories such as performance requirements and functional requirements. The presence of these

requirement stereotypes queued the team to account for each type of requirement in the list available in Cameo. Many of these were overlooked during the drafting of the document-based RFI.

### Rater Reliability

The raters had a high reliability with a Cronbach Alpha of 0.876. A Cronbach Alpha value of 0.7 is generally accepted as reliable (Field, 2009). Removal of a single rater did not have a significant impact and only raised the Cronbach Alpha to a maximum of 0.882. A correlation matrix comparing the types of responders is illustrated in Table 3. While the raters were reliable, the correlation matrix does imply a divergence between the enlisted subject matter expert's interpretation or rating of results and much of the team, especially with the officer subject matter expert.

**Table 3. Inter-Rater Correlation Matrix Comparing Types of Responders**

| Inter-Rater Correlation Matrix Comparing Types of Responders | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rater Type | Officer/SME/Engineer | Engineer | Engineer | Acquisition Support | Program Manager | Program Manager | Enlisted/SME |
| Officer/SME/Engineer | 1 | 0.563 | 0.563 | 0.594 | 0.57 | 0.622 | 0.392 |
| Engineer | 0.563 | 1 | 0.466 | 0.449 | 0.729 | 0.637 | 0.427 |
| Engineer | 0.563 | 0.466 | 1 | 0.696 | 0.687 | 0.668 | 0.47 |
| Acquisition Support | 0.594 | 0.449 | 0.696 | 1 | 0.596 | 0.612 | 0.458 |
| Program Manager | 0.57 | 0.729 | 0.687 | 0.596 | 1 | 0.81 | 0.454 |
| Program Manager | 0.622 | 0.637 | 0.668 | 0.612 | 0.81 | 1 | 0.503 |
| Enlisted/SME | 0.392 | 0.427 | 0.47 | 0.458 | 0.454 | 0.503 | 1 |

### Subscales and Questions Reliability

The subscales of Quality, Velocity/Agility, User Experience, and Knowledge Transfer had high reliability. Each subscale's Cronbach Alpha is illustrated in Table 4.

**Table 4. Subscale Reliability Statistics**

| Subscale Reliabilty | | | | |
|---|---|---|---|---|
| | Quality | Velocity/Agility | User Experience | Knowledge Transfer |
| **Cronbach Alpha** | 0.96 | 0.98 | 0.958 | 0.916 |

Further analysis of each question's reliability show that all questions were reliable with a lowest Cronbach Alpha value of .759 for the question regarding "Early V&V" and a maximum Cronbach Alpha value of .930 for the question regarding "Improved deliverable quality". Table 5 lists each question's Cronbach Alpha, color codes them all from most reliable (Green) to least reliable (Red), and ranks the subscales based off their average question reliability. While the highest Cronbach Alpha values are of questions within the "Quality" subscale, reliability does not appear to cluster in any one specific subscale.

**Table 5. SERC Subscales w/ Question Reliability (Ranked)**

| SERC Subscales w/ Question Reliability (Ranked) | | | | |
|---|---|---|---|---|
| Subscale | Q# | Question | Cronbach Alpha | Ranked Reliability |
| Quality | Q01 | Improve system quality | 0.879 | 3 |
| | Q02 | Increased rigor | 0.916 | |
| | Q03 | Increased traceability | 0.869 | |
| | Q04 | Reduce errors | 0.857 | |
| | Q05 | Reduce cost | 0.807 | |
| | Q06 | Reduce risk | 0.798 | |
| | Q07 | Improved risk analysis | 0.807 | |
| | Q08 | Improved system design | 0.889 | |
| | Q09 | Increased effectiveness | 0.92 | |
| | Q10 | Improved deliverable quality | 0.93 | |
| | Q11 | Increased accuracy of estimates | 0.903 | |
| | Q12 | Improved predictive ability | 0.799 | |
| | Q13 | Better analysis capability | 0.892 | |
| | Q14 | Improved capability | 0.866 | |
| | Q15 | More stakeholder involvement | 0.911 | |
| Velocity/ Agility | Q16 | Reduce time | 0.869 | 4 |
| | Q17 | Improved consistency | 0.91 | |
| | Q18 | Increased capacity for reuse | 0.883 | |
| | Q19 | Easy to make changes | 0.863 | |
| | Q20 | Reduce rework | 0.89 | |
| | Q21 | Reduce waste | 0.866 | |
| | Q22 | Increased productivity | 0.888 | |
| | Q23 | Increased efficiency | 0.863 | |
| | Q24 | Increased transparency | 0.871 | |
| | Q25 | Increased confidence | 0.849 | |
| | Q26 | Increased flexibility | 0.853 | |
| | Q27 | Better requirements management | 0.872 | |
| | Q28 | Ease of design customization | 0.872 | |
| | Q29 | Higher level of support for integration | 0.856 | |
| | Q30 | Increased uniformity | 0.891 | |
| | Q31 | Increased precision | 0.87 | |
| | Q32 | Early V&V | 0.759 | |
| | Q33 | Reduce ambiguity | 0.864 | |
| User Experience | Q34 | Reduce burden of SE tasks | 0.895 | 2 |
| | Q35 | Better manage complexity | 0.85 | |
| | Q36 | Improved system understanding | 0.864 | |
| | Q37 | Reduce effort | 0.884 | |
| | Q38 | Better data management/ capture | 0.914 | |
| | Q39 | Better decision making | 0.892 | |
| Knowledge Transfer | Q40 | Improved architecture | 0.892 | 1 |
| | Q41 | Multiple viewpoints of model | 0.9 | |
| | Q42 | Better communication/ info sharing | 0.879 | |
| | Q43 | Improved collaboration | 0.911 | |

