DISSERTATION

AN ENTERPRISE SYSTEM ENGINEERING ANALYSIS OF KC-46A MAINTENANCE PROGRAM DECISION-MAKING

Submitted by

Kyle E. Blond

Department of Systems Engineering

In partial fulfillment of the requirements

For the Degree of Doctor of Engineering

Colorado State University

Fort Collins, Colorado

Summer 2023

Doctoral Committee:

Advisor: Thomas Bradley

Tommer Ender
Steven Conrad
Daniel Herber
Mehmet Ozbek

ABSTRACT

AN ENTERPRISE SYSTEM ENGINEERING ANALYSIS OF KC-46A MAINTENANCE PROGRAM DECISION-MAKING

The KC-46A Pegasus is a United States Air Force (USAF) tanker, transport, and medical evacuation commercial derivative aircraft based on the Boeing 767. It is a top acquisition priority to modernize the USAF's refueling capabilities and is governed by a lifecycle sustainment strategy directed by USAF commercial variant policies aligned to Federal Aviation Administration (FAA) policy. While this strategy provides robust mechanisms to manage the KC-46A's performance during its operations and support phase, opportunity exists for the KC-46A sustainment enterprise to better achieve reliability, availability, maintainability, and cost (RAM-C) objectives through enhancing KC-46A maintenance program decision-making in the context of USAF and FAA policies.

This research characterizes the KC-46A maintenance program as an industrial enterprise system governing the maintenance, repair, overhaul, and modification of KC-46A aircraft. Upon this basis, enterprise systems engineering (ESE) characterizes the KC-46A maintenance program and identifies decision-making improvement opportunities in its management. Canonical ESE viewpoints are tailored to abstract the organizations, processes, and information composing KC-46A maintenance program decision-making and model how decision support methods can better achieve KC-46A sustainment enterprise objectives.

A decision-making framework then evaluates the RAM-C performance of KC-46A maintenance tasks as part of the KC-46A Continued Analysis and Surveillance System (CASS)

program. The framework's heuristics classify the compliance, effectiveness, and optimality of a maintenance task to prescribe KC-46A CASS responses. A rule-based expert system applies this framework and serves as the knowledge engine for the KC-46A CASS decision support system referred to as the "Pegasus Fleet Management Tool." A focus group of KC-46A sustainment experts evaluated the framework and produced consensus that it advances the state of the art in KC-46A maintenance program decision-making. A business case analysis roadmaps the programmatic and technical activities required to implement the framework in PFMT and improve KC-46A sustainment.

ACKNOWLEDGEMENTS

This work benefited from the contributions of many people, both directly and indirectly, and I would be remiss to not acknowledge them. First, I would like to thank Dr. Thomas Bradley for his help throughout my time in this program and for seeing it through to completion. Thank you also to my advisory committee for their time and guidance in supporting this effort.

Thank you to the Georgia Tech Research Institute (GTRI) for making this degree program a reality through its culture of academic excellence and generous educational support programs. Additionally, I would like to thank the leadership of GTRI's Electronic Systems Laboratory, specifically Dr. Tommer Ender and Dr. Anne Clark, for their unwavering support in my pursuit of this degree and professional success. GTRI's Strategic Sustainment Team also significantly contributed to the research results that made this dissertation possible. I cannot thank you enough for your teamwork, friendship, and thought leadership.

To the men and women of the United States Air Force who supported this effort, thank you for answering my countless questions and providing your feedback on the direction of this research. Specifically, I'm grateful for the generosity and expertise of the KC-46A System Program Office and Headquarter Air Force Logistics, Engineering, and Force Protection directorate's Tesseract Office of Innovation.

Most importantly, thank you to my family. Thank you to my three children for doing their best to understand why daddy has to do homework at night after being at work all day, to my parents and in-laws for their encouragement and support, and my beautiful spouse, Lauren, who is the reason any of this is possible.

Lauren, thank you for selflessly picking up the extra workload while I went back to graduate school. In the words of Nick Maggiulli, "for every public accomplishment, there is a private sacrifice that is often overlooked" [1]. Know that your sacrifice is at the forefront of everything that follows in this dissertation. I love you forever and am happy that we earned our doctorate together.

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CHAPTER 1: INTRODUCTION

1.1. Program Overview

The KC-46A Pegasus is a United States Air Force (USAF) tanker and transport commercial derivative aircraft (CDA) of the Boeing 767-200 Extended Range (ER), 767-300 Freighter, and 767-400ER. It is the first phase of recapitalizing the USAF's aging aerial tanker fleet to provide next generation refueling, cargo, and aeromedical evacuation capabilities to national and allied forces. The first KC-46A was delivered to McConnel Air Force Base (AFB) in January 2019 and the current contract delivers 179 tankers to the USAF from Boeing by 2027 [2].

The KC-46A, pictured in Figure 1, has a fuel capacity of over 212,000 pounds to refuel most fixed-wing aircraft via its centerline aerial refueling boom, hose and drogue system, and Wing Aerial Refueling Pods capable of multi-point simultaneous refueling. Additionally, its cargo capacity includes 58 passengers, 65,000 pounds of cargo, and 18 pallet positions to support military transport and tanker operations simultaneously. In development since 2011, the USAF received 61 KC-46A aircraft as of January 2021 at four different bases [3]. The deliveries are the first step to replace the USAF's aging Boeing KC-135 Stratotanker fleet that has been in service since 1965. [2, 4]

Figure 1: Boeing KC-46A Pegasus [5]

The KC-46A's improved operational capabilities and the USAF's critical need to modernize its refueling fleet make it a top USAF acquisition priority. Due to the program's $51.7 billion cost evaluation and extensive schedule slippages due to failures in operational testing, the KC-46A's cost, schedule, and performance are under close scrutiny from military and congressional leadership. [6, 7] This is especially true given the KC-46A's CDA acquisitions and sustainment strategy intended to save costs and increase performance by leveraging commercially developed solutions and resources. This cost-wise decision is made after a weapon systems' material solution analysis phase during pre-systems acquisition. The use of CDA is a longstanding acquisition strategy that manifests itself in extensive lifecycle management activities guided by USAF policy documents. For example, Air Force Instruction (AFI) 62-601 USAF Airworthiness directs Federal Aviation Administration (FAA) type certification as the preferred method of certifying airworthiness for USAF operated CDA [8].

What makes the KC-46A sustainment approach new is that the FAA certifies almost all of the KC-46A military-unique parts, versus just the aircraft and commercial components like previous USAF CDA, to take advantage of commercial regulations on the global B767 supply chain [9]. USAF acquisition and sustainment experts responded that maintaining FAA regulations for CDA not only leverages established FAA processes but more importantly expands CDA market access to maintenance, supply, and data resources [10]. Specific to the KC-46A, the Government Accountability Office (GAO) reported that an estimated $420 million in lifecycle cost savings was expected from the USAF's participation in the B767 commercial parts pool and safety related design changes[1] [9].

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[1]Additional cost savings were projected by the USAF to compete with other suppliers in the commercial parts pool (i.e., the USAF could sell refurbished KC-46A parts to commercial operators). Upon further analysis by the GAO, USAF leadership failed to properly understand the KC-46A's sustainment environment resulting in a loss of

1.2. Sustainment Environment and Performance

While the KC-46's acquisition and procurement are currently underway, the majority of the weapon system's total lifecycle performance and cost will be realized during its sustainment phase after becoming fully operational capable. Specifically, the operations and support (O&S) phase of the KC-46A is expected to account for 65-80 percent of its total ownership cost [11]. These costs pay for the life-cycle sustainment and disposal of the KC-46A during the O&S phase to provide tanker capabilities to the Department of Defense (DoD). They represent the culmination of the sustainment planning done in previous phases of the acquisition lifecycle and are documented in the Lifecycle Sustainment Plan. [12].

In 2018 and 2019, the reliability, availability, maintainability, and cost (RAM-C) performance of the KC-46A was expected to meet or exceed Lifecycle Sustainment Plan objectives when the aircraft fleet reaches 50,000 flight hours in approximately 2025 [6, 9, 13]. Yet, in Fiscal Year 2021 (FY21), KC-46A sustainment performance was significantly below these requirements in critical RAM-C attributes (i.e., Mission Capable Rate, Fix Rate, and Break Rate) as illustrated in Figure 2 [7, 14]. This presents an especially challenging problem as the USAF accepts responsibility from Boeing for organic KC-46A sustainment; this includes adherence to FAA regulations that present unique implications and challenges to the USAF sustainment enterprise (i.e., closer regulation and participation in B767 industry/regulatory activities) [9].

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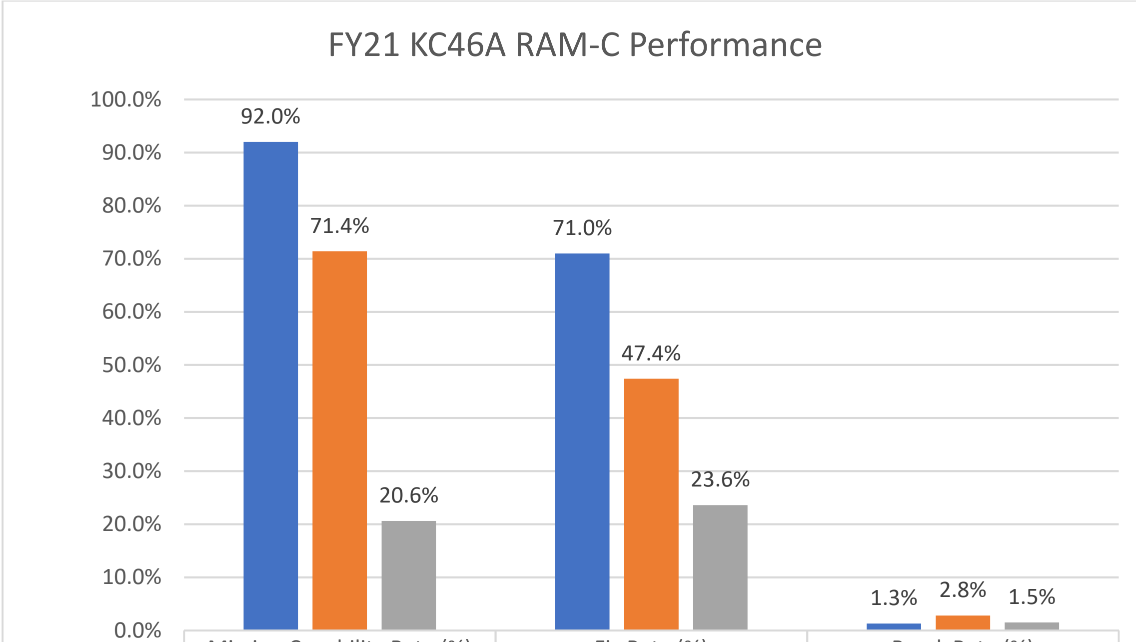
these additional cost savings. Specifically, commercial B767 operators did not want to use reconditioned KC-46A parts on their aircraft given the risk of how the aircraft are operated differently [9].



	Mission Capability Rate (%)	Fix Rate (%)	Break Rate (%)
Goal	92.0%	71.0%	1.3%
Actual	71.4%	47.4%	2.8%
Difference	20.6%	23.6%	1.5%

Figure 2: KC-46A RAM-C Performance [adapted from 7, 14]

To this end, appropriately engineering and managing the performance of KC-46A sustainment activities is crucial in obtaining the cost-wise readiness demanded of the tanker/transport fleet. Accomplishing this within the complex USAF sustainment enterprise is a daunting task that quickly becomes a systems and systems-of-systems (SoS) problem. An abundance of stakeholders and their sub-enterprises present diverse interests and objectives to manage. Interconnected dependencies between individuals, processes, and organizations develop into dynamic emergent behavior internal and external to the USAF sustainment enterprise. The unfeasibility of understanding, representing, and influencing the KC-46A's complete system/SoS behavior dictates that solutions only focus on describing and managing selected aspects of such complexity.

In ESE application, Giachetti emphasizes that managers must understand the relationships of a self-adaptive and goal-seeking enterprise system such as the KC-46A sustainment enterprise to properly implement control actions [15]. Dabney et al. also detail critical systems engineering perspectives, such as functional, strategic, organizational, and enterprise views, required for successful sustainment of modern military systems [16]. Unlike traditional systems engineering efforts, managing the KC-46A's sustainment enterprise is a matter of quickly adapting to an uncertain and changing political, operational, economic, and technical landscape [17].

Lastly, the National Research Council identified USAF weapon system sustainment as a process "largely facilitated by interpersonal relationships rather than clear, concise lines of authority and modern enterprise reporting and planning tools, which results in escalating costs and inefficiencies" [18]. The council identified many systemic changes to USAF lifecycle management required to meet future sustainment needs. Additionally, the USAF's 2020 sustainment modernization strategy identified very similar institutional changes, such as synchronizing sustainment activities through decision support tools, to focus the sustainment enterprise on global readiness outputs and cost reductions [19].

1.3. The KC-46A Maintenance Program

KC-46A sustainment enterprise activities are primarily executed or influenced via the KC-46A maintenance program. Sustainment enterprise outputs include mission capable and operationally relevant aircraft to satisfy an operational demand (referred to as full mission capable or FMC aircraft). The input to the KC-46A sustainment enterprise is an aircraft requiring inspection, repair, overhaul, or servicing (referred to as non-mission capable or NMC aircraft) and/or requiring an upgrade due to obsolete capabilities [20]. Additionally, raw resources, including materiel, data, funding, and policies, are considered an input into the KC-46A sustainment enterprise functions as they are required to perform aircraft maintenance and modernization.

Activities related to sustaining the aircraft's material and operating conditions include parts procurement/provisioning, logistics support, sustainment engineering, and sustainment management (e.g., production planning, readiness reporting/analysis, business operations, policy regulation). These activities are applied to NMC aircraft to transform them into FMC aircraft via the KC-46A maintenance program. Functionally, the maintenance program governs the translation of airworthiness and operational requirements into demand signals on supporting agencies for physical resources and maintenance, repair, overhaul, and modification services (e.g., the maintenance program requires a certain material condition of a KC-46A's tires before takeoff else the tire must be replaced and/or serviced, documented in accordance with regulations, and supported by a supply chain). This workflow of resources, activities, and governance is illustrated in Figure 3.

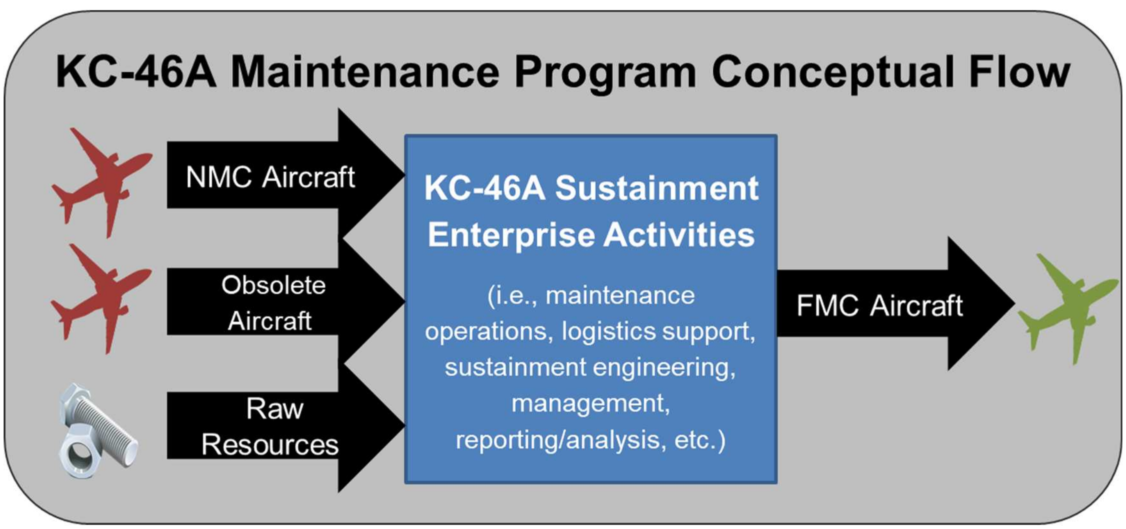


Figure 3: KC-46A Sustainment Enterprise Workflow and Maintenance Program Governance

Leveraging FAA regulations in its sustainment strategy, the KC-46A’s 1,200+ maintenance tasks include scheduled and special inspections/maintenance, time change items, and repair instructions regulated by FAA Advisory Circular (AC) 120-16G - Continued Airworthiness Maintenance Program (CAMP) [21]. A key element of the CAMP required of the KC-46A is the Continuing Analysis and Surveillance System (CASS) program governed by FAA AC 120-79A and USAF TO 00-25-266-KC46. The CASS program ensures the intent, effectiveness, and performance of KC-46A maintenance is continually monitored and adjusted via a unified enterprise framework. The CASS program seeks to achieve an effective and optimized maintenance program defined by the FAA in AC 120-17B - Reliability Program Methods - Standards for Determining Time Limitations.

Figure 4 illustrates AC 120-17B’s specific decision criteria connecting unscheduled/scheduled maintenance defects to infer a maintenance task’s performance; the green, yellow, and red boxes indicate the task’s effectiveness and optimality. While the goal of the KC-46A CASS program is to achieve a high number of scheduled maintenance defects and a low number of low impact unscheduled maintenance defects for its maintenance tasks, our discussions with KC-46A sustainment experts and review of maintenance data indicates the KC-46A maintenance program is currently effective but not optimized (i.e., unnecessary maintenance is being performed on aircraft) [22, 23].

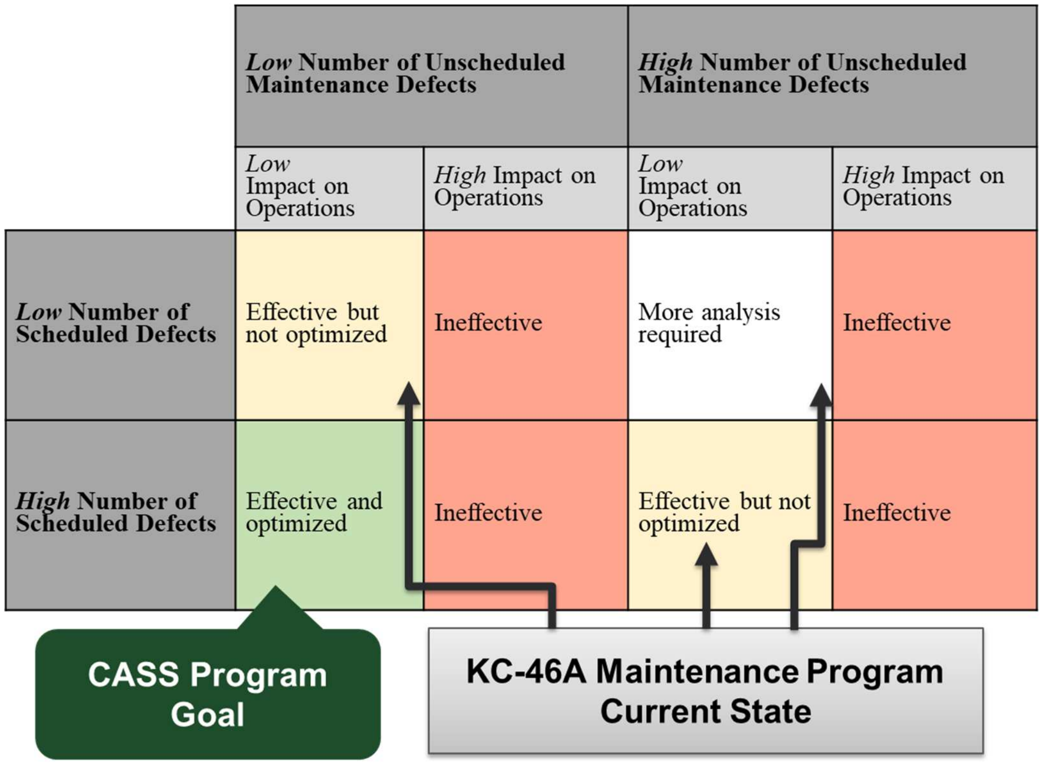


Figure 4: KC-46A Maintenance Program Goal via CASS [adapted from 24]

Additionally, the KC-46's Customized Maintenance Planning Document (CMPD) states that it is the USAF's "responsibility to justify an escalation of (maintenance) intervals and other time limitations to their regulatory authority based on substantiating operating experience" [21]. Despite a leading B767 commercial operator receiving FAA approval for a significant escalation of hundreds of maintenance tasks in 2019 [25], repeated attempts by the KC-46A System Program Office (SPO) to improve RAM-C performance via escalating maintenance task intervals revealed insufficient data capture and communication from the KC-46A sustainment enterprise to justify the change to the FAA [22, 26].