| Score Rank |
|---|
| Low -> High |

## Survey Response

The median response of each question, categorized by RFI and response type, is illustrated in Figure **10**. First, responses to "Reduce Cost" and "Early V&V" stand out due to their median response of 0 or "neutral" for all types of RFIs and responses. The

results for “Reduce Cost” may be attributed to a perceived lack of relevance from the raters. The RFIs did not include a request for quote and therefore impact on cost was difficult to determine. “Early V&V”, or verification and validation, may be justified because no further testing of the proposals had been conducted at the time of the survey and nobody would be able to validate or verify if a proposal indeed worked.

The model-based RFI and model-based responses scored better than the document-based response in just about every question; it is easier to identify questions where the model-based RFI was lower than its average response. Two areas that stand out are risk and cost. “Reduce Errors,” “Improved Risk Analysis,” and “Improved Predicative Ability” are all scored lower than their respective RFI’s other questions. “Reduce Cost” and “Increased Accuracy of Estimates” scored lower than their respective RFI’s other questions as well.


**Figure 10. Median RFI Question Response**

An unexpected outcome was response rate. The model-based RFI received twice as many responses and had a 64% increased rate of receiving a model-based response (Table **6**). A model-based RFI response was, on average, 21% more likely to be followed-up or pursued by the program office (Table **7**). Increasing the number of responses is seen as favorable, it provides the government more options to consider in meeting its needs. Further experiments with model-based RFIs could reveal if the use of model-based RFIs increases industry response rates.

**Table 6. RFI Response Comparison**

| RFI Response Comparison | | | |
|---|---|---|---|
| RFI | Total Responses | Model-Based Response | Percent Model-Based |
| Document-based RFI | 7 | 1 | 14% |
| Model-based RFI | 14 | 11 | 79% |

**Table 7. RFI Response Follow-Up Comparison**

| RFI Response Follow-up Comparison | | | | | | |
|---|---|---|---|---|---|---|
| | Model-based RFI | Document-based RFI | Model-based RFI w/ Model-based Response | Model-based RFI w/ Document-based Response | Document-based RFI w/ model-based response | Document-based RFI w/ Document-based Response |
| Responded to Category | 186 | 71 | 153 | 33 | 25 | 46 |
| Recommend Follow-up | 85 | 28 | 73 | 12 | 17 | 11 |
| Pursuit Rate | 46% | 39% | 48% | 36% | 68% | 24% |

Model-based responses were scored higher across each subscale than the document-based responses. The subscale with the largest improvement was "User Experience" with an improvement of 42% when comparing the rate of positive results (highly agree and agree). The subscale with the least improvement was "Quality" with an improvement of 31% (Table 8). Overall, responses for the model-based RFI were, on

average, 38% better than the document-based response based off a comparison of positive answers.

**Table 8. Positive RFI Response Comparison**

| Positive RFI Response Comparison | | | |
|---|---|---|---|
| Subscale | Model-based RFI Positive Response Average | Document-based RFI Positive Response Average | Delta |
| Quality | 53% | 22% | 31% |
| Velocity/Agility | 56% | 19% | 38% |
| User Experience | 60% | 19% | 42% |
| Knowledge Transfer | 58% | 18% | 40% |
| Total | 57% | 19% | 38% |

A complete comparison of each type of RFI response is illustrated in Table 9. In each category, the model-based response had a higher rate of positive responses compared to the document-based response. Model-based responses to the model-based RFI scored better than any other category.

**Table 9. Complete RFI Response Survey Results Comparison**

| RFI Response Survey Results Comparison | | | | | | |
|---|---|---|---|---|---|---|
| | Model-based RFI | Document-based RFI | Model-based RFI w/ Model-based Response | Model-based RFI w/ Document-based Response | Document-based RFI w/ model-based response | Document-based RFI w/ Document-based Response |
| Response | Percent | Percent | Percent | Percent | Percent | Percent |
| Positive | 57% | 19% | 63% | 32% | 52% | 14% |
| Neutral | 35% | 29% | 33% | 42% | 45% | 26% |
| Negative | 8% | 52% | 3% | 26% | 4% | 60% |

Figure 11 through Figure 15 illustrate the response rating for each type of RFI based on the subscales of Quality, Velocity/Agility, User Experience, and Knowledge Transfer. Through visual examination we can conclude that the model-based RFI had significantly better responses than the document-based RFI across all categories. We can

also conclude that model-based responses were rated significantly higher than their document-based counterparts.

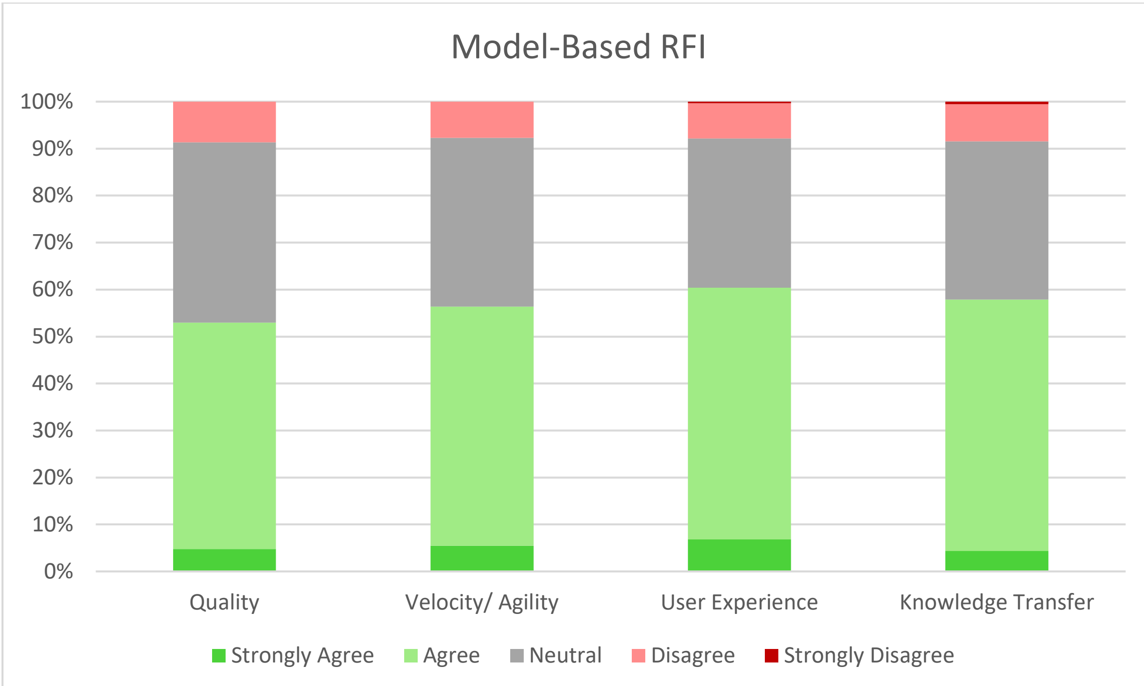


**Figure 11. Model-Based RFI Response Summary**

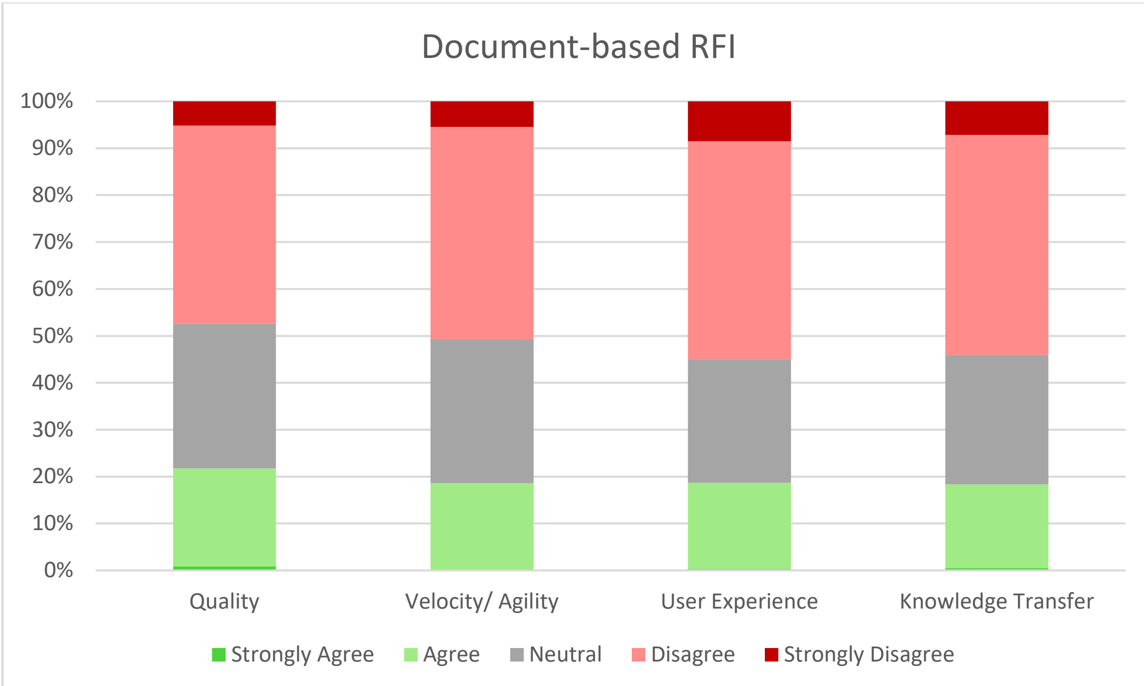


**Figure 12. Document-based RFI Response Summary**

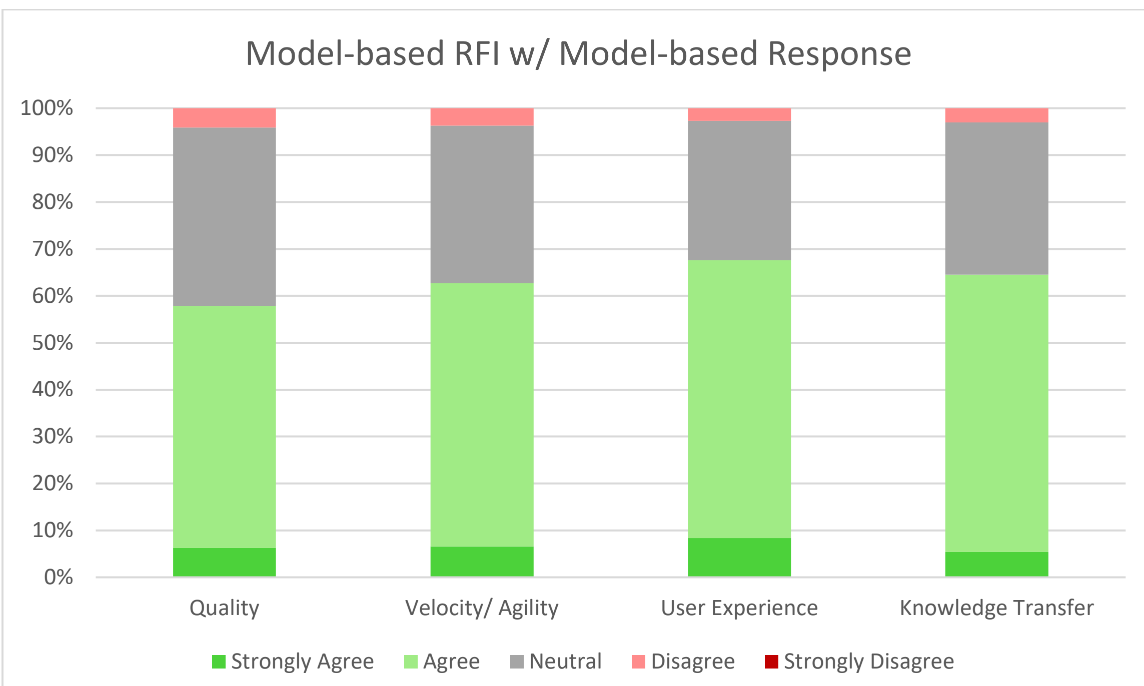


**Figure 13. Model-based RFI w/ Model-based Response Summary**

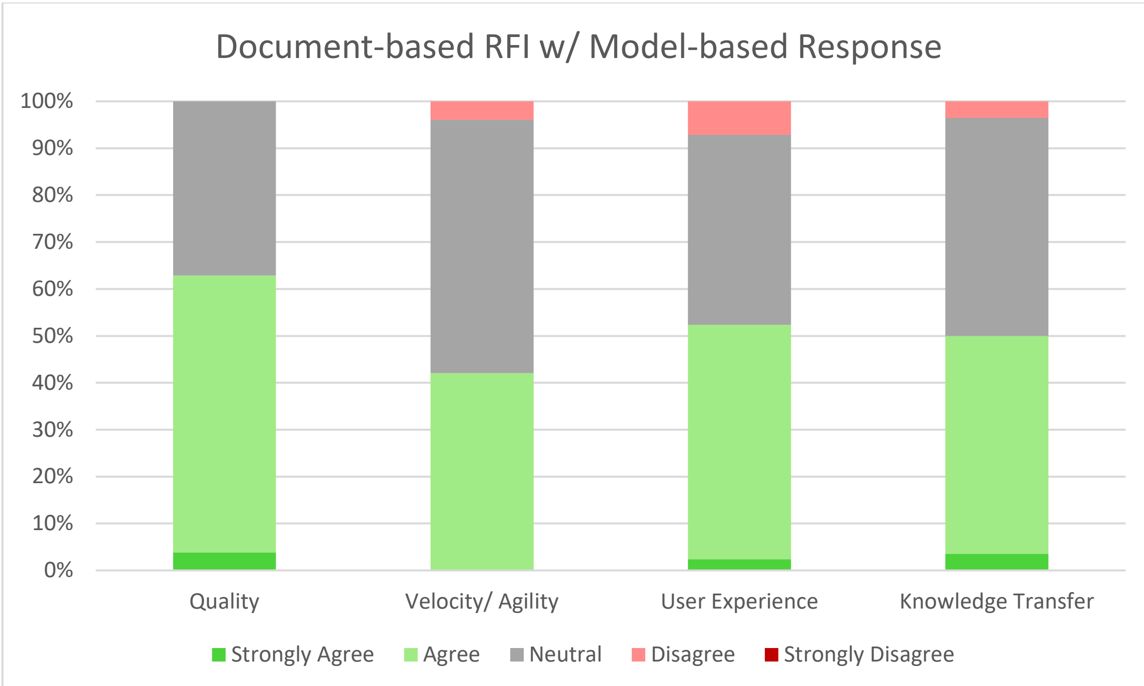


**Figure 14. Document-based RFI w/ Model-based Response Summary**

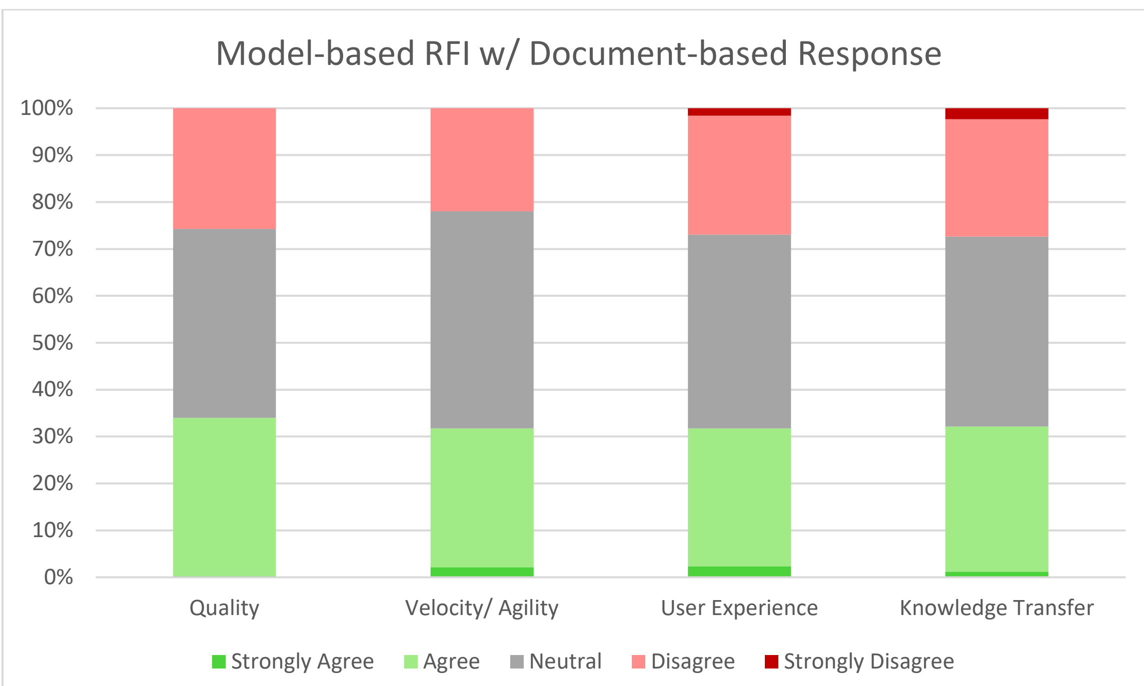


**Figure 15. Model-based RFI w/ Document-based Response Summary**

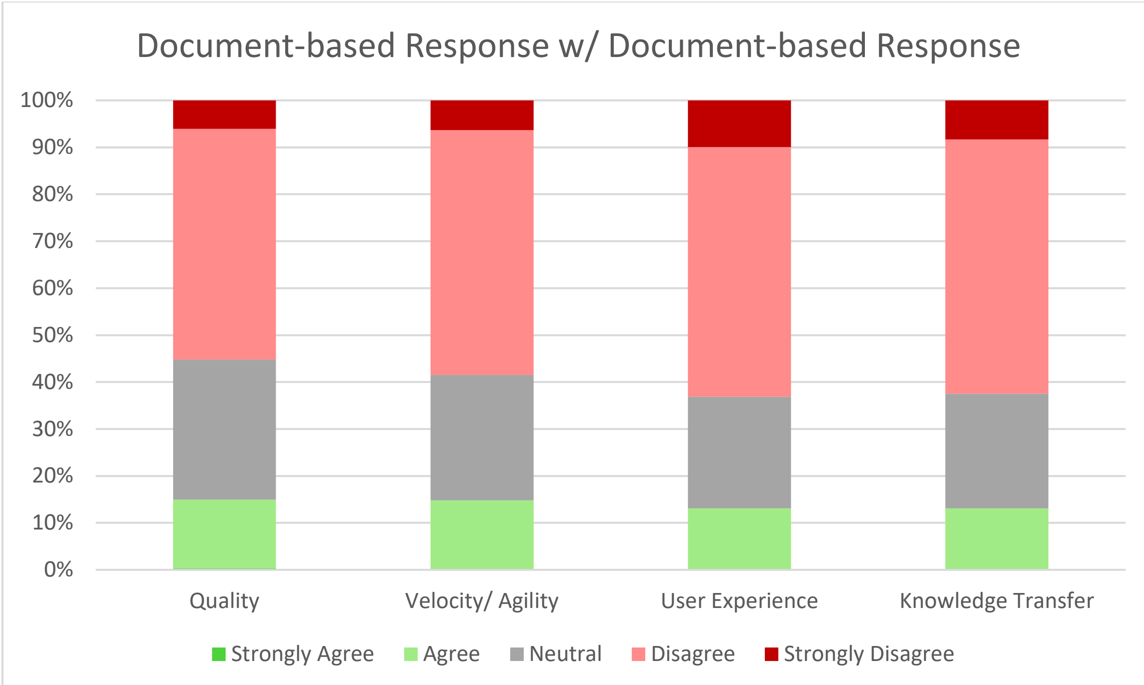


**Figure 11. Document-based RFI w/ Document-based Response Summary**

A rank structure was applied to the type of RFI and its respective response type (Table 10). What is interesting here is that a model-based response to a document-based RFI was still received better than a document-based response to a model-based RFI. From this chart we can infer that model-based responses are superior to document-based responses and that model-based RFIs will elicit a higher rate of model-based responses.

**Table 10. RFI and Response Rank Structure**

| | | | |
|---|---|---|---|
| Model Based Request | Yes | 3 | 1 |
| | No | 4 | 2 |
| | | No | Yes |
| | | Model Based Response | |

**Principal Component Analysis**

The rotated component matrix for the survey based on the responses from the model-based RFI is illustrated in Table 11. Responses from the document-based RFI were not included in this analysis because those were deemed as not measuring the effect of MBSE as they were not responding to an RFI that was influenced by the introduction of MBSE. Principal component coefficients were highlighted in blue, secondary principal components (if a question had them) were highlighted in red. Notional component subscales are also listed in Table 11. These were developed based on personal interpretations of question groupings according to their principal component.