1.4. State of the Art

To better achieve KC-46A sustainment goals defined by the USAF and FAA, this research asserts that the maintenance program be managed as an industrial enterprise system. The KC-46A maintenance program is considered a modern industrial system where a vast number of devices and actors are continuously interacting with each other and enterprise systems to form sophisticated infrastructures via modern technology (e.g., web services, cloud computing) [27]. Lasi et al. characterize the management of complex industrial systems like the KC-46A maintenance program by the changing operative framework conditions and emerging, technology-driven disciplines of systems engineering [28].

As an enterprise system, the KC-46A maintenance program is a complex and adaptive socio-technical system comprising of interdependent resources (e.g., people, processes, information, and technology) that must interact with each other and their environment in support of a common operational mission [15]. It contains numerous intraprises, or internal enterprise systems, across the USAF including organic and contracted logistics support. These intraprises make up the larger KC-46A sustainment enterprise and collaborate via its maintenance program to transform the enterprise's operations in a competitive and constrained environment. [17]

Decision-making in the KC-46A maintenance program and other modern industrial enterprise systems increasingly struggles with data stream backlog, sensitivity, and value to effectively manage and measure the efficacy of KC-46 maintenance program activities [29]. KC-46A maintenance information systems, appropriately integrated with industrial and digital user co-created value chains, are critical in KC-46A maintenance operations to properly manage multi-source data integration architectures and big data technology ecosystems [30, 31]. Current literature also characterizes the KC-46A's sustainment enterprise as existing in an information-intensive environment where advances in information systems drive innovative enterprise business models and resource mobilization within the enterprise by means of collaboration, contextualization, and information technology [29, 32].

While much of KC-46A maintenance program decision-making is completed manually outside of modern data management and computing capabilities [33], KC-46A sustainment experts continue to advocate for the migration of maintenance program decisions to the KC-46A's Amazon Web Services Government Cloud (AWS GovCloud) and Tableau data visualization platforms [22, 23, 34]. Additionally, decision-support systems and multi-criteria decision making methods have proven successful in aircraft maintenance program management and operations [35-38]. Liu et al., for example, develop an autonomous decision-making system for aircraft maintenance scheduling in a simulated operation, [39] while Dinis et al. develop a maintenance capacity planning and scheduling decision framework to handle the stochastic nature of aircraft maintenance [40].

A leading B767 commercial operator also states that the most effective tool in determining maintenance task intervals is a full systems understanding of the KC-46A's maintenance program execution in its enterprise environment to augment the experience of sustainment decision-makers and their decision support tools [41]. These types of decision-making and optimization tools are specifically cited by AF/A4 as needed technologies to synchronize sustainment enterprise activities using modern data analytics [19].

In summary, this literature review reveals a preponderance of decision-support tools for maintenance scheduling and resourcing in commercial airline operations. The USAF and other industry leaders identify a need for modern decision-making applications across the KC-46A sustainment enterprise to achieve its performance objectives. Specifically, decision support methods to determining the effectiveness and efficiency for the KC-46A maintenance program, versus just the execution of it as most of the literature addresses, are required to manage this industrial enterprise system governing KC-46A sustainment activities.

1.5. Research Approach

On the basis of the above reflections regarding the state of the field, the researcher identifies opportunity for enterprise systems engineering (ESE) and decision support applications to advance the KC-46A maintenance program. ESE's organizational, informational, and process viewpoints coupled with decision support/expert systems methods can enable the KC-46A maintenance program to exploit the design, joint production, and delivery of maintenance, repair, overhaul, and modification services by harnessing modern predictive tools that influence decision making [15, 42, 43]. A translational decision-making framework is proposed to begin informing the operation and enhancement of the KC-46A maintenance program via ESE and decision support methods.

This decision-making framework is intended to advance the state of the art by making the KC-46A maintenance program more proactive, adaptive, and responsive in the context of the KC-46A sustainment enterprise. The framework informs reliability and maintainability (R&M) analyses of the current performance and effectiveness of the KC-46A maintenance program while identifying enhancement opportunities based on enterprise data and objectives. Additionally, the researcher benchmarks a leading commercial B767 operator to inform other enterprise decision-making improvements for the KC-46A sustainment enterprise.

This proposed decision-making framework is a tool for KC-46A CASS Office analysts to evaluate and improve the KC-46A's 1,200+ scheduled maintenance program requirements. It specifically answers if there are a high or low number of scheduled/unscheduled maintenance defects to determine if a specific scheduled maintenance task in the KC-46A maintenance program is effective and optimized (see Figure 4). In addition, the framework leverages prototype decision-support tools to verify if the KC-46A sustainment enterprise is compliant with the maintenance task in accordance with FAA and USAF regulations.

The preliminary design of a decision support system (DSS) using PFMT and decision support is evaluated to increase the systems understanding of the maintenance program and accelerate decision-making by encoding the logic of KC-46A and B767 expert knowledge. A database, inference engine, and user interface are prototyped to process KC-46A sustainment knowledge based on rules, facts, and goals of the enterprise. Forward and backward chaining of KC-46A maintenance program rules, facts, and conclusions comprises the expert system to satisfice CASS program requirements. Rule-base validation and knowledge acquisition is conducted from subject matter experts (SME), applicable FAA and USAF regulations, and case-based reasoning. Object-oriented (OO) programming in Excel and Python encodes the decision logic for KC-46A maintenance program enterprise knowledge development.

This decision-making framework is then evaluated with a focus group of KC-46A sustainment SMEs. Upon validation of the framework's improvement over current state decision-making methods and a supporting business case analysis, implementation plans (i.e., technical and programmatic roadmaps) are developed to define requirements for enterprise adoption of the framework.

Lastly, this research was part of a larger project at GTRI supporting the KC-46A SPO that the author co-led[2]. The other GTRI researchers the author collaborated with are primarily focused on the KC-46A sustainment enterprise's compliance with maintenance requirements and comparison to commercial B767 maintenance intervals. Compliance involves the scheduling and documentation of completing all 1,200+ scheduled maintenance tasks at the correct time interval. Proving compliance with current maintenance requirements establishes the basis needed for the decision-making framework, whose integration with ESE processes, development and assessment

[2] See the following link for details on the contract between the KC-46A SPO and GTRI: <https://www.usaspending.gov/award/CONT_AWD_FA852321F0056_9700_FA852319D0006_9700>

comprises the contributions of this research. Validating the author's assumption that the current state satisfies maintenance requirements is the first step in justifying RAM-C improvements to intervals and is included in the framework.

Additionally, the GTRI's research team's comparison of KC-46A maintenance requirements to commercial limits provides supporting evidence to justify changes to KC-46 maintenance intervals. While this data is considered in the author's first research question, the proposed decision-making framework is intended to analyze primary source KC-46A operational data (versus commercial data) to adjust maintenance intervals. Thus, the author's individual contribution for our research is an extension and further application of compliance documentation and commercial benchmarking to advance the state of the art in KC-46A sustainment decision-making.

CHAPTER 2: RESEARCH QUESTIONS AND TASKS

The following describes the research questions and associated tasks answered to accomplish the aforementioned research results.

2.1. Research Question 1: Current State Decision-Making

What are the substantive benefits and shortcomings of current KC-46A maintenance program decision-making frameworks that ESE and decision support methods may be able to address?

2.1.1. Task 1

As per the philosophies of ESE, establish the major organizations, functions, activities, and attributes of the KC-46A sustainment enterprise and maintenance program. This includes documenting their purpose, management, and influence on decision-making to support operational needs.

- Result: Definition of the KC-46A maintenance program as an industrial enterprise system.
- Method: Semi-structured stakeholder interviews, enterprise modeling, and a review of academic, industry, and KC-46A use case literature.

2.1.2. Task 2

Using ESE frameworks, model KC-46A sustainment enterprise viewpoints (i.e., organizational, informational, and process viewpoints) to characterize the KC-46A maintenance program's relationship with the enterprise. This informs the decision-making framework's assessment of KC-46A maintenance task performance.

- Result: Development of KC-46A maintenance program enterprise dependencies influencing decision-making.

- Method: Root cause and critical function analysis of KC-46A maintenance program activities, analysis of maintenance program policies (e.g., FAA regulations) affecting decision-making, and a review of current decision support methods used in KC-46A maintenance program management.

2.1.3. Task 3

Compare the KC-46A sustainment enterprise operation and its maintenance program to a leading B767 commercial operator. This assesses opportunities for translational ESE and decision support applications to the KC-46A based on commercial airline best practices.

- Result: Qualify KC-46A maintenance program improvement opportunities and supporting decision-making methods to better meet KC-46A sustainment enterprise RAM-C objectives.
- Method: Commercial benchmarking to compare and contrast the KC-46A sustainment enterprise's operation, maintenance program, and decision-making to an industry leading B767 commercial airline.

2.2. Research Question 2: ESE and Decision Support Business Case Analysis

What aspects of ESE and decision support methods are beneficial or costly to the KC-46A maintenance program?

2.2.1. Task 1

Determine how ESE and decision support methods could improve decision-making in the KC-46A maintenance program through analysis of KC-46A sustainment enterprise performance. Obtain historical data and expert knowledge on the KC-46A maintenance program to evaluate the applicability of human domain knowledge engineering (e.g., heuristic rule sets), expert systems, and stochastic multi-criteria optimization methods.

- Result: Identification of ESE and decision support opportunities and their respective methods in KC-46A maintenance program decision making.
- Method: Examine the KC-46 Pegasus Fleet Management Tool's (PFMT) role in KC-46A sustainment enterprise performance as a specific use case. PFMT is an enterprise decision-making solution for the KC-46A maintenance program using Tableau and Amazon Web Services Government Cloud managed by the KC-46A SPO and Booz Allen Hamilton Incorporated.

2.2.2. Task 2

Identify the costs involved with ESE and decision support methods applied to the KC-46A maintenance program. Analyze the technical and programmatic barriers ESE/decision support tools are expected to face during their implementation.

- Result: Understand the technical, business, and cultural risks of implementing ESE and decision support tools in the KC-46A maintenance program.
- Method: Semi-structured stakeholder interviews and use case analysis of PFMT adoption challenges in KC-46A maintenance program decision making.

2.2.3. Task 3

Develop a plan to implement ESE and decision support methods based on the cost-benefit analysis performed in Tasks 1 and 2. Complete data exploration and problem framing/discovery to propose which ESE and decision support methods should be applied to KC-46A maintenance program decision making.

- Result: The development of a high-level product development plan for the KC-46A decision-making framework to execute in Research Question 3.

- Method: Internal development of the schedule, resources, and other project management activities required to complete the product development plan.

2.3. Research Question 3: ESE and Decision Support Implementation

How would ESE and decision support methods be implemented to advance KC-46A maintenance program decision-making?

2.3.1. Task 1

Develop a decision-making framework based on applicable ESE and decision support methods identified in Research Question 2. Demonstrate the framework in a prototype application that can be developed into a DSS.

- Result: A demonstration of the benefits ESE and decision support methods provide to KC-46A maintenance program management.
- Method: The decision-making framework is developed using a combination of Excel, Python, Cameo, and Tableau to design the database, model, and user interface elements of the framework. A rule-based inference engine is the focus of the framework as the researcher observed this to be the greatest need in KC-46A maintenance management decision-making compared to the database and user interface elements.

2.3.2. Task 2

Evaluate the decision-making framework compared to existing decision-making methods with KC-46A sustainment SMEs. Given the KC-46A SMEs are the primary end users of the framework, conduct a business case analysis of the framework's applications in KC-46A maintenance program management.

- Result: Achieve an objective assessment on the decision-making framework's advancement of the state of the art.

- Method: A focus group is conducted with KC-46A sustainment SMEs using the decision-making framework for notional and/or historical use cases.

2.3.3. Task 3

Propose cost, schedule, and system performance requirements to plan enterprise adoption of the improved KC-46A maintenance program decision-making framework. These requirements inform the scaling of the decision-making framework to the KC-46A and other weapon systems.

- Result: High-level programmatic and technical requirements to scale the framework based on sustainment stakeholder's needs.
- Method: Technical and programmatic roadmapping, project management plan, and test and evaluation plan development.

CHAPTER 3: KC-46A MAINTENANCE PROGRAM DECISION-MAKING BACKGROUND

The KC-46A's sustainment strategy follows several industry activities to support USAF sustainment operations. Figure 5 illustrates the KC-46A maintenance program in the context of this commercial industry activity which governs changes to its maintenance tasks. Starting in the figure's top left corner, management decisions to improve KC-46A maintenance are either directed/advised by industry actors (such as Boeing), government regulators (i.e., the FAA), or initiated internally by the USAF based on operational data. The KC-46A SPO participates in the B767 Industry Steering Committee (ISC) which cooperates with other B767 operators and Boeing to advise the FAA's Maintenance Review Board (MRB). KC-46A maintenance recommendations are generated by the KC-46A CASS program which proposes maintenance program revisions to the MRB. The MRB Report determines what changes are made to the B767 Maintenance Planning Document (MPD) in order to comply with the FAA's Airworthiness Type Certification (ATC) and improve operational performance. Specific Supplemental Type Certifications (STC) and Military Type Certifications (MTC) are governed by USAF policy to regulate the airworthiness of KC-46A unique systems/capabilities such as its aerial refueling systems and defensive counter measures. These processes satisfy the "Meets the Intent" determination from the FAA enabling the USAF to synergize with B767 commercial resources (e.g., supply chain, maintenance services) while maintaining continued airworthiness compliance[3].

The B767 MPD is customized to the KC-46A based on STC and MTC maintenance requirements (referred to as the Customized Maintenance Planning Document or CMPD). This

[3] The KC-46A CDA sustainment strategy is regulated by Air Force Policy Document 62-6: USAF Airworthiness to comply with FAA Federal Acquisition Regulations (FAR) Parts 43, 65, 121, and 145 responsible for the regulation of commercial airlines.

process is currently managed by Boeing but is expected to transition to an organic USAF responsibility in the 2024 – 2025 timeframe [22]. At that point, the KC-46A SPO will be primarily responsible for the CMPD Technical Orders (TO) that dictate maintenance requirements to field and depot KC-46A maintenance units. Additionally, during this post-type certification phase, the SPO's CASS program will monitor scheduled maintenance task adequacy based on operational data. This analysis of scheduled task effectiveness is the primary means to recommend adjustments to KC-46A task intervals during industry reviews (e.g., as stated by the FAA, "Operator reliability programs should continue to ensure continuous evolution/optimization of their maintenance programs."[4]). Thus, it is incumbent on the KC-46A sustainment enterprise to adjust its maintenance program to achieve RAM-C objectives for the aircraft. Currently, [26] documents the enterprise's inability to do so citing "insufficient data to escalate tasks." Addressing this gap using in KC-46A decision-making disciplines such as ESE and decision support is critical for the USAF to effectively participate in industry activity with Boeing and the FAA. [25] details how a B767 operator successfully did this to adjust maintenance task intervals to optimize their maintenance operation.

[4] See FAA Advisory Circular (AC) 121-22C - Maintenance Review Boards, Maintenance Type Boards, and OEM/TCH Recommended Maintenance Procedures and AC 120-17B - Reliability Program Methods—Standards for Determining Time Limitations for additional policy on pre and post type certification responsibilities between the KC-46A SPO and ISC.

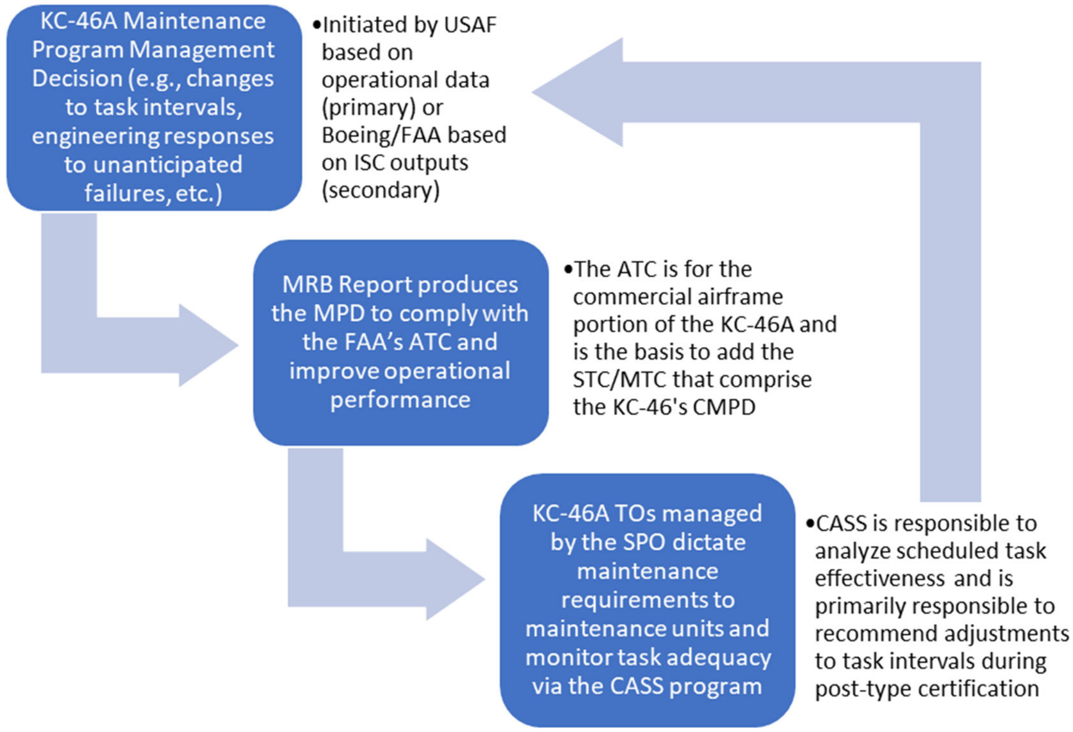


Figure 5: KC-46A Maintenance Program Management Decisions and Industry Activity

In the context of this set of industry activities, this chapter seeks to answer Research Question 1, which is restated here:

Research Question 1 - What are the substantive benefits and shortcomings of current KC-46A maintenance program decision-making frameworks that ESE and decision support methods may be able to address?

To answer this question, this chapter describes the USAF's context when making decisions and proposing changes for the KC-46A maintenance program. An ESE approach focused on internal USAF processes characterizes the KC-46A maintenance program as an industrial enterprise system. Additionally, given the CDA sustainment strategy of the KC-46A, a comparison of the KC-46A's maintenance program to a leading B767 commercial operator informs the proposed decision-making framework's knowledge engine.

3.1. System Definition

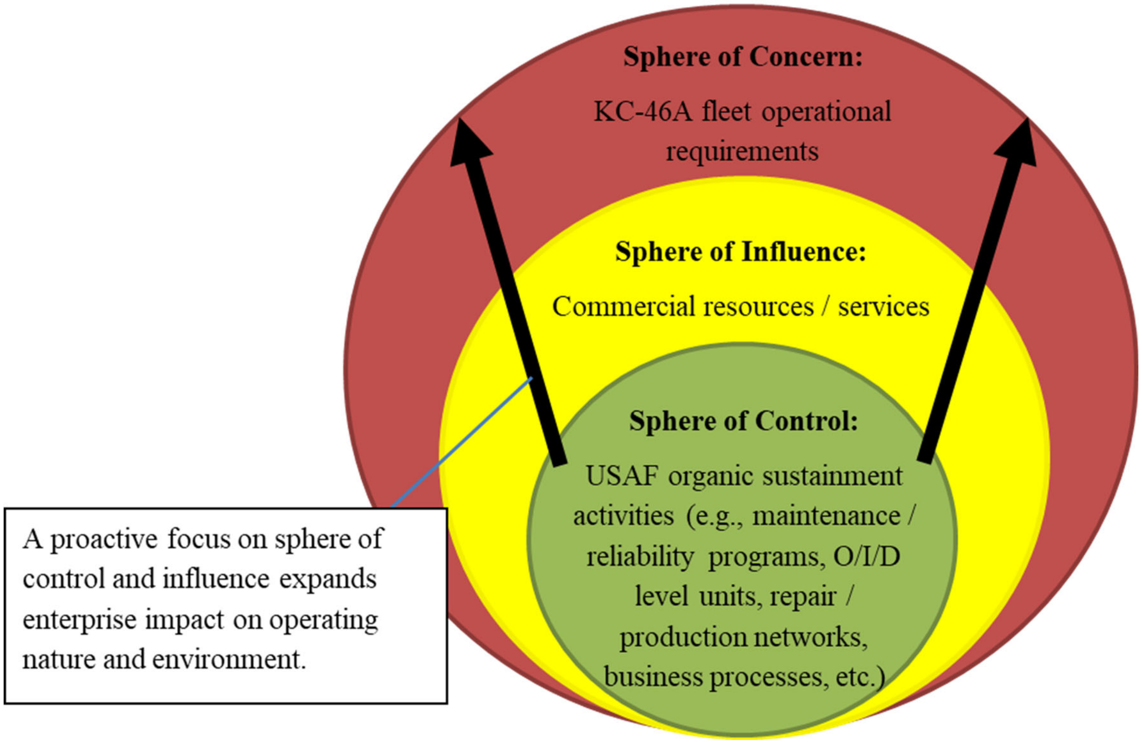
To bound the decision aperture under consideration, the researcher defines the KC-46A maintenance program as an industrial enterprise system in the larger KC-46A sustainment enterprise. This is to identify what decisions are made regarding the maintenance program, who is responsible for them, and how they relate to and govern other KC-46A sustainment activities. Rizzo, Blond and Covey [44] and the National Research Council [18] identify the need to model these enterprise systems to assist in understanding their complexity and governing their behaviors to achieve enterprise objectives. Applications of decision theory are also considered to contextualize the impact of decisions by KC-46A actors in facilitating organizational change.

3.1.1. KC-46A Maintenance Organizations, Functions, and Relationships

The primary purpose in modeling the KC-46A sustainment enterprise is to establish its major organizations, functions, activities, and attributes to understand how the KC-46A maintenance program interacts with its sustainment enterprise as an intraprise. Additionally, given the expansive operating environment of the KC-46A, it is important to consider what aspects of the USAF sustainment enterprise are in decision-makers' spheres of control, influence, and concern. Doing so focuses decision making on proactive changes to the KC-46A sustainment enterprise's circle of control and influence to enlarge and better manage external factors and constraints the weapon system must manage. [45]

3.1.1.1. Decision-Making Focus

Because of complex enterprise relationships, the Covey and Collins theory [45] prescribes that the KC-46A sustainment enterprise first act upon activities in its sphere of control (i.e., USAF organic sustainment activities) and sphere of influence (i.e., commercial resources and services such as those provided by Boeing and the FAA). Doing so proactively impacts enterprise performance and expands the enterprise spheres of control and influence as depicted in Figure 6.



Specific to the KC-46A, delivering operational capability and services to achieve or

Figure 6: KC-46A Sustainment Enterprise Spheres of Control, Influence, and Concern

support strategic, operational, and tactical effects across the range of military operations serves as the ultimate purpose of the aircraft fleet. This ability to refuel, transport, and evacuate joint forces in support of an operational commander is a dynamic and uncertain demand signal to which the KC-46A sustainment enterprise is subordinate. For this reason, operational requirements, often dictated by a response to world events, are considered in the KC-46A's sustainment enterprise's sphere of concern and is not recommended as a focus of engineering and management applications applied to the enterprise.

Sphere of influence elements include those actors, systems, processes, and resources that the KC-46A sustainment enterprise can indirectly control via relationships and exchanges with external agencies. In his articles on enterprise transformation, Rouse describes the increasing need for enterprises to successfully leverage these complex and global interfaces to maintain a competitive advantage. Applications of his theory to the KC-46A sustainment enterprise highlight the need for the USAF to deliberately engineer and manage commercial resources and services in response to needs presented by value opportunities, threats, competition, and crises. [46, 47] Such commercial resources and services are especially applicable to the KC-46A CDA given FAA regulatory requirements and the more than 630 B767 model series jets delivered by Boeing to United States operators [48].

Lastly, the primary items in the sphere of control for the KC-46A sustainment enterprise are organic sustainment activities to the USAF. These activities are separated by organizational, intermediate, and depot (O , I, and D respectively) level repair stations providing on/off aircraft maintenance and overhaul of components and airframes. They are categorized as inside the sphere of control of the KC-46A sustainment enterprise due to the USAF being the primary requirements owner and executioners of such sustainment activities.

3.1.1.2. Enterprise Models

Additionally, sophisticated models exist to manage the complexities presented by intraprises, enterprises, and extended enterprises. These are better applied in detailed design activities and the management of emergent behaviors between products, services, and organizations in an enterprise. Complex enterprise models account for more than two dozen general domain interfaces along with drivers/inputs and outcomes/outputs of intraprises [17, 49]. Metamodeling standards, such as the Department of Defense Architecture Framework (DoDAF) Version 2.0, maintains eight different viewpoints to provide an ontology for these complex enterprise models and frameworks.

Conversely, simple enterprise models better assist enterprise stakeholders in developing governance models by discussing relationships between actors, functions, strategies, and systems at a higher level of abstraction. They establish a common lexicon to framework, map, and mature matrixed enterprises at various levels of organization. Recommended to be applied to the USAF after successful implementation in the United States Navy, the simple Triangle Enterprise Model offers an elegant solution in identifying key outputs of requirements owners, providing organizations, and resource sponsors [18]. Figure 7 illustrates this model and describes the roles, responsibilities, and resource exchanges of the primary actors involved.

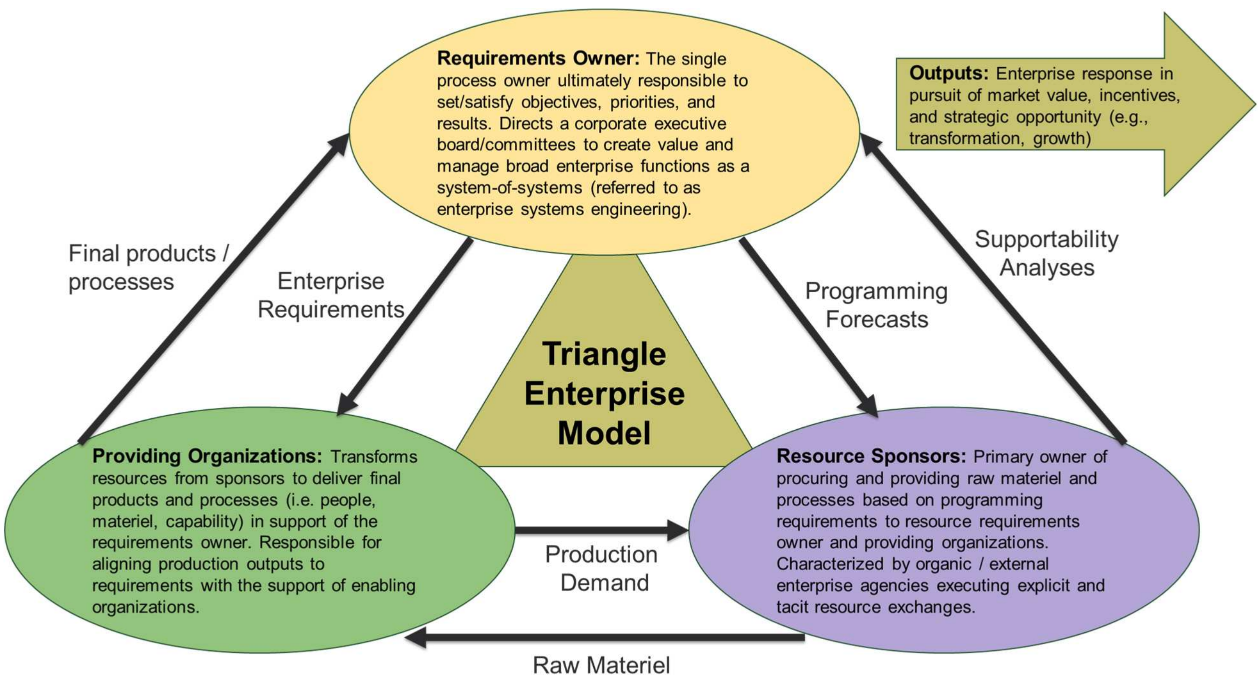


Figure 7: Triangle Enterprise Model [Adapted from 18]

3.1.1.3. Enterprise Modeling

3.1.1.3.1. KC-46A Enterprises

To frame the context and governance of the KC-46A sustainment enterprise, this Triangle Enterprise Model is applied to model higher-level KC-46A enterprises as illustrated in Figure 8.

Starting in the bottom left hand corner, the KC-46A sustainment enterprise includes O, I, and D units at the wing, group, squadron, and subordinate levels who collaborate with the Air Force Lifecycle Management Center System Program Office (AFLCMC/SPO) and enabling organizations, such as Air Mobility Command's Logistics Directorate (AMC/A4). They are modeled as the providing organizations in the KC-46A readiness enterprise; they utilize major acquisition program level raw materiel (e.g., aircraft, engines, and bulk fuel) from resource sponsors (i.e., the Defense Logistics Agency (DLA), Original Equipment Manufacturers (OEMs)) and regulatory actions from the FAA such as the B767 MPD.

The KC-46A sustainment enterprise delivers the transformed raw resources as FMC KC-46A aircraft to the requirements owners. Specifically, AMC serves as the primary requirements owner while other functional major command's (MAJCOMs) requirements are supported via the Numbered Air Forces (NAFs). The KC-46A sustainment enterprise, serving as the providing organization in the KC-46A readiness enterprise triangle model, and corresponding resource sponsors are typically led by a USAF Colonel (denoted by an eagle as the rank insignia), civilian equivalent, or lower rank. They collaborate with KC-46A readiness requirements owners at the Brigadier General through General (one through four star rank insignia respectively) to produce KC-46A operational units ready for tasking.

3.1.1.3.2. Higher USAF Enterprises

At the fleet readiness enterprise level above the KC-46A readiness enterprise, functional MAJCOMs, including AMC, and NAFs are the providing organizations that convert raw resources from their corresponding resource sponsors into a family of systems employed to support a large geographic area. For context, they comprise approximately 5,000 to 150,000 permanent personnel and execute an annual operating budget typically between 1 and 10 billion U.S. dollars. Fleet readiness resource sponsors include the operational forces personnel, logistics, and programs and financial management directorates (A1, A4, A8 respectively), Air Force Material Command's (AFMC) Air Force Sustainment Center (AFSC), and DLA. Fleet enterprise providing organizations and resource sponsors collaborate with requirements owners at the General (Gen.) rank (four-star rank insignia) and above to produce all forces ready for tasking as a family of systems (i.e., theater-size operational units spanning multiple warfighting domains).

These requirements owners include the USAF's two geographic MAJCOMs, Pacific Air Forces (PACAF) and United States Air Forces in Europe – Air Forces Africa (USAFE), as well as the unified combatant commands (COCOMs). The Assistant Secretary of the Air Force (ASAF) for Acquisition, Technology, and Logistics (ASAF/AQ) is also listed due to the organization's mission to modernize and deliver superior warfighting capabilities for fleet forces. These four star and above requirements owners typically lead over 150,000 personnel and execute a 10 billion dollar and greater annual operating budget.

The Corporate USAF enterprise at the highest-level includes providing organizations (i.e., PACAF, USAFE, COCOMs, and ASAF/AQ) who collaborate with their peer resource sponsors, primarily Headquarters Air Force (HAF) A1, A4, and A8 directorates and ASAF, Financial Management and Comptroller (ASAF/FM). Together they execute the functional responsibilities of the Corporate USAF requirements owners (i.e., the Secretary of the Air Force (SecAF) and Chief of Staff of the Air Force (CSAF)), to organize, train, and equip the department.

The Corporate USAF enterprise provides strategic guidance and fiscal decisions to the fleet and KC-46A enterprises to support the National Defense Strategy (NDS). The NDS, executed by the DoD's Joint Chiefs of Staff (JCS), is the primary strategy for operational employment of United

States military forces supported by the administration and resources of the various service branches. [50-54]

3.1.1.3.3. Model Applications

The diagramed enterprises of Figure 8 include the KC-46A sustainment enterprise as the KC-46A readiness enterprise's providing organization (see yellow highlighted label in the graphic's bottom left-hand corner). KC-46A sustainment activities are the focus of this research since they are considered inside the sphere of control/influence the proposed maintenance program decision-making framework. The operation/employment of the KC-46A and higher echelon forces by the KC-46A readiness enterprise is considered in the KC-46A sustainment enterprise's sphere of concern and an extended enterprise the KC-46A sustainment enterprise supports.

Figure 9 presents a triangle model of the KC-46A sustainment enterprise supporting the higher-level environment illustrated in Figure 8. Resource sponsors in the bottom right hand corner include the AFLCMC/SPO who provides maintenance program requirements to providing organizations. The SPO collaborates with AMC/A4 as the operational bridge to deliver maintenance operations guidance and policy to O, I, and D-level KC-46A units. Lastly, OEM's and vendors from the commercial B767 and defense industry sectors are the resource sponsors providing raw materiel to providing organizations at the sub-system and local procurement level (e.g., aircraft components, consumable piece parts, and location-specific fuel distribution to operating bases).

The providing organizations in the KC-46A sustainment enterprise include I and D-level operational units (i.e., wings, groups, squadrons) that provide off-aircraft maintenance, repair, overhaul, modification, and logistics services/support to O-level units. In coordination with DLA who primarily manages consumable materiel procurement and provisioning, I and D-level units provide maintenance program inputs (i.e., finished products and processes such as ready for issue aircraft components) to O-level units who then transform them via on-aircraft maintenance. The sustainment enterprise collaborates to produce mission capable aircraft ready for tasks by the KC-46A readiness enterprise.

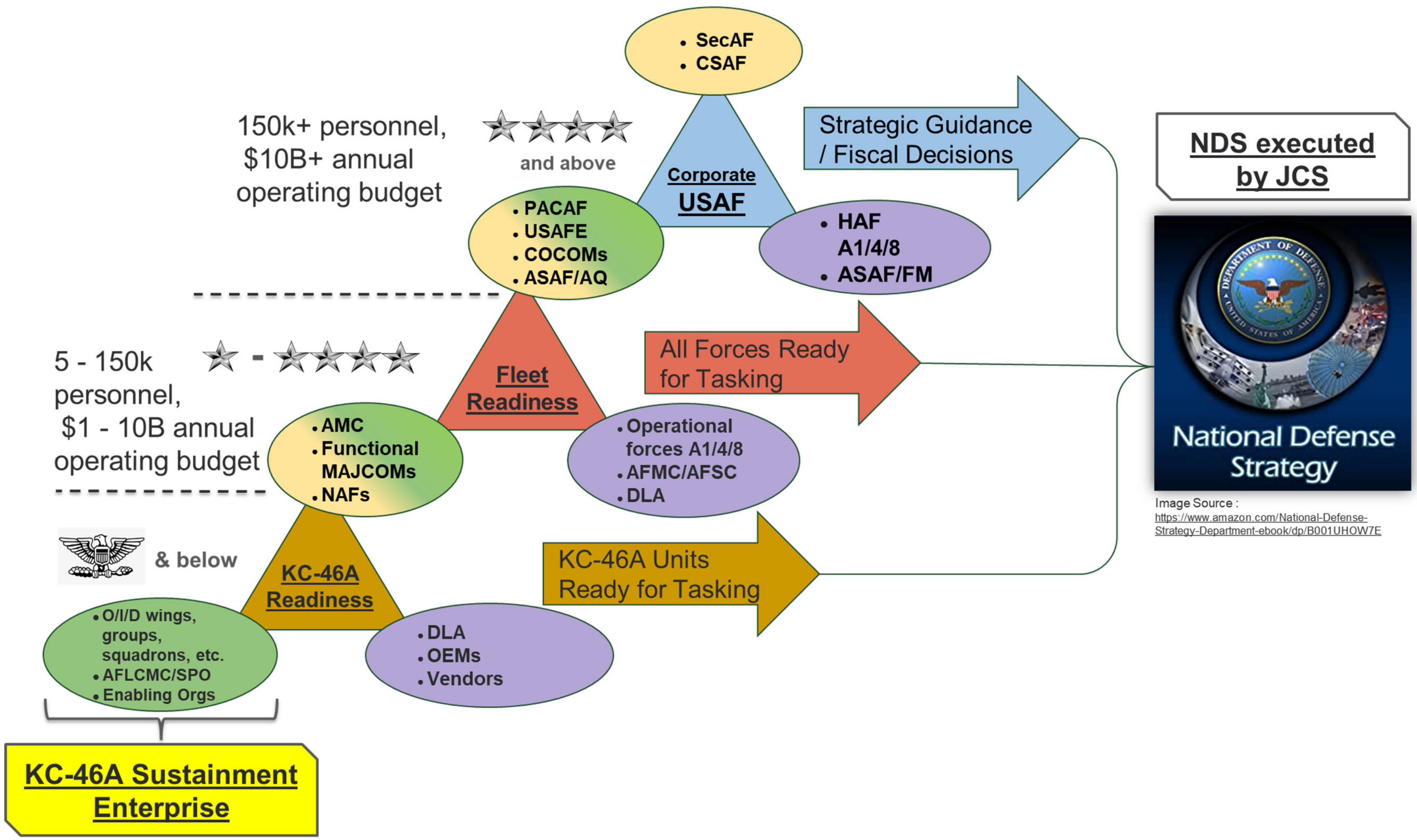


Figure 8: KC-46A Sustainment Enterprise Higher-Level Environment [Adapted from 18]

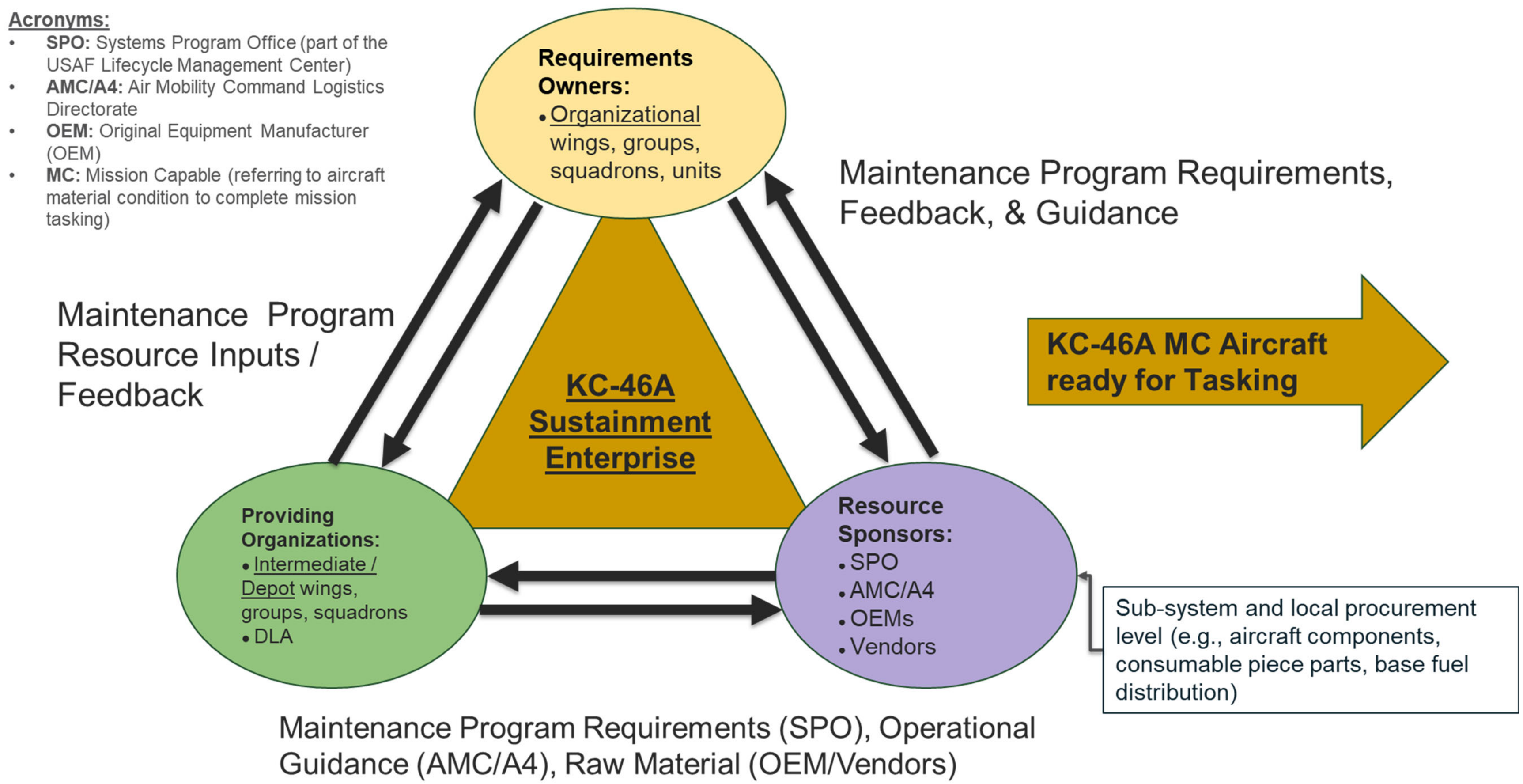


Figure 9: KC-46A Sustainment Enterprise Triangle Model

3.2. Maintenance Program Relationships

Continuing to expand the KC-46A maintenance program's relationships with enterprise and extended enterprise actors, the researcher observes that the KC-46A SPO and AMC/A4 are the primary interface between the KC-46A maintenance program and industry actors (i.e., Boeing), and government regulators (i.e., the FAA) who serve as resource sponsors in the KC-46A readiness enterprise. Specifically, the KC-46A SPO and AMC/A4 receive industry maintenance requirements and guidance from Boeing and the FAA (e.g., CMPD, ACs) to translate into USAF specific maintenance requirements at the O, I, and D-levels. They then receive feedback and operational data from those maintenance units to make B767 and KC-46A maintenance program recommendations (e.g., scheduled maintenance task adjustments, notification of unanticipated failures) to Boeing and the FAA via the ISC and MRB. These relationships are illustrated in Figure 10 [5].