## Table 11. Survey Rotated Component Matrix

| | Rotated Component Matrixa | | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|---|
| | Question | Component | 1 | 2 | 3 | 4 | 5 | 6 |
| **Quality** | Q01 | Improve system quality | 0.657 | | | | | |
| | Q02 | Increased rigor | | | 0.457 | | | |
| | Q03 | Increased traceability | 0.577 | | | | 0.436 | |
| | Q04 | Reduce errors | | | | 0.486 | | |
| | Q05 | Reduce cost | | | | | | 0.814 |
| | Q06 | Reduce risk | | 0.808 | | | | |
| | Q07 | Improved risk analysis | | 0.748 | | | | |
| | Q08 | Improved system design | 0.571 | 0.531 | | | | |
| | Q09 | Increased effectiveness | 0.471 | | | | 0.528 | |
| | Q10 | Improved deliverable quality | 0.447 | | 0.518 | | 0.478 | |
| | Q11 | Increased accuracy of estimates | | 0.461 | | | 0.511 | |
| | Q12 | Improved predictive ability | 0.531 | 0.612 | | | | |
| | Q13 | Better analysis capability | 0.672 | 0.44 | | | | |
| | Q14 | Improved capability | 0.612 | 0.454 | | | | |
| | Q15 | More stakeholder involvement | | | 0.759 | | | |
| **Velocity/ Agility** | Q16 | Reduce time | 0.443 | | | | 0.673 | |
| | Q17 | Improved consistency | 0.541 | | | | | |
| | Q18 | Increased capacity for reuse | 0.434 | | | | | |
| | Q19 | Easy to make changes | | | | 0.772 | | |
| | Q20 | Reduce rework | | | | 0.782 | | |
| | Q21 | Reduce waste | | | | 0.663 | | |
| | Q22 | Increased productivity | | | 0.557 | | | |
| | Q23 | Increased efficiency | 0.636 | | 0.445 | | | |
| | Q24 | Increased transparency | 0.758 | | | | | |
| | Q25 | Increased confidence | 0.508 | | 0.443 | | | |
| | Q26 | Increased flexibility | | | 0.711 | 0.463 | | |
| | Q27 | Better requirements management | | 0.442 | | | 0.577 | |
| | Q28 | Ease of design customization | | 0.456 | 0.604 | | | |
| | Q29 | Higher level of support for integration | 0.557 | | 0.45 | | | |
| | Q30 | Increased uniformity | 0.513 | | | 0.486 | | |
| | Q31 | Increased precision | 0.634 | 0.447 | | | | |
| | Q32 | Early V&V | 0.493 | 0.646 | | | | |
| | Q33 | Reduce ambiguity | | 0.516 | | | | |
| **User Experience** | Q34 | Reduce burden of SE tasks | 0.592 | 0.438 | | | | |
| | Q35 | Better manage complexity | 0.67 | | | | | |
| | Q36 | Improved system understanding | 0.768 | | | | | |
| | Q37 | Reduce effort | 0.488 | | | 0.476 | | |
| | Q38 | Better data management/ capture | 0.644 | | | | | |
| | Q39 | Better decision making | 0.778 | | | | | |
| **Knowledge Transfer** | Q40 | Improved architecture | 0.654 | | | | | |
| | Q41 | Multiple viewpoints of model | | | | 0.471 | 0.437 | |
| | Q42 | Better communication/ info sharing | 0.858 | | | | | |
| | Q43 | Improved collaboration | | | 0.615 | | 0.481 | |

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

Primary Secondary

Notional constructs/principle components
A- Clarity in communcations
B - Early risk reduction through system awareness and ability to analyze
C - Customer involvement and engagement, ability to customize capabilities to meet specific needs
D - Improved program direction - schedule compliance and requirement management
E - Ease in change and reduced error in development
F - Costs

Table 12 is an update to Table 5 and shows survey questions grouped by their newly proposed subscale, individual question reliability, and subscale rank based off the average reliability of its questions. We can see the low (red) scores clustering around the risk subscale, these are the same questions that were identified through the median of the

individual questions in Figure 10. This would imply that the least reliable area to measure the impact MBSE is having on the RFI process surrounds the issue of risk reduction and management. There is also a clear clustering of high scores in the “Customer Involvement and Engagement” subscale. This would imply the most reliable area to measure the impact of MBSE is having in the RFI process surrounds the issue of customer involvement.