To further contextualize KC-46A sustainment enterprise interactions, Dabney et al. [16] prescribe multiple ESE perspectives to manage the complex operations supporting KC-46A RAM-C performance. Using the methods prescribed by [55, 56] and , Figure 11 is a critical functions analysis of Dabney et al. [16] ESE applications to illustrate how KC-46A maintenance program decisions translate sustainment plans into maintenance and logistics actions. These sustainment components serve as inputs to the KC-46A sustainment enterprise's five critical functions (e.g., O/D-level maintenance, logistics support)[6]. The critical functions are categorized based on their functional outputs where product services produce MC aircraft ready for tasking.

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[5] Related to the sphere of influence model in Figure 6, Boeing and the FAA are considered in the KC-46A SPO and AMC/A4's sphere of influence given their direct interaction exchanging industry requirements and operational feedback.

[6] Only O/D-level maintenance activities are depicted as the current KC-46A sustainment strategy does not include I-level maintenance (i.e., local maintenance of off-aircraft components). I-level maintenance is included in previous sections for discussion of the USAF's traditional three-level maintenance construct.

Business services include business operations and sustainment engineering enterprise functions that facilitate product service outputs through exchanges with the KC-46A maintenance program. The exchanged resources (e.g., management of technical, operational, and business sustainment strategies, decision support/performance evaluation activities) are sustainment plans translated by the KC-46A maintenance program into sustainment requirements.

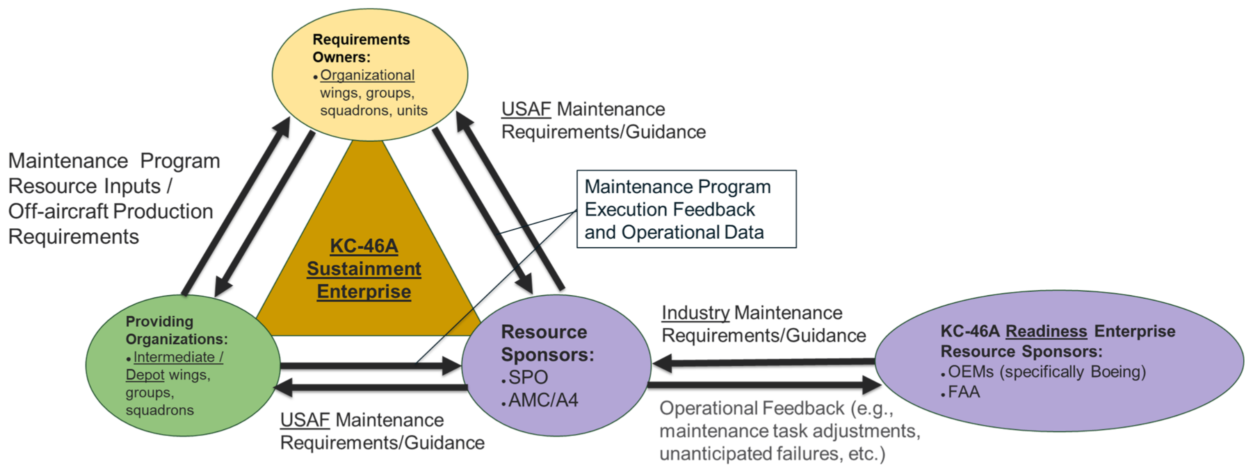

Figure 10: KC-46A Maintenance Program Enterprise Relationship

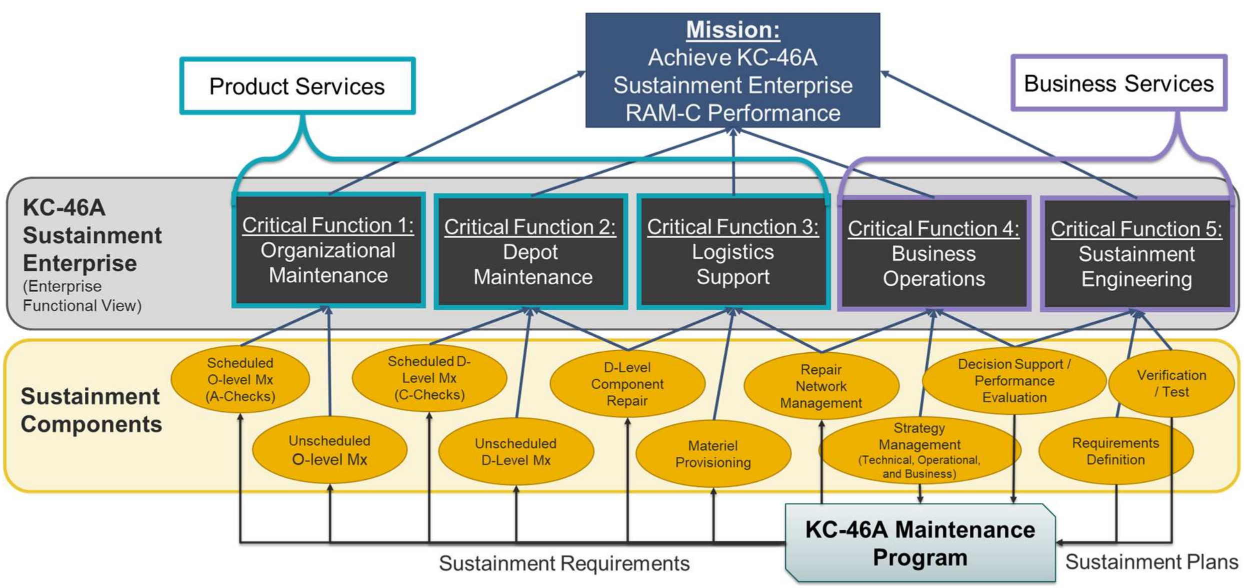

Figure 11: KC-46A Sustainment Critical Function Analysis

During the execution of these critical functions and their components, Conley et al. [57] describe difficulties in KC-46A maintenance program decision-making due to compliance errors identified when converting sustainment plans into requirements. Specifically, during the decision support/performance evaluation sustainment component, they found discrepancies in the KC-46A's A-check maintenance inspection when comparing Boeing's CMPD (i.e., sustainment plans) to the KC-46A's maintenance information system (MIS) across the O-level operating bases and AMC/A4 (i.e., sustainment requirements). This lack of standardization and suspected non-compliance was highlighted by Kaplun [26] and Kelly [22] as a limiting factor to justify KC-46A scheduled maintenance task interval escalations to Boeing and the FAA.

3.2.1. Decision-Making System Definition

The gaps observed in the decision support/performance evaluation component of KC-46A sustainment directly relate to the ESE challenges described by HAF/A4 and the National Research Council to modernize USAF sustainment [18, 19]. Predominantly, synchronizing the KC-46A sustainment enterprise via robust decision support systems relies on the thorough understanding, management, and consensus of organizations, processes, and information that comprise the enterprise. To develop these ESE viewpoints, Model Based Systems Engineering (MBSE) provides robust methods to connect operational data and decision-making to enterprise actors and processes. MBSE products aid in managing these complexities by characterizing the KC-46A maintenance program as an industrial enterprise subsystem of the KC-46A sustainment enterprise. Thompson et al. successfully demonstrate this MBSE approach to optimize maintenance scheduling of military aircraft fleets such as the KC-46A [58]. Additionally, Thompson and Blond applied these MBSE practices using the DoDAF to represent the KC-46A sustainment enterprise's architecture [59].

3.2.1.1. Operational Views

In assessing the effectiveness of KC-46A maintenance tasks to revise sustainment plans and requirements, DoDAF's operational views detail the corresponding decision-making processes in the KC-46A maintenance program. At the highest level of abstraction, the High Level Operational Concept Graphic (OV-1) shown in Figure 12 displays the progression of collecting, categorizing, calculating, associating, and assessing KC-46A maintenance data to determine task effectiveness.

First, KC-46 O-level maintenance data is collected from the KC-46A MIS (referred to as G081, short for the Core Automated Maintenance System for Mobility). Additionally, the MPD and KC-46 Scheduled Maintenance Requirements Technical Order (referred to as TO -6) is collected from the Enhanced Technical Management Information Management System (ETIMS). This collected data then initiates the effectiveness algorithm to categorize specific maintenance actions as scheduled or unscheduled. Unscheduled events are further categorized to determine if an operational event (e.g., flight cancellation or delay) occurred as a result of the unscheduled maintenance.

During the calculation stage, the number of scheduled maintenance defects (i.e., inspection findings requiring repairs) and unscheduled defects (i.e., corrective maintenance actions) are aggregated. Additionally, the interruption time for operational events is also calculated. Using the results of these calculations, the events are then associated to an MPD task to determine percentage, count, and interruption time of scheduled and unscheduled maintenance events. These can be assessed against the criteria listed in Figure 4 to determine whether a scheduled maintenance task found in the KC-46A CMPD is effective and optimized.

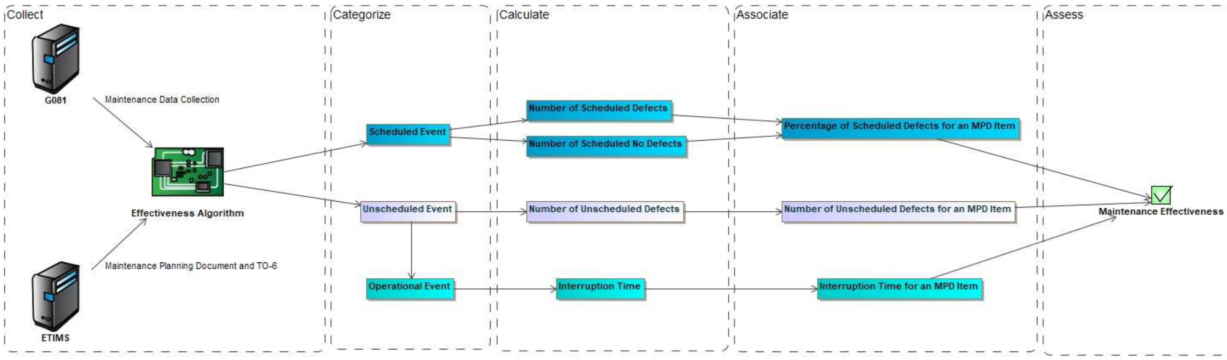

Figure 12: Maintenance Task Evaluation OV-1[7]

An Operational Activity Model (OV-5b) for assessing the effectiveness maintenance tasks is located in Appendix A and details the complete steps in the OV-1 decision making-process. These 47 steps are isolated by functional swim lanes for the maintenance program decision-maker, G081 MIS, and ETIMS. Excerpts from the OV-5b are simplified to show the decision-making steps in the OV-1's categorize, calculate, and associate stages. Figure 13 is a decision tree of the decision-making steps found in the OV-1's categorize and calculate stages which adjudicates specific fields in the collected maintenance data (e.g., Job Control Number (JCN), How Malfunction (HM) Code). Figure 14 illustrates the decision process in the OV-1's associate stage to then quantify the effectiveness and optimality of an MPD task in the calculate stage.

[7] An expanded view of the MBSE diagrams in Figures 12, 13, 14 and 16 is provided in Appendix A for better readability.

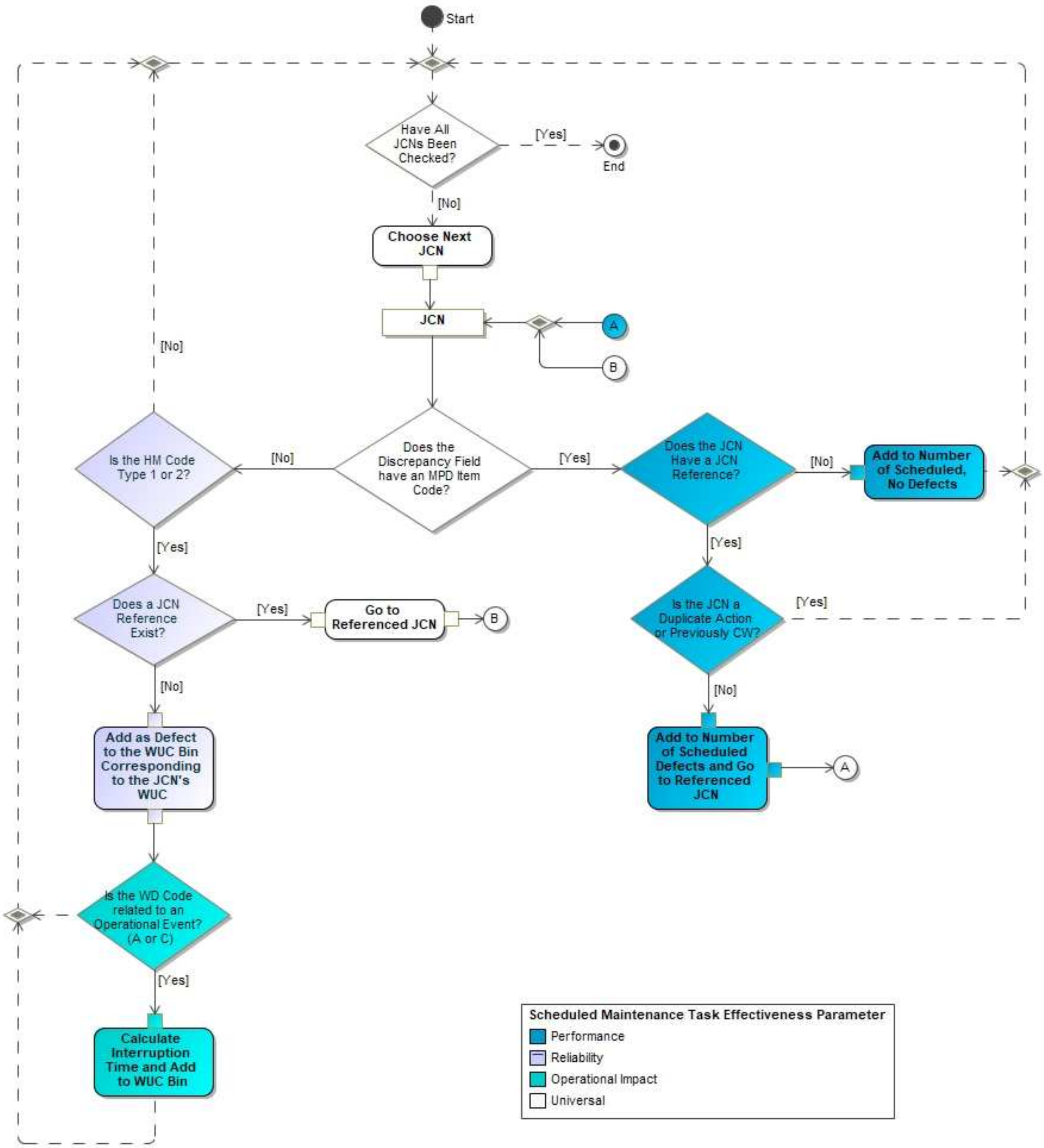

Figure 13: OV-1 Categorize and Calculate Stage Decision Tree

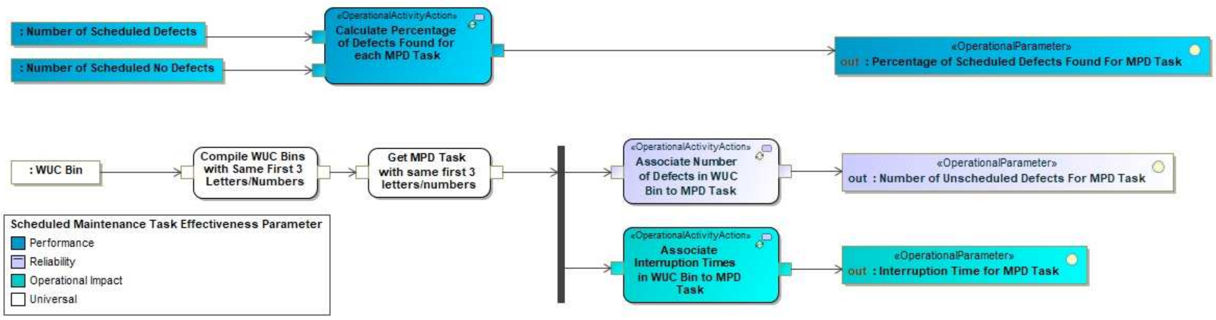

Figure 14: OV-1 Associate Stage Decision Process

3.2.1.2. Information Views

As prescribed by Giachetti in his book *Design of Enterprise Systems: Theory, Architecture, and Methods*, the information view is third and final domain to be integrated with organizational and process viewpoints when applying ESE [15]. For the KC-46A maintenance program, performance metrics inform decision-making related to maintenance intraprises and processes. Figure 15 displays the conceptual data model, or Data and Information View (DIV-1), of information elements that measure the effectiveness and efficiency of the KC-46A maintenance program. The SPO's CASS program evaluates the overall effectiveness of KC-46A maintenance tasks to inform adjustments to their execution and/or scheduled interval. The AMC Health of the Fleet (HOF) metrics report the performance and efficiency of individual O-level operating units based on their execution of the KC-46A maintenance program.

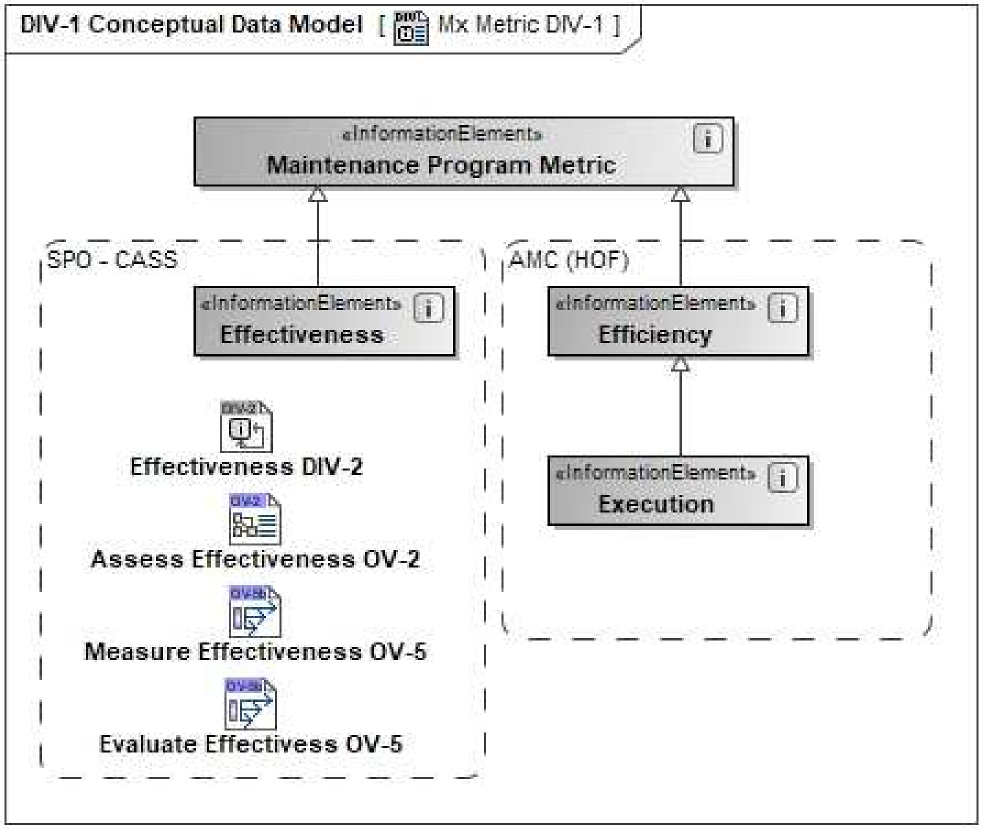

Figure 15: Maintenance Program Decision-Making Conceptual Data Model (DIV-1)

At a lower level of abstraction, Figure 16 is a logical data model (DIV-2) showing the execution of the KC-46A maintenance program driven by ETIMS (specifically the maintenance requirements found in the MPD and TO-6) and collected by G081. The Job Control Number (JCN), colored in orange, serves as the primary key for O-level maintenance actions with many other fields composing the complete unit of work. This G081 data is consumed by the KC-46A CASS office to assess the effectiveness of an MPD task based on its reliability, performance, and operational impact. Appendix A also contains an Operational Resource Flow Description (OV-2) to show how O-level maintenance data is captured and provided to the KC-46A SPO and AMC via G081. An entity relationship diagram of a KC-46A maintenance task is also provided in

Appendix A for reference in data base design activities.

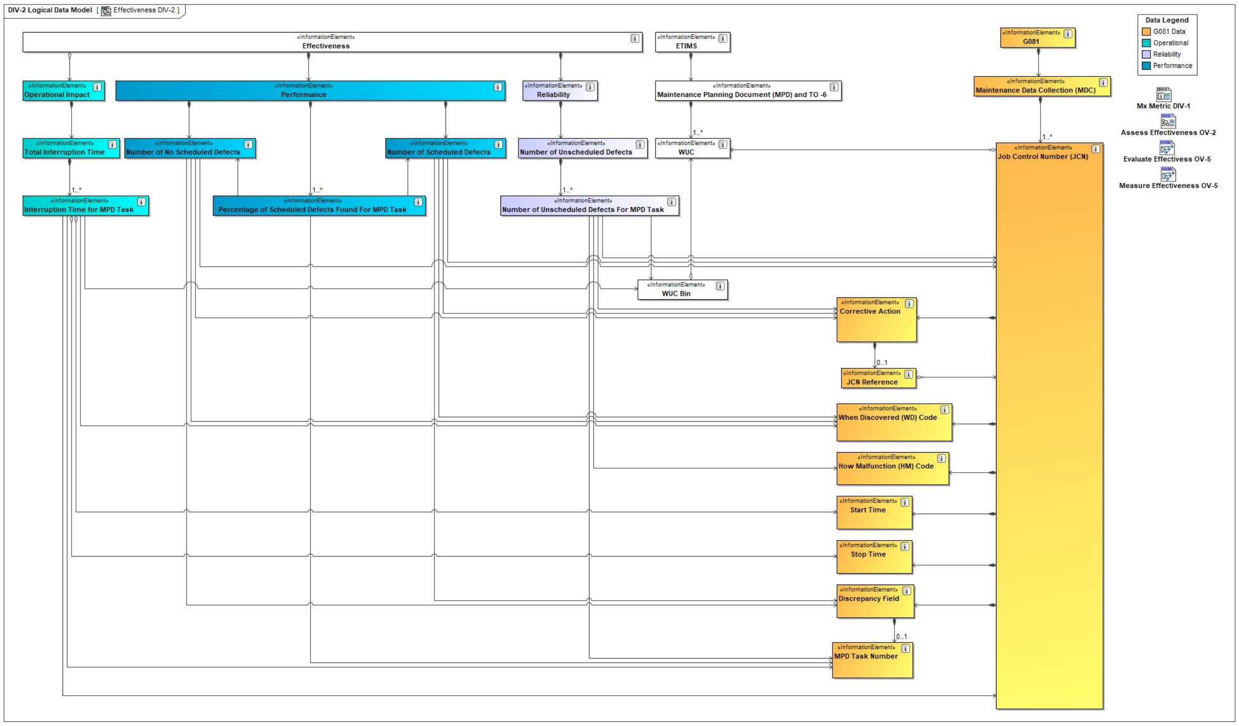

Figure 16: Maintenance Program Decision-Making Logical Data Model (DIV-2)

3.2.1.3. Maintenance Program Relationship Summary

These MBSE products begin to define decision-making in the KC-46A maintenance program system across the organization, process, and information domains. They also inform how the KC-46A SPO and AMC leverage operational data from O-level maintenance units to manage the USAF's relationships with Boeing and the FAA[8]. Additionally, they provide a foundation to improve KC-46A maintenance program management to address observed decision-making limitations and underperformance of the KC-46A sustainment enterprise's five critical functions.

[8] While D-level data from KC-46A C-checks are also of interest, the scope of this research is limited to O-level data on A-checks.

3.3. B767 Commercial Comparison

While the first KC-46A was fielded in 2019, its B767 commercial counterpart has been in operation since the 1980's. This operational history is a salient opportunity to evaluate and benchmark KC-46A maintenance program decision-making to an industry-leading B767 commercial operator. Several opportunities are identified for translating ESE and decision support applications from the commercial B767 maintenance program to the KC-46A maintenance program including:

- Fleet maintenance performance metrics:
    a. **KC-46A**: Primarily lagging metrics including Aircraft Availability and Mission Capability rates versus
    b. **Commercial B767**: Primarily leading metrics including Composite Aircraft Risk and Irregular Operations Buffer,
- Customization of the B767 MPD:
    a. **KC-46A:** Accepted as-is from Boeing resulting in conservative maintenance requirements versus
    b. **Commercial B767:** Customized to optimize operational performance, and
- Maintenance Task Interval Parameters:
    a. **KC-46A:** Fixed A/C-check calendar-based intervals versus
    b. **Commercial B767**: Dynamic A/B/C check utilization-based intervals.

These differences of the B767 maintenance program (i.e., only the MPD excluding military unique requirements for the KC-46A) are illustrated in Figure 17 and detailed in Sections 3.3.1, 3.3.2, and 3.3.3 respectively.

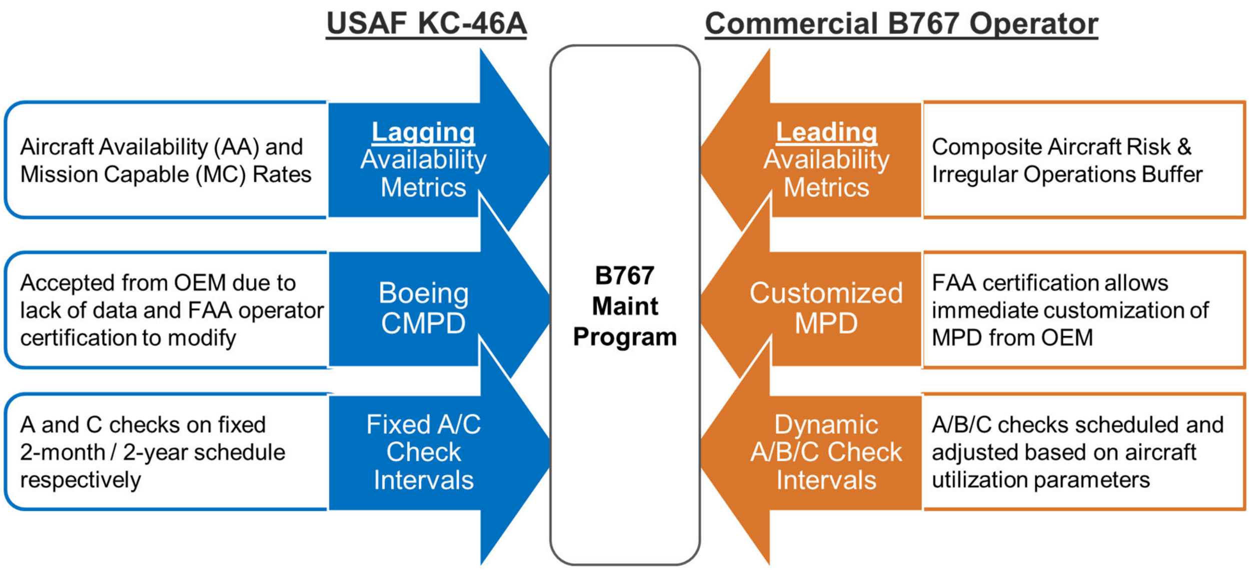

Figure 17: B767 Maintenance Program Comparisons

3.3.1. Lagging versus Leading Metrics Comparison

In terms of B767 maintenance program decision-making, a critical opportunity for ESE and decision support methods is in benchmarking the sustainment metrics (i.e., enterprise information) reported between the KC-46A and B767. These metrics incentivize organizational behavior in the respective sustainment enterprises and are directly related to the proposed ESE and decision-support disciplines via their critical role in measuring enterprise management decisions and the performance of the KC-46A maintenance program[9]. Specifically, Ead and Blond et al. highlight how reported sustainment metrics drive significant differences in the operational success of the B767 maintenance program between the two operators (i.e., the USAF and the B767 commercial airline) [60, 61].

For the KC-46A, Aircraft Availability and Mission Capable rates are the primary RAM-C metrics reported regarding sustainment. These lagging metrics measure aircraft operational

[9] To quote Dr. Eli Goldratt, the father of the systems engineering discipline Theory of Constraints, regarding performance metrics, “Tell me how you will measure me, and I will tell you how I behave.”

availability at the organizational maintenance unit and fleet level by the SPO and AMC. Comparatively, the B767 operator focuses on the leading metrics of aircraft composite risk scores and irregular operations buffer (also referred to as days of aircraft health) [62, 63]. These forward-looking metrics project the reliability and availability of a B767 to inform maintenance management decisions associated with future plans.

The key observed differences in the USAF and commercial sustainment enterprises is that the KC-46A is often reactive to maintenance decisions while the B767 operator is more proactive. Often, the KC-46A's lagging metrics result in local optima of maintenance program performance focused on availability with limited synchronization across the rest of the enterprise. While the commercial operator is more centralized in their organizational construct compared to the distributed nature of the USAF, AF/A4 [19] and Blond et. al recognize that the airline's improved sustainment performance is a product of the leading metrics used that prioritize operational reliability with a secondary focus on availability [41] [19, 61]. These different approaches to metrics offer unique perspectives in ESE and decision-support applications for the KC-46A maintenance program management.

3.3.2. Maintenance Program Customization

Additional differences observed between the KC-46A and B767 is the extent of maintenance program customization to support their respective operations. The KC-46A SPO directly transcribes Boeing's MPD into its technical orders that set maintenance requirements for O/D-level units. Boeing must achieve a 95 percent confidence level when setting these maintenance requirements due to approving an MRB Report for global fleet use without the ability to continually monitor its performance. Thus, the requirements in the KC-46A's CMPD are often more conservative in their interval determination compared to the commercial operator's program[10]. [64, 65]

In contrast, the B767 commercial operator emphasizes the FAA's guidance stating "operator reliability programs should continue to ensure continuous evolution/optimization of their maintenance programs" [66]; the operator highlights that Boeing does not have direct access to operational data to revise maintenance requirements and thus relies on operators, like the USAF, to customize the generic B767 maintenance program. The B767 commercial operator actively participates in industry activities to advocate for maintenance task interval adjustments and modify the MRB Report to best meet their operational needs/performance standards while satisfying regulatory requirements. GTRI and the KC-46A SPO recognize the need for these adaptations to improve KC-46A sustainment and best utilize commercial resources in its sustainment[11].

These maintenance program customizations have critical implications across the KC-46A sustainment enterprise and SPO maintenance leadership has identified the need for more agile means of adapting the maintenance program in the context of industry regulation [22, 23, 33]. ESE provides a means of addressing this need to manage the complexities of KC-46A sustainment with decision support methods providing the necessary techniques to augment and improve decision-making to achieve KC-46A sustainment goals.

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[10] Tilden et al. [63] determined that more than half of the KC-46A's scheduled maintenance program intervals received from Boeing are more conservative than their commercial B767 counterparts despite significant less aircraft utilization. This results in decreased availability and higher maintenance costs for the USAF compared to the commercial airline.

[11] A contract summary where GTRI is classified as an "expert witness" for the KC-46A maintenance program on this topic can be found at the following link: <https://www.usaspending.gov/award/CONT_AWD_FA852321F0056_9700_FA852319D0006_9700>

3.3.3. Fixed versus Dynamic Inspection Intervals

A final ESE and decision support related observation is the difference between how maintenance requirements are scheduled for the KC-46A and commercially operated B767. During the KC-46A's acquisition, the USAF decided to perform major scheduled maintenance inspections/servicing, referred to as letter checks, on a fixed calendar-day interval. This resulted in the A-check, or smallest maintenance check, to be scheduled every two months at O-level maintenance units and the C-check, or largest check, to be scheduled every two years at the D-level. While this scheduling predictability and simplicity is conducive to the federated organizational construct of the KC-46A sustainment enterprise, Tilden et al. [67] highlight the opportunity cost of strictly calendar-based intervals compared to utilization driven intervals such as flight hours and flight cycles (i.e., take off and landings). Additionally, Bowers [33] identifies additional RAM-C decreases caused by the KC-46A's calendar-based letter checks from scheduling them in a start to start manner (i.e., the two-month interval for the next A-check begins counting down when the aircraft starts its current A-check). This is the opposite of the commercial operator's finish to start approach which begins counting down letter check intervals after the previous check is completed and the aircraft re-enters service. Thus, maintenance costs are accrued for the commercial B767 only when it is in operation versus the KC-46A which continues to accrue maintenance costs while it is not flying during a maintenance visit.

Conversely, the experiences of the benchmarked B767 commercial operator illustrates how dynamic letter check intervals enable optimization in its maintenance program to deliver increased aircraft utilization, reliability, and availability. Coupled with the customization of the B767 MPD discussed in the previous section, the commercial airline flies their aircraft at a much higher rate while incurring less down time due to scheduled maintenance requirements. This is accomplished through a combination of A, B, C, and D checks (ranging from least to most maintenance requirements respectively). The commercial airline also proactively accomplishes standalone maintenance tasks usually performed outside of a hangar (referred to as “line” tasks) concurrently with letter checks to reduce costs and increase availability. In a similar fashion, they also extract tasks scheduled for a letter check to be completed overnight if it optimizes their B767 RAM-C performance. [68]

These differences are illustrated in Figure 18’s representative maintenance schedule highlighting the KC-46A’s 30 days of fixed A-check unavailability versus the commercial B767 operators three days of dynamic A/C-check unavailability per C-check cycle [adapted from 68]. The resulting impact on sustainment performance is more operational availability at lower maintenance costs for the commercial operator. Given the KC-46A’s underperformance in meeting RAM-C objectives, the observed differences in scheduling, maintenance customization, and reported metrics aptly inform ESE and decision support applications to current KC-46A maintenance program decision-making.

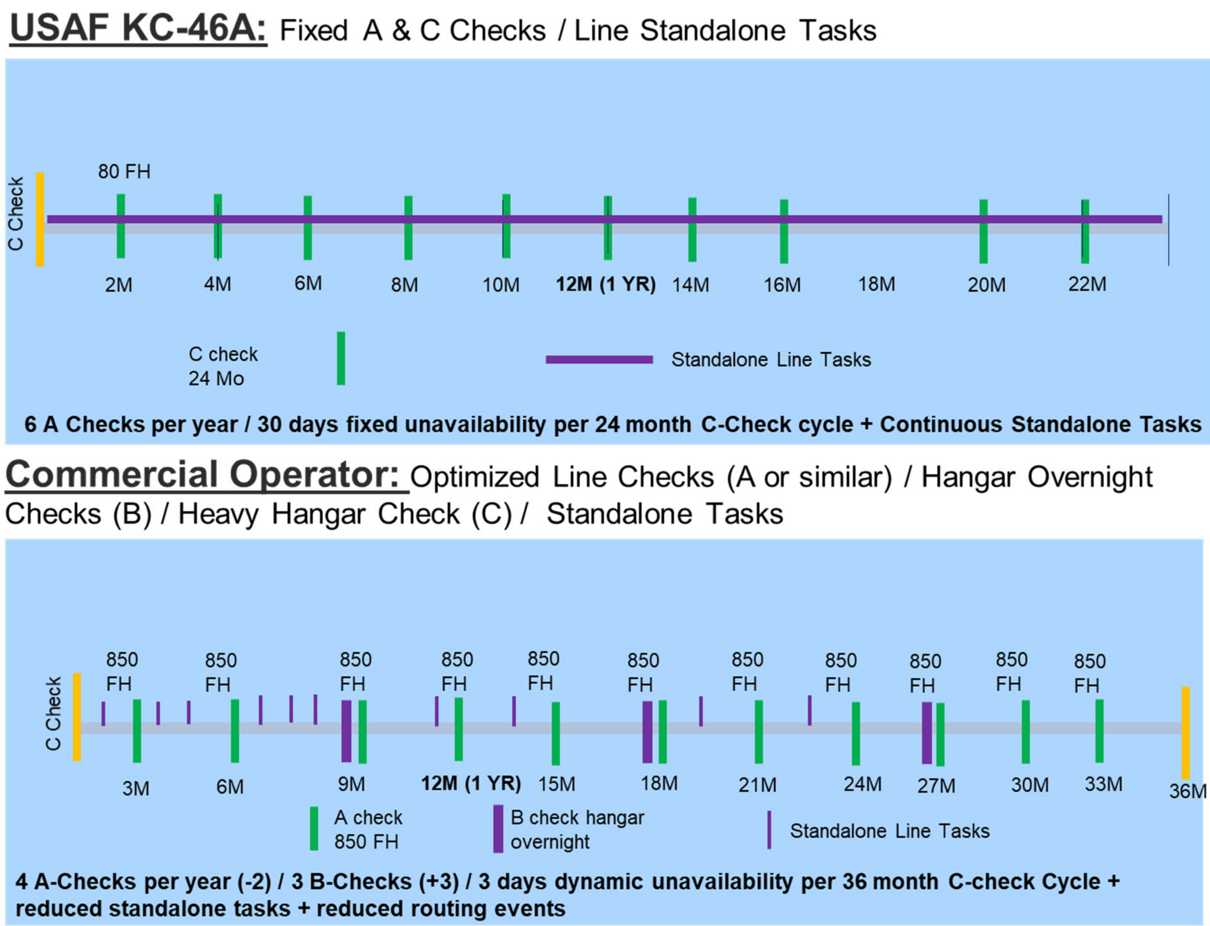

Figure 18: KC-46A versus Commercial Operator Representative Maintenance Schedule [Adapted from 68]

3.3.4. Conclusion

Research Question 1's answer defines the substantive benefits and shortcomings of current KC-46A maintenance program decision-making frameworks that ESE and decision support methods may be able to address. This question was answered through three research tasks resulting in the definition of the KC-46A maintenance program as an industrial enterprise system, the development of enterprise relationships influencing decision-making, and the observation of ESE/decision-support improvement opportunities based on comparison to a leading commercial B767 operator.