**Table 12. Proposed Updates to Subscales**

| Proposed New Subscales w/ Question Reliability | | | | |
|---|---|---|---|---|
| **Subscale** | **Q#** | **Question** | **Cronbach Alpha** | **Ranked Reliability** |
| Clarity in communcations | Q01 | Improve system quality | 0.879 | 3 |
| | Q03 | Increased traceability | 0.869 | |
| | Q08 | Improved system design | 0.889 | |
| | Q13 | Better analysis capability | 0.892 | |
| | Q14 | Improved capability | 0.866 | |
| | Q17 | Improved consistency | 0.91 | |
| | Q18 | Increased capacity for reuse | 0.883 | |
| | Q23 | Increased efficiency | 0.863 | |
| | Q24 | Increased transparency | 0.871 | |
| | Q25 | Increased confidence | 0.849 | |
| | Q29 | Higher level of support for integration | 0.856 | |
| | Q30 | Increased uniformity | 0.891 | |
| | Q31 | Increased precision | 0.87 | |
| | Q34 | Reduce burden of SE tasks | 0.895 | |
| | Q35 | Better manage complexity | 0.85 | |
| | Q36 | Improved system understanding | 0.864 | |
| | Q37 | Reduce effort | 0.884 | |
| | Q38 | Better data management/ capture | 0.914 | |
| | Q39 | Better decision making | 0.892 | |
| | Q40 | Improved architecture | 0.892 | |
| | Q42 | Better communication/ info sharing | 0.879 | |
| Early risk reduction through system awareness and ability to analyze | Q06 | Reduce risk | 0.798 | 6 |
| | Q07 | Improved risk analysis | 0.807 | |
| | Q12 | Improved predictive ability | 0.799 | |
| | Q32 | Early V&V | 0.759 | |
| | Q33 | Reduce ambiguity | 0.864 | |
| Customer involvement and engagement, ability to customize capabilities to meet specific needs | Q02 | Increased rigor | 0.916 | 1 |
| | Q10 | Improved deliverable quality | 0.93 | |
| | Q15 | More stakeholder involvement | 0.911 | |
| | Q22 | Increased productivity | 0.888 | |
| | Q26 | Increased flexibility | 0.853 | |
| | Q28 | Ease of design customization | 0.872 | |
| | Q43 | Improved collaboration | 0.911 | |
| Improved program direction - schedule compliance and requirement management | Q04 | Reduce errors | 0.857 | 4 |
| | Q19 | Easy to make changes | 0.863 | |
| | Q20 | Reduce rework | 0.89 | |
| | Q21 | Reduce waste | 0.866 | |
| | Q41 | Multiple viewpoints of model | 0.9 | |
| Ease in change and reduced error in development | Q09 | Increased effectiveness | 0.92 | 2 |
| | Q11 | Increased accuracy of estimates | 0.903 | |
| | Q16 | Reduce time | 0.869 | |
| | Q27 | Better requirements management | 0.872 | |
| Cost | Q05 | Reduce cost | 0.807 | 5 |

Score Rank
Low -> High

Figure 16 shows the question composition of the proposed subscales based with question size based off the principal component coefficient.   This may be used in future research to reduce the survey to questions that have the most impact on determining the score of a specific subscale.  43 questions for a multitude of RFIs can be very time consuming and participation may possibly be expanded if the survey is not as long.