The triangle enterprise model is used to define the KC-46A sustainment enterprise and its maintenance program by defining the inputs and outputs of requirements owners, resource sponsors, and providing organizations. Specifically, the model defines the FAA and Boeing inside the KC-46A SPO's sphere of influence to focus CASS maintenance task improvements by providing operational feedback to the FAA and Boeing's industry maintenance requirements. This enterprise model is coupled with a critical function analysis of KC-46A sustainment to map key USAF organic sustainment activities to industry and regulatory decision-making vehicles (e.g., ISC, MRB). Organizational, process (i.e., operational), and information viewpoints are developed using MBSE and DoDAF version 2.0 to detail KC-46A maintenance program decision-making in the KC-46A sustainment enterprise.

The resulting conclusions identify that the KC-46A sustainment enterprise can improve maintenance program decision-making, specifically the adjustment and optimization of maintenance tasks and their intervals, by providing recommendations to the B767 MRB based on operational data and FAA guidance. Additional evidence supporting performance improvements relates to readiness metrics, maintenance program customization, and letter check scheduling through comparing the KC-46A sustainment enterprise to a B767 commercial operator.

These results of Research Question 1 provide a foundation for understanding the specific aspects of ESE and decision support methods beneficial and costly to the KC-46A maintenance program (i.e., Research Question 2). Specific research contributions from these results include the formal mapping of maintenance program management decisions to KC-46A sustainment enterprise activities and a novel demonstration of ESE applications to a DoD maintenance program.

CHAPTER 4: ESE AND DECISION SUPPORT APPLICATIONS TO THE KC-46A MAINTENANCE PROGRAM

The KC-46A CASS TO states “CASS Office analysts will continuously analyze KC-46 data in the PFMT to identify characteristics indicating a need for program adjustment, revision of operational or maintenance practices, or equipment improvement (i.e. modification)”[69]. These standard KC-46A procedures are derived from the FAA’s guidance on developing and implementing a CASS program which states “your CASS documentation should include a means of identifying data that is relevant and useful for you to use in monitoring the effectiveness of your specific and unique maintenance program” [70]. Additionally, Figure 19 contains the FAA’s framework to manage and administer the KC-46A CASS program. This framework serves as the basis for any B767 operator to generate reports that provide Boeing and the FAA operational feedback on the performance of the maintenance program via a reliability program such as a CASS.

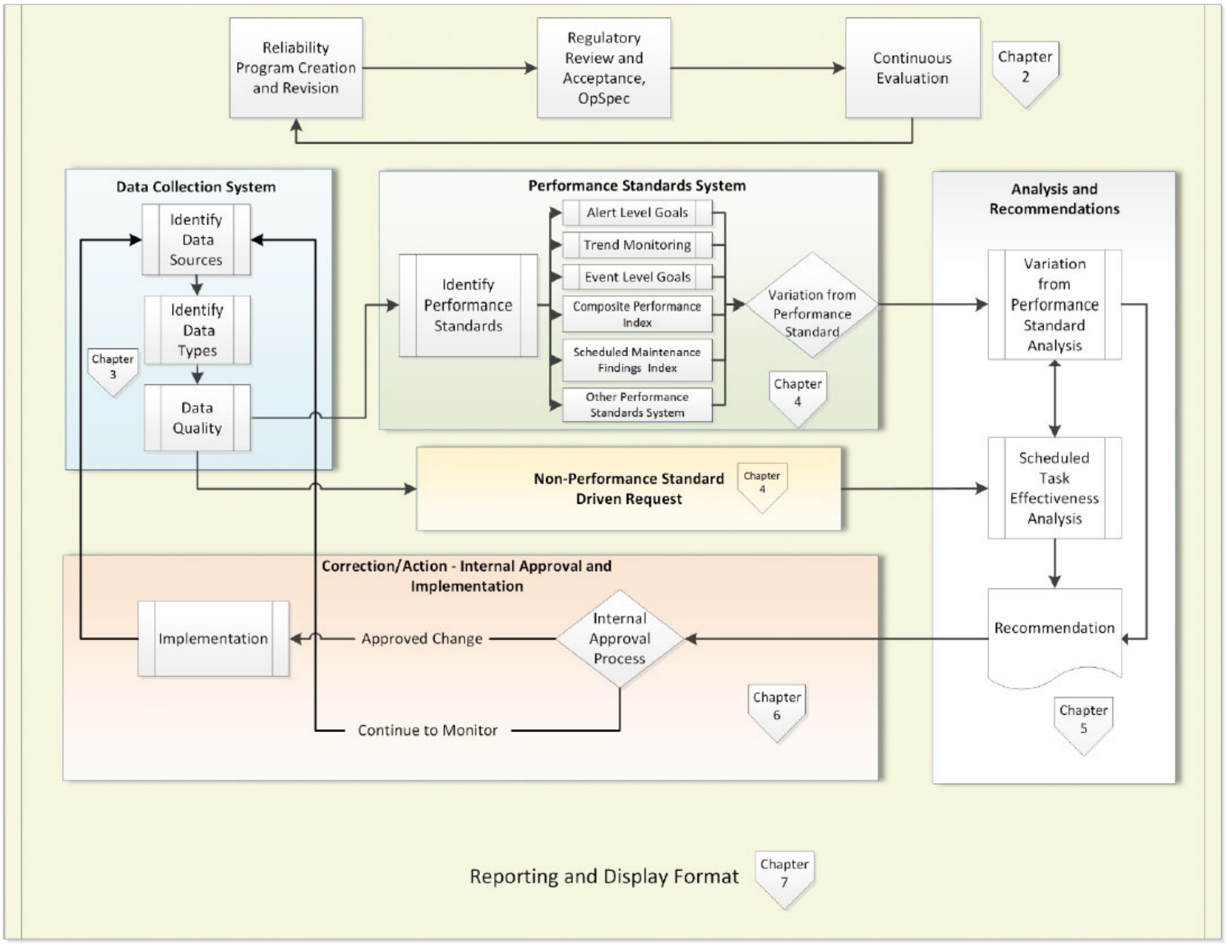

Figure 19: FAA's CASS Management and Administration Framework [24]

In order to apply, execute, and manage ESE and decision support methodologies for the KC-46A maintenance program via its CASS, the USAF invested in PFMT as an enterprise decision-making platform. It is built on an AWS GovCloud back end and a Tableau front end. PFMT is intended and capable of conducting many fleet management functions related to the KC-46A maintenance program. These include hosting G081 maintenance data, conducting analysis on aircraft flight data, and managing workflows between engineering and O/D-level maintenance units. Figure 20 from the KC-46A CASS TO shows how PFMT captures this documentation and supports decision-making for the KC-46A maintenance program. The reports generated by PFMT are intended to provide operational feedback to Boeing and the FAA via the B767 ISC and MRB.

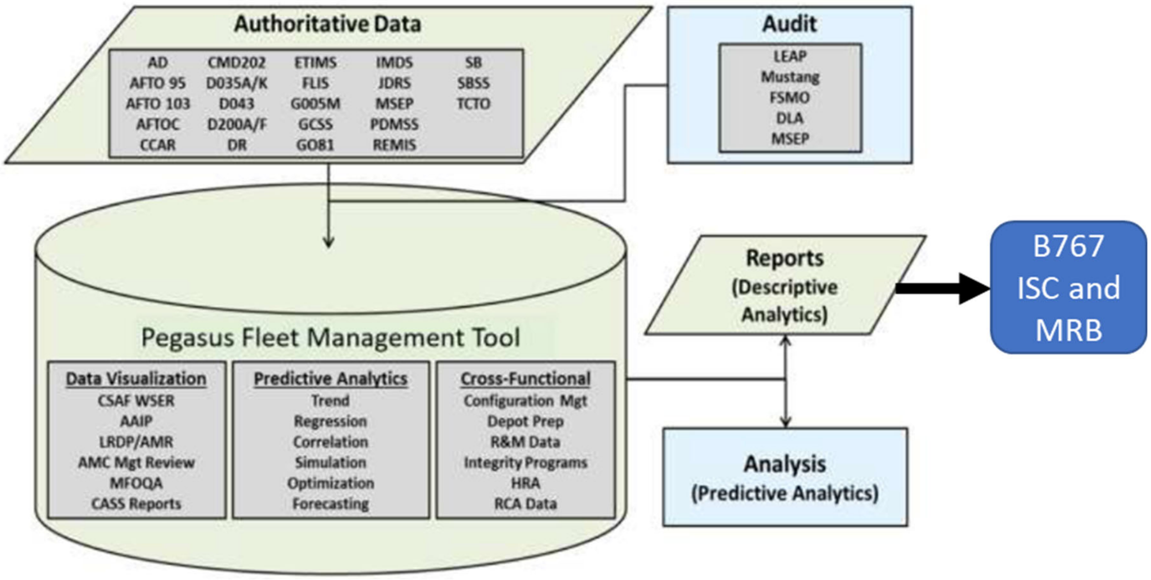

Figure 20: PFMT Overview in the KC-46A CASS Program [Adapted from 69]

To this end, PFMT is the focus to answer Research Question 2 in this chapter restated here:

Research Question 2 - What aspects of ESE and decision support methods are beneficial or costly to the KC-46A maintenance program?

The researcher answered this question by examining PFMT to understand the opportunities (Section 4.1), costs (Section 4.2.1), and barriers (Section 4.2.2) for ESE and decision support opportunities in the KC-46A maintenance program. Lastly, a high-level plan is proposed in Section 4.3 to implement selected ESE and decision support methods. In summary, answering Research Question 2 completes data exploration and problem framing/discovery to propose which ESE and decision support methods the proposed framework recommends for KC-46A maintenance program decision-making.

4.1. ESE and Decision Support Opportunities

To understand the current state of KC-46A maintenance program decision-making, the researcher accessed and evaluated PFMT and the CASS TO governing its purpose. An analysis of critical functions in PFMT informed opportunities to apply ESE and decision support methods. These methods are intended to support the CASS Office in analyzing the KC-46A maintenance program's performance as illustrated in Figure 21. Gaps related to PFMT that present ESE and decision support improvement opportunities include:

- Section 4.1.1: The monthly CASS Review Board (CRB) lacking an information viewpoint
- Section 4.1.2: Underdevelopment of PFMT's CASS modules
- Section4.1.3: A knowledge engine as a missing DSS element in PFMT

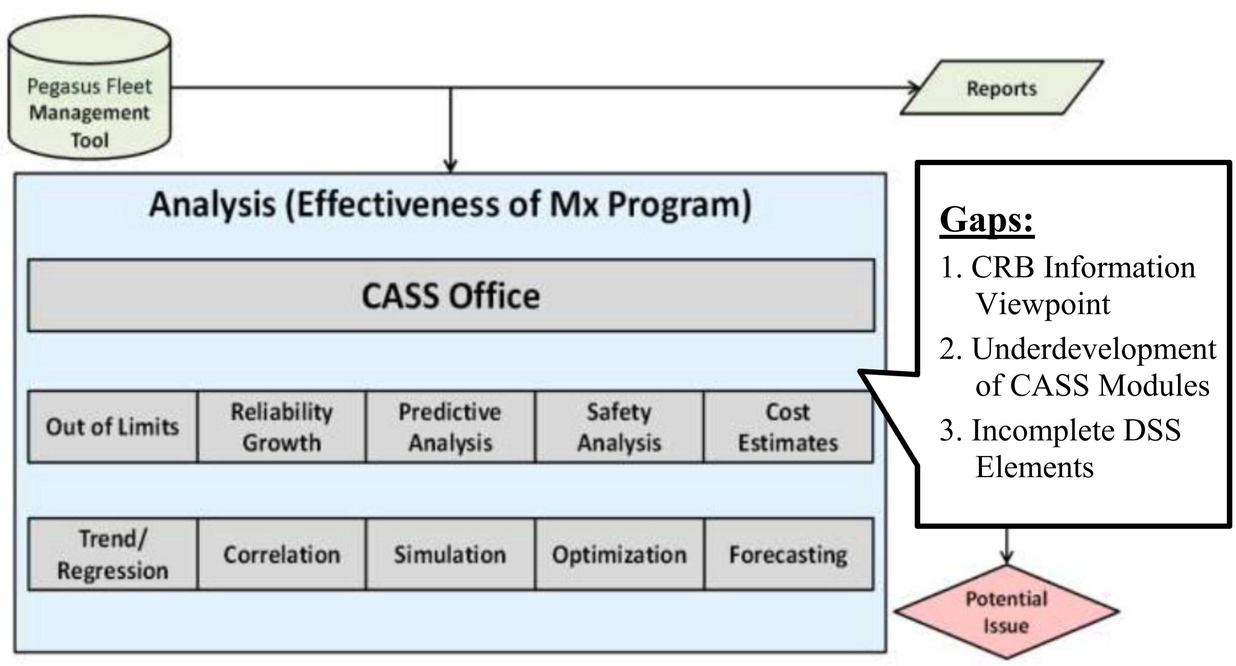

Figure 21: PFMT Analysis Functions and Gaps [Adapted from 69]

4.1.1. CRB Information Viewpoint

The CRB is a monthly meeting to review and report the data in PFMT and generate action items to address potential issues or pursue improvement opportunities. These action items cover the breadth of KC-46A sustainment functional activities to resolve maintenance program issues (e.g., ineffective scheduled maintenance tasks). The CASS TO includes the CRB's high level organizational and process viewpoints shown in Figure 22.

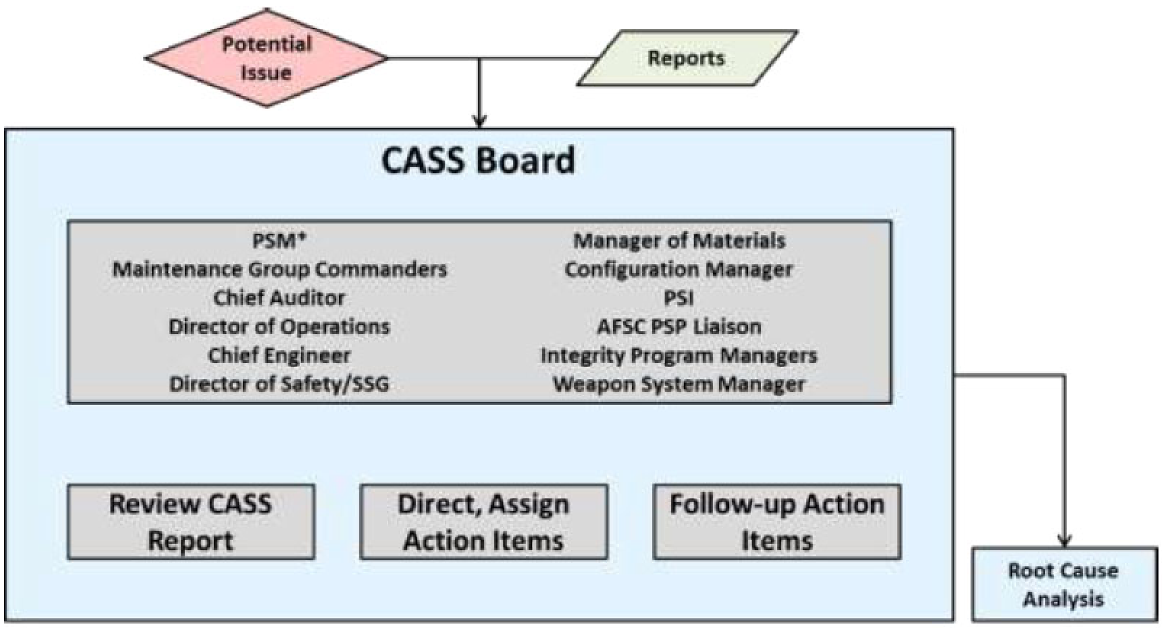

Figure 22: CRB Organizational and Process View [69]

The CASS TO states a CRB report can include "Maintenance Reports by Work Unit Code (WUC) (e.g., top drivers or trends)" [69]. These WUCs are the data representation of physical systems and maintenance actions including the KC-46A's scheduled maintenance tasks. While WUCs, along with other required fields in G081 data adequately describe the maintenance action being performed on an aircraft, the literature[12] resolutely describes the limitations of KC-46A

[12] In 1987, RAND stated USAF maintenance data "do not contain all of the information necessary to make …final R&M decisions" and "no new or improved data systems will either" [69]. Under contract with the KC-46A SPO, Blond et al. validated the longevity of these shortfalls by detailing 28 related gaps and their corrective actions in KC-46A maintenance data to enhance and optimize the KC-46A maintenance program [70].

maintenance data to achieve the FAA's intent for CASS data to understand "the potential significance of each data set and how to process the data to understand its significance" [70-72]. It is also clear from literature that information viewpoints are critical for the architecting of information intensive aerospace systems such as the KC-46A CASS program [73].

To overcome these challenges in KC-46A maintenance data, opportunity exists to better trace KC-46A maintenance data to CRB activities and decisions. Specifically, ESE's integrated application of organizational, process, and information viewpoints combine the organizational and process views found in the KC-46A CASS TO (e.g., Figure 22) with the information/data views provided in Section 3.2.1.2 and Appendix A. This approach is required to achieve the necessary understanding of the KC-46A maintenance program as an industrial enterprise system. Using this understanding enables us to engineer the CRB's complex decision-making to formally and continuously evaluate KC-46A maintenance performance in PFMT.

4.1.2. Underdevelopment of PFMT's CASS Modules

Upon accessing PFMT and conducting interviews with SMEs regarding its function as a DSS in the KC-46A's CASS program, the various analytic modules in PFMT's CASS workspace are currently underdeveloped to support KC-46A decision-making. Specifically, the help screen for PFMT's CASS workspace states that its five modules are either actively being enhanced or will be enhanced upon delivery of KC-46A aircraft[13]. A particular module of interest is the Maintenance Effectiveness Module intended to track the maintenance program effectiveness requirements of CASS. Figure 4 illustrates the decision criteria, as recommended by the FAA, to

[13] PFMT's CASS workspace modules include CASS Management, Performance, Maintenance Effectiveness, Analytics, and R&M. Upon accessing these modules and interviewing KC-46A sustainment SMEs, the researcher observes that they are not being developed or maintained in accordance with the delivery of KC-46A aircraft.

evaluate maintenance program effectiveness based on the number and operational impact of scheduled/unscheduled maintenance defects in the KC-46A's operation.

PFMT's Maintenance Effectiveness module under the CASS workspace, along with other modules, are inactive and not currently used in CASS decision-making. Correspondence with KC-46A SMEs indicates these modules are not a formally funded requirement by the USAF due to other higher priority acquisition and sustainment challenges facing the KC-46A. As a result, much of the CASS decision-making is performed manually and ad hoc by SMEs in a functionally isolated manner across the enterprise.

Given PFMT's capabilities as a modern DSS, this gap presents opportunities to scale decision support methods in the KC-46A maintenance program. Specifically, implementing the FAA's CASS guidance to improve KC-46A maintenance program effectiveness can begin to address the sustainment underperformance illustrated in Figure 2's RAM-C metrics. Additionally, ESE considerations integrating organizational, process, and information viewpoints enable the organizational change management in the KC-46A sustainment enterprise to realize these KC-46A maintenance program improvements.

4.1.3. Incomplete DSS Elements in PFMT

A complete DSS contains the following four functional components [74]:

1. Database: Responsible for the storage, organization, and distribution of KC-46A sustainment data.
2. Dialogue Manager (i.e., user interface): Serves as the user interface to input and output information for the DSS.
3. Model Library: Maintains and manages a library of models to be queried by the DSS.

4. Knowledge Engine: Applies models to data to support decisions.

Mapping these requirements to the PFMT's current state, PFMT's AWS GovCloud back end serves as the database, knowledge engine, and model library while its Tableau front end is the dialogue manager. As an objective-level DSS model[14], PFMT is intended to enhance decision processes for KC-46A sustainment stakeholders by better understanding the problem at hand [74]. In application, PFMT provides CASS decision support through representing the KC-46A maintenance program as an industrial enterprise system and providing details on KC-46A maintenance improvement opportunities. This support is based on objective historical data, primarily KC-46A maintenance data from G081, and subjective expert knowledge to make inferences on that data.

The observed decision-making behavior in the KC-46A maintenance program, along with PFMT's CASS workspace underdevelopment, indicate that expert knowledge has not been expressed in PFMT to fully leverage its role as a DSS. Specifically, techniques and assumptions used by KC-46A sustainment decision-makers have not been appropriately modeled to translate KC-46A maintenance data into enterprise actions (i.e., developing knowledge from data to inform actions). Opportunity exists to address this gap through knowledge engineering in PFMT (i.e., decision support) to improve CASS performance outcomes during CRB enterprise collaborations (i.e., ESE).

Regarding KC-46A maintenance program effectiveness, the proposed ESE and decision support solutions provide a knowledge engine and model(s) to complete PFMT as a DSS executing the standard procedures prescribed in the KC-46A CASS TO. These knowledge engine and

[14] Objective level as compared to meta level which seeks to optimize versus support the decision being made. Given the unstructured nature of KC-46A maintenance program decision-making making analytic optimization beyond the scope of this research, an objective level DSS is most applicable to support end users with heuristic optimization using expert rule-based systems.

model(s) are recommended to be the knowledge process element of PFMT's Maintenance Effectiveness Module and infer the CASS R&M performance of maintenance tasks from G081 operational data. Boeing offers an extremely relevant solution to apply the FAA's CASS guidance to the KC-46A's commercial counterparts through their Statistical Analysis for Maintenance Optimization (SASMO) tool. Figure 23 shows SASMO's commercial-specific process map and data flows. Figure 24 illustrates SASMO's objective of minimizing the total dollar cost of a maintenance task at the optimal interval based on cumulative percentage of unit cost from scheduled and unscheduled maintenance.

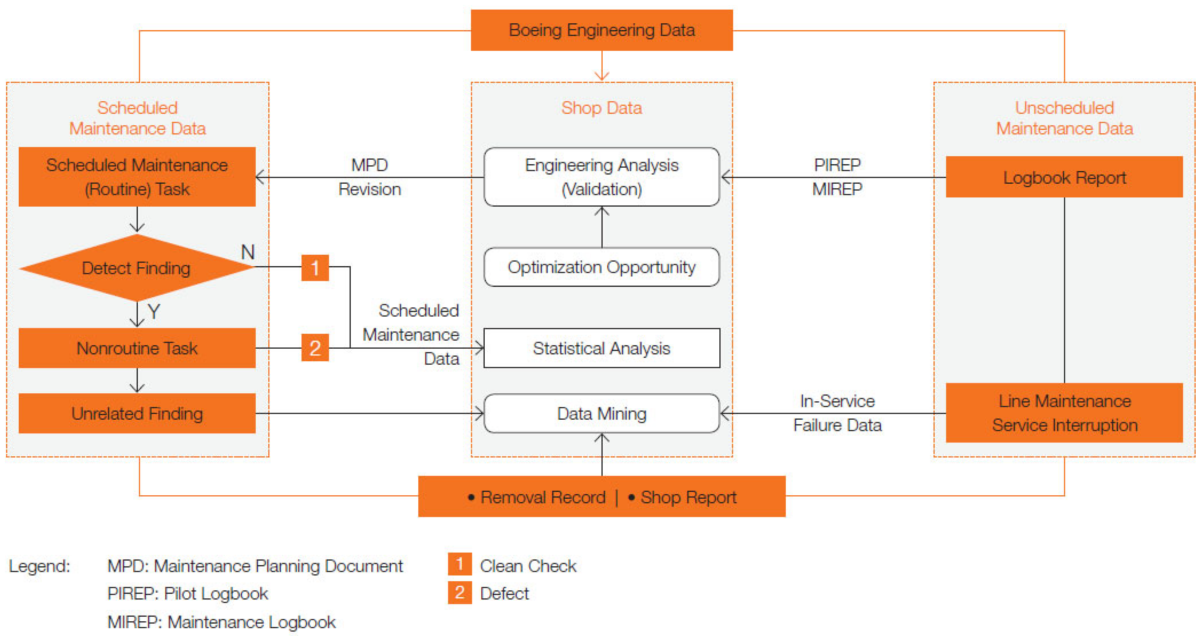

Figure 23: Boeing's SASMO Tool Process and Data Map for Commercial Fleets [75]

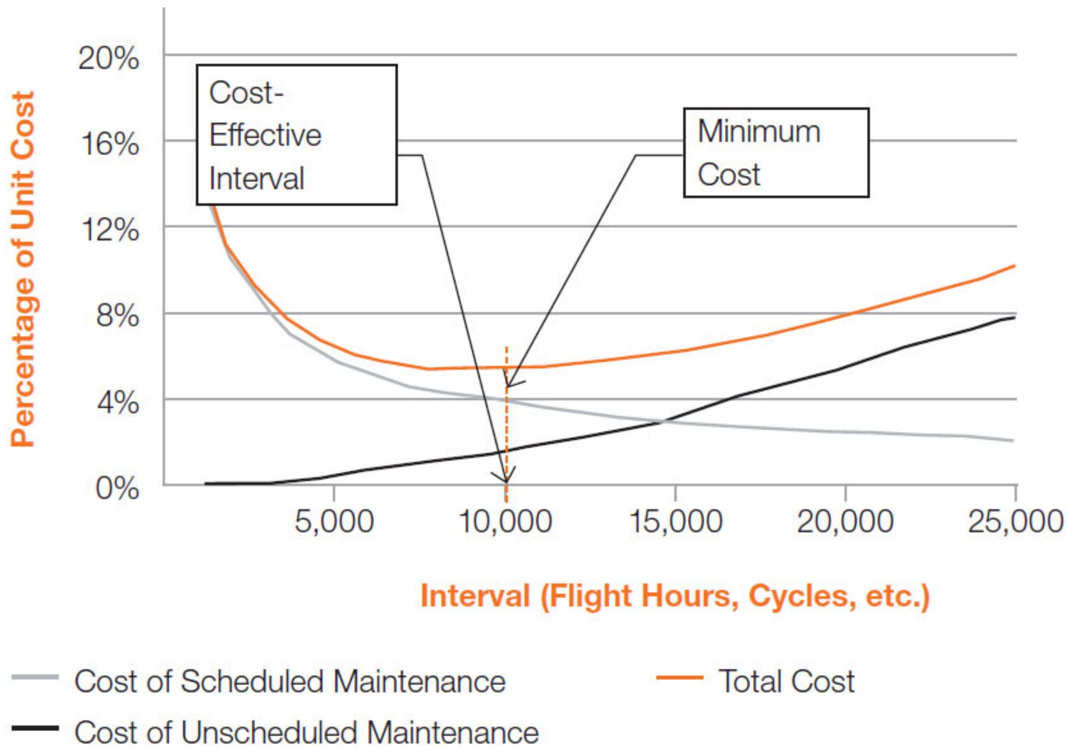

Figure 24: SASMO Economic Analysis of a Maintenance Task [75]

While the SASMO tool represents the art of the possible for a CASS knowledge engine in PFMT, the USAF plans to organically sustain the KC-46A, versus contracting its product support to Boeing[15], through maintaining "equivalency to commercial certification requirements" (i.e. the KC-46A CASS program is required to "monitor, analyze, and optimize the performance and effectiveness of their air carrier maintenance program") [69]. The need for this type of comprehensive ESE approach to serve as the foundation for a decision support tool like SASMO was demonstrated in 2020 when the KC-46A SPO could not justify optimizing two scheduled maintenance tasks due to insufficient KC-46A maintenance data from the sustainment enterprise [26]. Thus, implementing a SASMO-informed knowledge engine and model library in PFMT

[15] Specifically, the GAO details how the USAF is providing its own product support for the KC-46A versus legacy CDA which used contracted sustainment (primarily from the OEM) [9]. This decreases the applicability of SASMO in the KC-46A sustainment strategy given Boeing's subscription business model for the tool.

inclusive of KC-46A specific enterprise attributes aligns to the KC-46A sustainment strategy and is best suited to improve KC-46A maintenance program decision-making.

4.2. ESE and Decision Support Costs/Barriers

Important to answering Research Question 2 is understanding the costs and associated risks of applying ESE and decision support methods to the KC-46A maintenance program. Of interest are the technical and programmatic barriers ESE/decision support are expected to face during implementation. In addition to the "hard" costs of implementing ESE/decision support solutions detailed in Section 4.2.1, the barriers described in Section 4.2.2 translate to technical, business, and cultural risks to the solution's success. Appropriately managing these risks and their relationship to programmatic costs is critical in advancing ESE and decision-support methodologies in the KC-46A maintenance program. Figure 25 summarizes the observed CASS knowledge engine risks, which are assessed and detailed in the following sections.

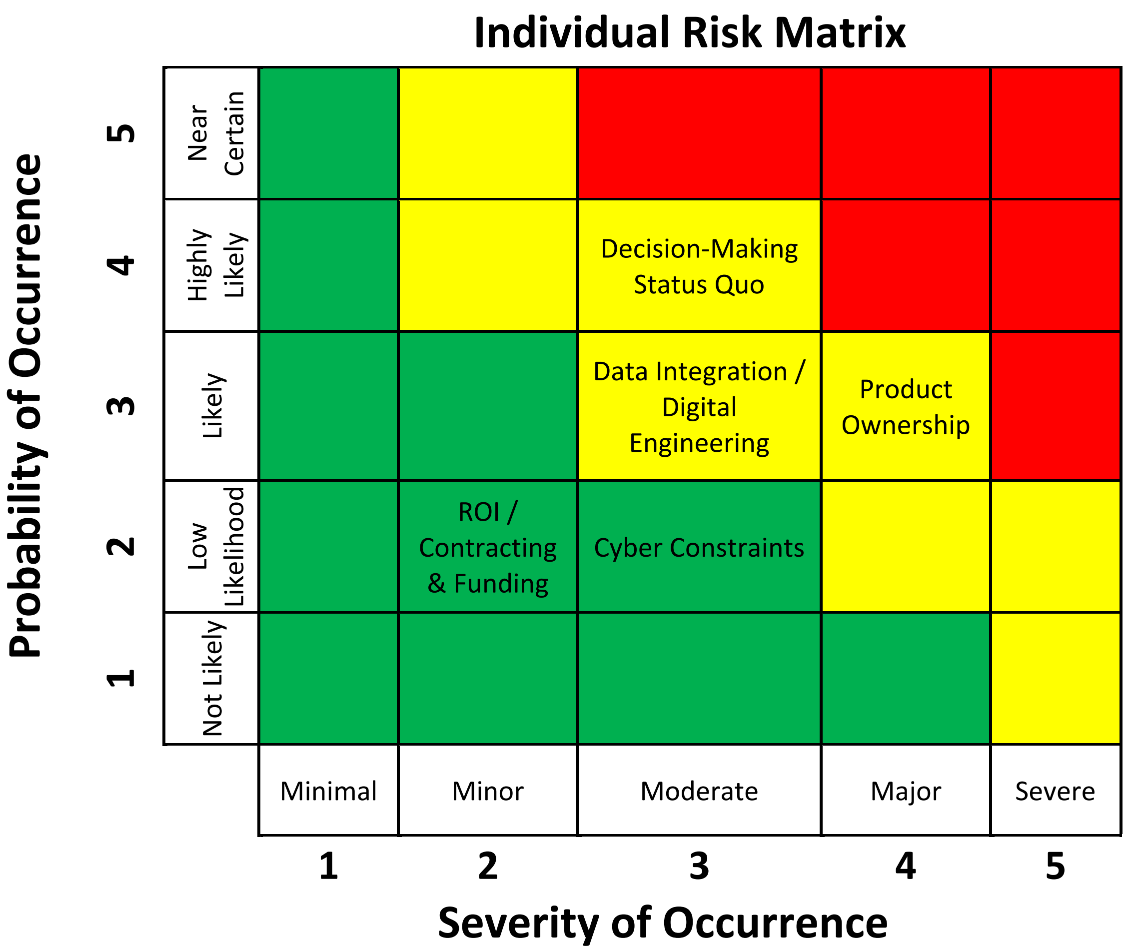

Figure 25: CASS Knowledge Engine Risk Matrix

4.2.1. Costs

Programmatic costs to close the gaps described in Sections 4.1.1 through 4.1.3 using ESE/decision support solutions primarily include monetary costs and time. These costs would pay for the labor, material, services, and fees required to update PFMT and the KC-46A CASS program. The schedule associated with the dollar costs would primarily be used for project management, software development inside PFMT, and organizational change management within the KC-46A sustainment enterprise. PFMT's longer term sustainment costs include its subscription under a software as a service business model.

While evaluating detailed monetary costs is beyond the scope of this research, implementing ESE and decision support solutions is expected to cost hundreds of thousands of dollars based on our estimates. A similar cost estimate is expected for Booz Allen Hamilton to deliver these solutions based on correspondence with the company's PFMT SMEs. The costs include the labor for a project manager, administrative support staff, and various engineers such as a systems, software, and cloud engineer.

The schedule to develop a knowledge engine and maintenance effectiveness model in PFMT is expected to be one year with an additional year of scaling and integrating the module into the CASS program. This two-year timeline includes coordination with KC-46A sustainment enterprise stakeholders (e.g., SPO, AMC/A4, O/D-level maintenance units) via the CRB and is dependent on maintaining a project scope focused on PFMT's Maintenance Effectiveness Module. Before project initiation, additional time is required to complete contracting actions between the USAF and its selected organic and/or contracted support to execute this engineering project.

4.2.2. Barriers

Variability in the monetary and temporal costs discussed in Section 4.2.1 are driven by technical (Section 4.2.2.1), business (Section 4.2.2.2), and cultural (Section 4.2.2.3) risks assessed based on their probability and severity. A risk matrix summarizing this assessment is depicted in Figure 25 and is used to inform risk response planning. If the proposed CASS knowledge engine and Maintenance Effectiveness Module is pursued by the USAF, a more robust risk management plan is recommended to assess and monitor risks, mitigate the impact of any realized risks via corrective actions and management reserves, and maximize the probability of success for the project.

4.2.2.1. Technical

Technical risks are primarily related to the software development and capabilities of the Maintenance Effectiveness Module in PFMT. They include common limitations faced by a DSS that is attempting to model, execute, and prescribe the complex decision-making process of KC-46A sustainment SMEs. Technical risks include:

1. Data integration limitations: While PFMT's AWS GovCloud backend pulls near real-time data from pertinent KC-46A data sources such as G081, the data sets are heterogenous, semi-structured, and require human validation when making critical decisions. While data conditioning and engineering improvements can overcome some of these data challenges, risk exists in not fully integrating and automating KC-46A sustainment data sets required for CASS program decision-making. If this occurs, the ability of the Maintenance Effectiveness Module to support KC-46A maintenance program decision-making may decrease to unacceptable performance levels for KC-46A sustainment stakeholders. The associated risk components are quantified as follows:
    a. Probability: 3 – Likely
    b. Severity: 3 – Moderate
2. Cybersecurity constraints: Given the sensitive and restricted nature of KC-46A data and decision-making, the USAF employs an extremely strong security concept of operations to protect critical data and operational assets. While PFMT has an Authority to Operate (ATO) in the USAF's intranet, cybersecurity controls may limit, delay, or prevent the Maintenance Effectiveness Module's development in PFMT. If these protocols create work stoppages during development, then schedule

and budget slips may occur impacting the project's performance. The associated risk components are quantified as follows:

a. Probability: 2 – Low Likelihood given PFMT's ATO
b. Severity: 3 - Moderate

4.2.2.2. Business

Business risks involve the proposed Maintenance Effectiveness Module's impact on organizational performance for the KC-46A CASS program. They extend to the CASS programs function within the larger KC-46A sustainment enterprise and orient on the organizational and process views of ESE. Business risks threaten the project realizing KC-46A sustainment enterprise RAM-C objectives and include:

1. <u>Measuring the project's return on investment (ROI):</u> The KC-46A is currently in its acquisition phase in which the KC-46A sustainment enterprise is developing as the aircraft is fielded and overcoming various acquisition challenges. Because of this dynamic environment, establishing causal relationships among ESE/decision support improvements in PFMT, CASS program objectives, and KC-46A sustainment enterprise goals is difficult. If the researcher is unable to measure the Maintenance Effectiveness Module's ROI for the KC-46A, then the project may not be supported or sustained by USAF stakeholders. The associated risk components are quantified as follows:
   a. Probability: 2 – Low Likelihood
   b. Severity: 2 - Minor
2. <u>Product ownership:</u> While the KC-46A SPO is responsible for managing the KC-46A CASS program, it operates as a matrixed organization supported by the

AFLCMC's Product Support Engineering Division (EZP). AFLCMC/EZP provides R&M expertise and technical processes to the KC-46A SPO. Thus, organizational debate may occur on whether the KC-46A SPO or EZP is primarily responsible for PFMT's Maintenance Effectiveness Module. If this product ownership is not established in a timely manner by the USAF, then significant schedule delays may occur. The associated risk components are quantified as follows:

   a. Probability: 3 – Likely
   b. Severity: 4 - Major

3. <u>Contracting and funding:</u> Similar to the product ownership risk, organizational ownership of the Maintenance Effectiveness Module results in various contracting and funding implications. These implications require certain conditions to be set between the USAF and its contracted support to execute the project. If these contracting and funding conditions delay or deter the project, then the module's schedule and budget may slip. The associated risk components are quantified as follows:

   a. Probability: 2 – Low Likelihood
   b. Severity: 2 - Minor

4.2.2.3. Cultural

Cultural risks implementing ESE/decision support improvements via PFMT are related to the depth and breadth of project adoption by KC-46A sustainment stakeholders. This user buy-in is critical to drive the organizational change management and decision-making enhancements proposed by this project. Effectively communicating plans and results to for the Maintenance

Effectiveness Module assists in navigating the cultural norms of the KC-46A sustainment enterprise. Similar to a comprehensive risk management plan, the USAF is recommended to develop a communication and stakeholder management plan if this effort is pursued.

Cultural risks identified during this research are as follows:

1. Decision-making status quo: As previously discussed, KC-46A maintenance program decision-making is currently manual, ad hoc, and functionally isolated in the enterprise. This characterization results in decision-makers skepticism of technology solutions changing decision processes across organizations. As a result, stakeholders such as the CRB may orient to the status quo when making KC-46A maintenance program decisions. If this occurs, then the proposed Maintenance Effectiveness Module may not achieve the required user adoption for it to be successful. The associated risk components are quantified as follows:
    a. Probability: 4 – Highly Likely
    b. Severity: 3 - Moderate
2. Digital engineering perception: The USAF and DoD writ large are advocating for a digital engineering approach to develop and manage weapon systems across their lifecycle. Because of emphasis on digital acquisition, digital sustainment is not as prioritized in the KC-46A community and often relies document based business processes. Thus, cultural risk exists for the KC-46A sustainment enterprise to perceive the proposed Maintenance Effectiveness Module as a digital sustainment effort. If this risk occurs, then document based decision-making will continue by key stakeholders (e.g., KC-46A SPO, CRB) and the product may not impact decision-making processes. The associated risk components follow:

a. Probability: 3 - Moderate

b. Severity: 3 - Moderate

4.3. ESE and Decision Support Implementation

To implement ESE and decision support methodologies into KC-46A maintenance program decision-making, the researcher proposes a high-level product development plan to identify and detail means to introduce the Maintenance Effectiveness Module's knowledge engine. This product development plan is one element of a larger project management plan that would be needed to fully adopt the product into the KC-46A sustainment enterprise.

The product development plan associated with this research focuses on the initial scope and approach of implementing ESE and decision support improvements into KC-46A maintenance program decision-making. The proposed deliverable is a framework entailing the high level context (Section 4.3.1), scoping (Section 4.3.2), and decision processes/applications (Section 4.3.3) of the ESE/decision support product. This framework intends to support the USAF's decision to develop ESE/decision support applications in PFMT's Maintenance Effectiveness Module.

4.3.1. Context

The proposed decision-making framework for the KC-46A maintenance program is developed in the context of the larger research effort discussed in Section 1.5 between the KC-46A SPO and GTRI. FAA regulations and KC-46A policy provide background references supporting the framework. Additionally, the framework's front matter details its disclaimers, restrictions, and content overview.

The framework's context will leverage and draw upon the research results produced by the joint KC-46A SPO and GTRI study described in Section 1.5. During that study and this research, future applications of the framework are proposed in PFMT as the DSS for KC-46A maintenance program decision-making, but the framework is initially developed in Microsoft Excel for ease of use, transition, development, and demonstration. The sub-products referenced in the framework were developed in various other tools such as Python and Cameo Systems Modeler.