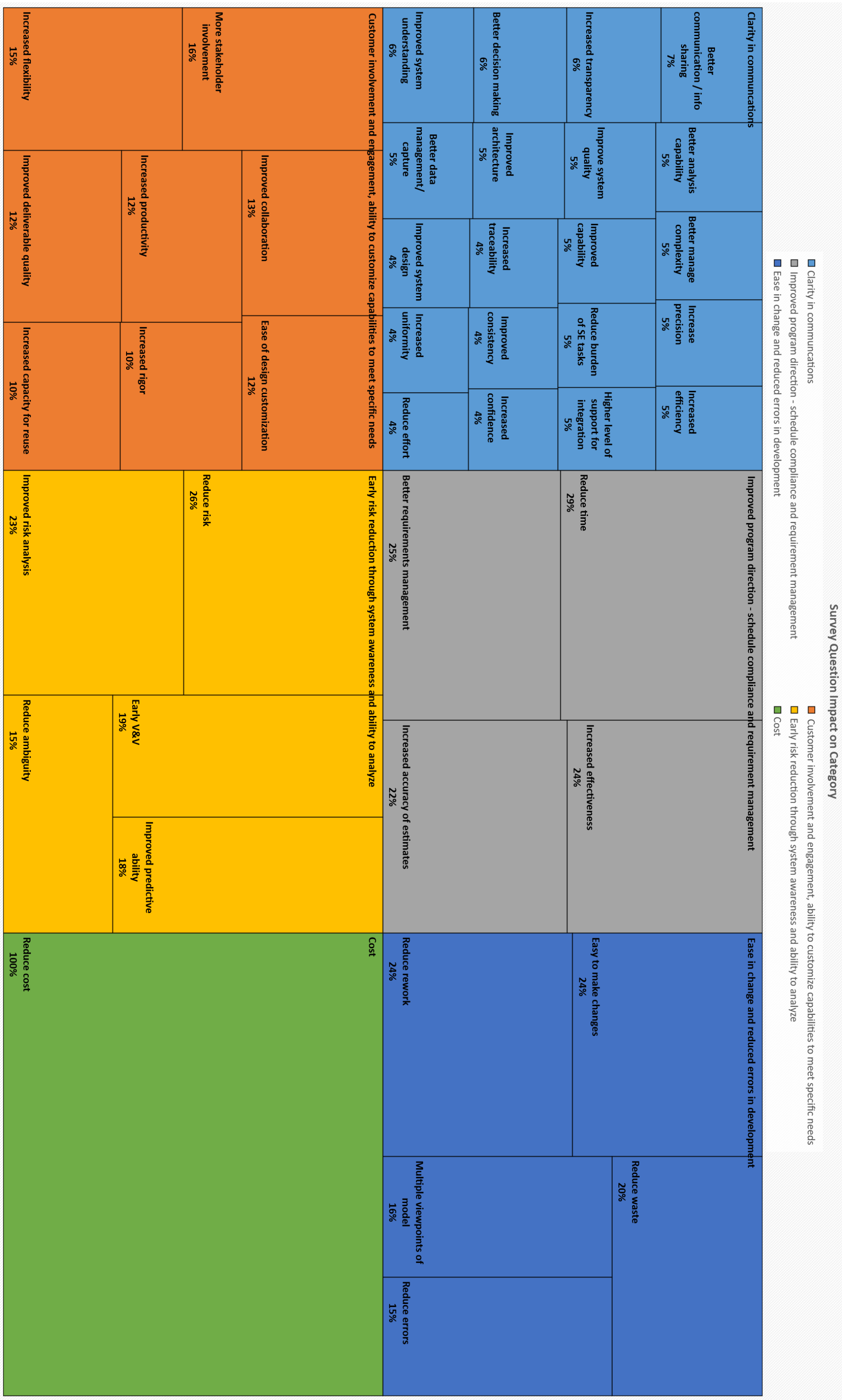


**Figure 16. Updated Subscale Composition Map**

## Summary

This chapter provided validation on the reliability for the raters, questions, and subscales. While the model-based RFI took twice as long to build as the document-based RFI it identified 48% more requirements. Further, it drove a revision/improvement of the document based RFI.

Analysis of the survey responses identified that:

1. Model-based RFIs elicit a higher rate of model-based responses.
2. Model-based responses were scored significantly higher than document-based responses in all regards, especially in the areas of User Experience.
3. The least reliable subjects measured were focused on risk and cost.
4. The most reliable subject measured was focused on user experience/customer involvement.

# V. Conclusions and Recommendations

## Significance of Research

The DoD, and specifically the United States Air Force, needs to progress the transition to digital engineering. Historically, there has been a lack of motivating factors for program offices to make the switch as well as a lack in guides on how to make the switch. This research identifies one available path to get a program office training (AFIT) and software (NSERC) to accomplish this first step in the transition to digital engineering. This research identifies two areas (requests for information and requirements generation/management) where a program office can see an immediate benefit to implementing MBSE. It gives examples of 3 diagrams (Requirements Diagram (Figure **7**), the Use Case Diagram (Figure **8**), and the System Context Diagram (Figure **9**)) used to improve RFI generation and in-turn improve the requirements generation process. The process used to generate the model-based-RFI also helped identify more than double the requirements that were initially missed by the document-based RFI generation process. Model-based RFIs saw a significant improvement in responses compared to document-based RFIs covering the same requirements.

A method to measure the impact MBSE has on an acquisition process or a program office is also identified. Those measurements were further analyzed to identify that the areas of risk and cost may be the least reliable areas to measure while the areas of knowledge transfer and user engagement/customer involvement were the most reliable with respect to RFIs.

**Research Objectives Met**

The research objectives outlined in Chapter I that were met through this research were:

1. Identify strengths associated with a program office's transition to digital engineering with respect to the Request For Information (RFI) processes.
2. Identify limitations associated with a program office's transition to digital engineering with respect to the RFI processes.
3. Identify and validate a set of measures that can be utilized to gauge the effectiveness of MBSE on day-to-day processes that are currently used within a program office.

Strengths associated with the program office's transition to digital engineering with respect to the RFI process are:

1. More than doubled captured requirements.
2. Doubled the RFI responses compared to traditional document-based RFI.
3. 64% increase in model-based RFI responses
4. Improved RFI response quality across the categories of Quality, Velocity/Agility, User Engagement, and Knowledge Transfer.
5. A 21% increase in likelihood of receiving a response worth pursuing.

Limitations associated with the program offices transition to digital engineering with respect to the RFI process are:

1. Increased training required to use software
2. Increased overhead (cost of software)

3. Longer timeframe to develop model-based RFI compared to the traditional document-based RFI.
4. Areas of risk and cost may have the least reliability when trying to measure the impact of MBSE on the RFI process.

The survey validated SERC's benefit categories as a set of measures for gauging the impact MBSE may have on a process within a program office. The original subscales of Quality, Velocity/Agility, User Engagement, and Knowledge Transfer were also validated as reliable. Additional subscales were identified through principal factor analysis and suggestions for an improved survey were also listed.

**Study Limitations**

This study was conducted on a relatively small (ACAT III) program office. The users who generated the document-based RFI also developed the model-based RFI and corrected the document-based RFI after identifying missing requirements through the MBSE process. RFIs covered in this study were listed at the same time covering the same requirements, companies could have used data from one RFI to answer the other.

**Recommendations for Action**

At a minimum, developers should strive to include requirements diagrams, use case diagrams, and system context diagrams in their RFIs and should request model-based responses. A new standard for model-based RFIs should be developed as a guide for program offices to follow.

## Recommendations for Future Research

The study should be reconducted at a larger program office, preferably with more experience in MBSE. Suggested updates to the subscales are recommended as well as the reduction in questions. Ideally two separate teams would draft their own RFIs and not one team drafting both as this influenced the requirements of the document-based RFI. Additionally, this survey and study should be conducted on other processes comparable to the RFI process. One example could be conducting this on the Request for Quote (RFQ)or Request for Proposal (RFP) process.

## Summary

This research identified the benefits MBSE had on the process of generating requirements and an RFI. Responses to the model-based RFIs were greatly improved when compared to the document-based alternative. Model-based responses to RFIs are also increased by including models in the response. A program office can do a little more work to see extensive benefits that could save time and money on the back end. A way to measure how MBSE is impacting a process has also been identified which will allow for further studies which in turn can help motivate program offices to pursue the transition to digital engineering.

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