4.3.2. Scoping

While PFMT covers an expansive decision space for the KC-46A maintenance program, the proposed framework is limited to PFMT's CASS Maintenance Effectiveness Module for the purposes of this research. This focus is a result of the module's activities and outputs being most in control of the KC-46A SPO (reference Figure 6) and tightly coupled to KC-46A RAM-C sustainment performance. Additionally, examples of commercial success in this decision-making area (e.g., B767 commercial operator maintenance effectiveness improvements and Boeing's SASMO tool) compel the KC-46A sustainment enterprise to overcome shortcomings realized in previous attempts to optimize its maintenance tasks.

Finally, the KC-46A SPO and GTRI study described in Section 1.5 developed initial requirements to implement ESE/decision support improvements via PFMT's Maintenance Effectiveness Module. The partnership conducted various research activities on the topic to include two educational sessions, product demonstrations, gap analyses, and technical and programmatic roadmapping. This research was reported/presented to the KC-46A sustainment enterprise in the form of formal contractual deliverables. Due to its advancement of the state of the art, this research provided the initial scope of the proposed KC-46A decision-making framework.

4.3.3. Decision Processes and Applications

In response to the risks identified in Section 4.2, the decision-making framework's processes and applications attempt to connect the heuristic decision-making steps of KC-46A maintenance program SMEs to operational KC-46A maintenance data. Specifically, the framework provides higher level principles, processes, and practices to proceed from information and desires to choices that inform actions and outcomes [76]. The framework seeks to prescribe recommended actions and responses for a selected and evaluated maintenance task to the KC-46A SPO's CASS office. The intent is to achieve a compliant, effective, and optimized KC-46A maintenance program through effectively and efficiently managing the performance of maintenance tasks.

Applying the framework to improve maintenance effectiveness decision processes is demonstrated on a set of 43 KC-46A A-check maintenance tasks that were evaluated for R&M improvements in 2022. The proposed knowledge engine executing the framework includes the parameter selection criteria quantifying the effectiveness and optimality of a maintenance task based on reliability, availability, and maintainability performance metrics. Lastly, the framework provides a template to evaluate a maintenance task to inform the proposed decision-making tool. The evaluation seeks to include KC-46A operational data and leverage B767 commercial comparisons. These evaluations are the justification to build an engineering data package the KC-46A SPO can use for maintenance program enhancements. As illustrated in the first block of Figure 5, the KC-46A SPO provides this analysis and justification as operational feedback to the FAA and Boeing to improve its maintenance program via the B767 MRB.

4.4. Conclusion

Research Question 2 asks "What aspects of ESE and decision support methods are beneficial or costly to the KC-46A maintenance program?" This question was answered through three research tasks detailing ESE and decision support opportunities, costs/barriers, and implementation plans. An initial product development plan is produced to identify the context, scope, and decision processes/applications for a knowledge engine framework to implement ESE/decision support improvements in KC-46A maintenance program decision-making.

Opportunity exists for ESE/decision support methods to address the lack of a mature CRB information viewpoint, underdevelopment of PFMT's CASS modules, and incomplete knowledge engine/model library DSS elements in PFMT. Project costs to close these gaps using ESE/decision support methods are approximated to be hundreds of thousands of dollars and two years. Technical, business, and cultural barriers also present risks that would need to be properly managed to maximize the project's success. Lastly, implementing ESE/decision support improvements should be placed in the context of FAA and KC-46A policy, scoped to leverage existing research produced by the KC-46A SPO and GTRI, and cover decision process/applications related to a KC-46A maintenance task's compliance, effectiveness, and optimality.

The resulting conclusion is that the benefits ESE/decision support improvements in KC-46A maintenance program decision-making outweigh their costs if the improvement's risks and implementation are properly managed. This cost-benefit analysis justifies the business case to develop, propose, and evaluate a decision-making framework for the KC-46A maintenance program in Research Question 3. Research contributions accomplished by answering Research Question 2 include developing an understanding of the risks and benefits of KC-46A maintenance program improvements through novel applications of ESE and decision support methods. Chapter 5 develops and describes these decision support method's application (i.e., an expert system to serve as PFMT's Maintenance Effectiveness Module knowledge engine) in further detail.

CHAPTER 5: ESE AND DECISION SUPPORT DEMONSTRATION AND EVALUATION

Research Question 1 examined the current state of KC-46A maintenance program decision-making to identify improvement opportunities using ESE and decision support methods. Research Question 2 discussed the costs, benefits, and risks of implementing ESE and decision support methods for the KC-46A maintenance program. Now that the researcher has defined the business case to insert ESE and decision support methods into KC-46A maintenance program decision-making, the researcher defines how to best employ these methods.

Engineering ESE and decision support methods in the KC-46A's complex and dynamic sustainment decisions requires a systems approach to the problem's enterprise nature. For the purposes of our research, a framework leveraging existing decision support applications is proposed to demonstrate and evaluate how ESE and decision support methods can improve the KC-46A maintenance program as an industrial enterprise system. Initial recommendations are proposed entailing how to advance this framework's application in KC-46A maintenance program decision-making as future work.

Specifically, this chapter seeks to answer Research Question 3 restated here:

Research Question 3 - How would ESE and decision support methods be implemented to advance KC-46A maintenance program decision-making?

This question is answered by proposing a decision-making framework in Section 5.1 that incorporates ESE and decision support methods, evaluating the proposed framework via a focus group with KC-46A maintenance SMEs in Section 5.2, and making recommendations to adopt and scale the framework in Section 5.3. In summary, answering Research Question 3 develops solutions to improve KC-46A maintenance program decision-making via ESE and decision support methods and provides a high level approach to implement them.

5.1. Proposed KC-46A Decision-Making Framework

Section 4.1 describes the need to develop a knowledge engine as the final DSS element in PFMT's CASS Maintenance Effectiveness Module. This knowledge engine should implement the guidance provided by the FAA and USAF regarding the execution of the KC-46A CASS program to improve the weapon system's sustainment. To facilitate this, Section 5.1.1 provides an inference table of the CASS performance decision criteria illustrated in Figure 4 to guide the decision logic of the proposed framework. Section 5.1.2 details decision support applications developed during the research efforts discussed in Section 1.5 to include in the decision-making framework. Finally, Section 5.1.3 proposes the decision-making framework itself to apply these decision support applications to Section 5.1.1's inference table and prescribe CASS actions to the KC-46A SPO in the context of ESE.

5.1.1. CASS Performance Inference Table

To establish the decision logic to improve the KC-46A maintenance program through CASS actions (e.g., reporting and monitoring maintenance task adjustments via the CRB), the FAA's guidance on evaluating a maintenance task is applied (as illustrated Figure 4 regarding a task's number of scheduled/unscheduled defects and their impact on operations). The three dimensions of scheduled defects, unscheduled defects, and unscheduled defect's impact on operations are used to assess a scheduled maintenance task's effectiveness and optimality. In addition to these three dimensions, compliance criterion is added to validate that the KC-46A sustainment enterprise is satisfying the existing requirements of the maintenance task (thus serving as the baseline for any changes in the future). This compliance check is to address the KC-46A maintenance program compliance issues described in Section 3.2.

These decision criteria are translated into an inference table, illustrated in Table 1, to display the rule set needed to make a management decision on a KC-46A maintenance task (i.e., what, if anything, needs to change regarding this maintenance requirement to support enterprise RAM-C objectives). This inference table also enables forward and backward chaining of KC-46A CASS maintenance program decisions to trace conclusions of a task's performance to the raw data supporting it (i.e., KC-46A operational data). Lastly, it serves as the framework's inference engine to advance PFMT into a knowledge-based DSS.

Rules, premises, attributes, and facts are used to classify KC-46A maintenance tasks as compliant, effective, and optimized and constitute an expert system as a decision support method. Table 1 organizes this expert system to infer a task's classification and record it in the working memory section in the bottom right corner. When executing forward or backward chaining[16] on Table 1, the rule and clause statuses are updated to show how the system inferred the task's classification based on the programmed rule set. [77] The initial statuses shown (i.e., active, unmarked, and free clause) are updated with the statuses below as the conditional logic in the rule set is processed:

- Rule Statuses:
    - Active: Indicates that no premise clauses for the rule have been proven false and the rule should continue to be evaluated based on new facts. All rules are set to active at the beginning of the forward/backward chaining algorithm.

[16] A detailed explanation on forward and backward chaining in expert systems can be found in Dr. Steven Conrad's lecture on knowledge representation methods and inferencing [74].

- Discarded: Indicates that a premise clause for the rule has been proven false and thus the rule's premise is invalid for the evaluated task. Do not continue to evaluate.
- Unmarked: Indicates that the rule is not to be evaluated for a free clause during the next fact's iteration through the inference table.
- Marked: Indicates that a free clause is to be queried during the next fact's iteration through the inference table.
- Triggered: Indicates that a premise in the rule is true to determine an attribute of the task. The rule should continue to be queried until a premise is false and the rule is discarded or all premises are proven true and the rule is fired.
- Fired: Indicates that all premises in the rule are true and the rule classifies the KC-46A maintenance task.

- Premise Clause Statuses:
  - Free Clause: Clause has not been proven true or false and is ready to be evaluated.
  - False Clause: A fact or attribute proves the clause and its respective premise false.
  - True Clause: A fact or attribute proves the clause and its respective premise true.

A maintenance task's facts and attributes are processed until all clauses in a rule are proven true. These premises indicate the classification of a task's performance regarding its compliance, effectiveness, and optimality (as recorded in the working memory table). Appendix B includes an example of forward and backward chaining algorithms applied to Table 1 for a notional KC-46A maintenance task.

Table 1: KC-46A Maintenance Program Decision-Making Framework Inference Table [Adapted from 77]

Rule Number and Description	Rule Status	Premise Clause Number and Description	Clause Status
1. IF the KC-46A sustainment enterprise is NOT compliant with a maintenance task,	Active Unmarked	1. THEN the task is not compliant AND perform corrective action on compliance discrepancies.	1. Free Clause
2. IF the KC-46A sustainment enterprise is compliant with a maintenance task: AND the operational impact of unscheduled defects is high,	Active Unmarked	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task is ineffective AND requires a reliability improvement.	1. Free Clause 2. Free Clause
3. IF the KC-46A sustainment enterprise is compliant with a maintenance task: AND the operational impact of unscheduled defects is low, AND there is a high number of unscheduled maintenance defects, AND there is a low number of scheduled maintenance defects,	Active Unmarked	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task requires more analysis to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.	1. Free Clause 2. Free Clause
4. IF the KC-46A sustainment enterprise is compliant with a maintenance task: AND the operational impact of unscheduled defects is low, AND there is a low number of unscheduled maintenance defects	Active Unmarked	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality.	1. Free Clause 2. Free Clause

OR there is high number of unscheduled maintenance defects AND there is a high number of scheduled maintenance defects,			
5. IF the KC-46A sustainment enterprise is compliant with a maintenance task: AND the operational impact of unscheduled defects is low AND there is a low number of unscheduled maintenance defects AND a high number of scheduled maintenance defects,	Active Unmarked	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality. 3. THEN the task is optimized AND continue to monitor.	1. Free Clause 2. Free Clause 3. Free Clause
Attribute Queue 1. Compliance (Rule 1) 2. Effectiveness (Rules 2 – 4) 3. Optimality (Rule 5)		**Working Memory** 1. Compliance = Yes/No 2. Effectiveness = Effective, Ineffective, or Requires More Analysis 3. Optimality = Optimized/Not Optimized	

5.1.2. KC-46A Decision Support Applications

During the research partnership between the KC-46A SPO and GTRI, GTRI developed decision support applications[17] to analyze the KC-46A maintenance program's performance. They are incorporated into the larger KC-46A maintenance program decision-making framework to curate and condition raw KC-46A maintenance data from G081. The outputs of these decision support applications, titled the Compliance Assurance Tool (CAT) and KC-46A Maintenance Effectiveness Decision Engine (K-MEDE), are inputs to Table 1's inference table with example outputs shown in Appendix C.

5.1.2.1. CAT Overview

CAT was developed to investigate suspected compliance issues in the KC-46A maintenance program. These compliance issues required further analysis for the KC-46A SPO to validate and correct them. CAT uses object-oriented (OO) programming in Python to compare a maintenance task's attributes across multiple source documents and databases[18]. This is to address ESE complexities executing and documenting a maintenance task across the KC-46A sustainment enterprise. For example, Figure 26 illustrates the numerous instantiations, identified by a letter and number for each instantiation, of the bi-monthly A-Check maintenance packages across the KC-46A sustainment enterprise. Each of the 11 A-check packages contains 6 – 46 maintenance tasks that build upon each other in a hierarchical manner (e.g., the 2A check contains eight maintenance tasks completed every four months in packages 4A, 6A, 8A, 10A, and 12A/1C). AMC/A4, colored in blue, creates unactionable records (i.e., a record of the maintenance

[17] These decision support applications served as temporary analysis tools and thus are not considered a complete and permanent DSS.

[18] Specifically, it compares the KC-46A CMPD authored by Boeing, the TO -6 published in ETIMS, and G081 managed by O-level maintenance units to identify discrepancies in a maintenance task's requirements recorded across the documents/databases.

requirement only used as a reference in G081) of this maintenance construct based on the TO -6 maintenance requirements. The O/D-level bases (i.e., Altus AFB, McConnell AFB) in the other colors load customized actionable packages (i.e., executable instantiations of maintenance requirements in G081) against their aircraft based on their interpretation of AMC/A4's records and the TO -6. This manual processing, along with customization of maintenance packages based on an O/D-level unit's operation, introduces risk in complying with KC-46A maintenance requirements, administratively burdens KC-46A maintenance managers, and presents data integrity challenges during R&M analysis and CASS monitoring. Additionally, the completed 12A maintenance tasks completed during the D-level bi-annual 1C check are maintained in a separate MIS and are not visible in G081, hence the question mark in the depot column. [72]

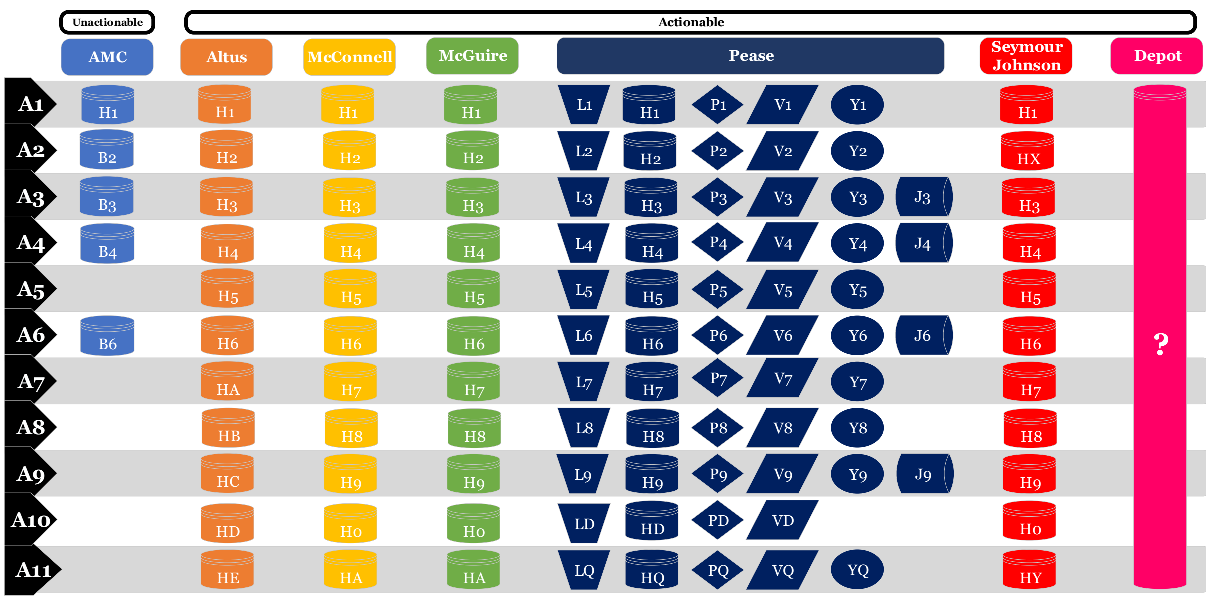

Figure 26: A-Check Maintenance Task Instantiation Across the KC-46A Sustainment Enterprise [72]

To identify suspected compliance discrepancies, CAT classifies suspected errors by one or more of the following:

- Missing MPD: Corresponds to a maintenance task that appears in the MPD but is missing from the A-check package of interest. This is the most severe compliance issue as it possesses the greatest risk to the airworthiness of the aircraft and violates policy requirements to perform all CMPD tasks at their specified interval.

- Misspelled MPD: Corresponds to a maintenance tasks that is misspelled or incorrectly titled in G081 compared to the CMPD. This issue presents data integrity challenges (i.e., edge cases) when querying KC-46A data for R&M analysis.
- Extra MPD: Corresponds to a maintenance task that was removed or never existed in the CMPD but appears in the G081 A-check package. This error can be a result of the O-level maintenance scheduler not updating the G081 package to reflect the latest revision of the TO -6. It is primarily an economical issue due to increased maintenance costs.
- Incorrect Interval: Corresponds to a maintenance task that is set at an incorrect interval in G081 when compared to the TO -6. This can present a compliance and airworthiness violation if the task is not performed frequently enough. If the task is completed too frequently, then it is an inefficiency over-maintaining the aircraft.
- Insufficient Removal: Corresponds to a task that was removed from certain A-check packages in a revision of the TO -6 but remains in the original packages in G081. This has similar effects as the incorrect interval error.

When GTRI ran CAT in April 2022 to compare the November 2021 CMPD and TO -6 to a March 2022 export of G081, 77 errors across the 5 categories were identified for adjudication. These errors are summarized in Table 2 with the specific discrepancies provided to the KC-46A SPO. As a result of this report, a cross-functional KC-46A sustainment enterprise working group was created to correct these errors. This enterprise response is recommended and included in the KC-46A decision-making framework.

Table 2: CAT Error Report Summary

Base	Error Type	Count
AMC/A4	Missing MPD	4
	Misspelled MPD	8
	Incorrect Interval	2
	Extra MPD	14
Altus AFB	Misspelled MPD	1
McConnel AFB	Missing MPD	1
	Insufficient Removal	4
McGuire AFB	Missing MPD	1
	Incorrect Interval	2
	Extra MPD	12
Pease Air National Guard Base	Missing MPD	4
	Misspelled MPD	1
	Incorrect Interval	2
	Insufficient Removal	2
	Extra MPD	12
Seymour Johnson AFB	Missing MPD	2
	Misspelled MPD	5
Total		77

5.1.2.2. K-MEDE Overview

K-MEDE is also an OO analysis program developed by the author and GTRI research team that labels raw KC-46A maintenance data for scheduled/unscheduled defects and operational impacts. It queries semi-structured data fields from G081 exports to apply to the inference models/algorithms found in Appendix A. Once the individual maintenance actions are labeled, K-MEDE subsets the data based on the maintenance task of interest. Thus, K-MEDE conditions the data to quantify maintenance defects and operational impact (e.g., number of flight/ground aborts, number of non-mission capable hours) for a specific task to be parameterized according to Table 1's attributes (i.e., classified as high or low for scheduled/unscheduled defects and unscheduled defect's operational impact).

To apply the inference model from Appendix A's OV-5b, KC-46A maintenance data from G081 is conditioned to label key data elements from various fields (e.g., Job Control Number (JCN), Discrepancy Narrative, Corrective Action) of the maintenance action. These facts, along with other facts produced by K-MEDE, are then evaluated against K-MEDE's rule set, to progressively infer if the maintenance action is scheduled, unscheduled, a defect, and if it had an operational impact (determined by the maintenance action causing an air or ground flight abort). K-MEDE's input fact(s), conditional logic, and output fact(s) are listed in Table 3 with scheduled and unscheduled defects and operational impacts highlighted yellow as key facts of interest for KC-46A maintenance program decision-making. It should be noted that while some of K-MEDE's rules may appear duplicative and/or contradictory, they are selectively applied to KC-46A maintenance actions depending on if it is scheduled or unscheduled maintenance and enable forward and backward chaining of K-MEDE results. The various inference paths in Appendix A's OV-5b inference model detail this progressive logic dependent on the type of maintenance.

Table 3: K-MEDE Rule Set

Rule Number	Input Fact(s)	Conditional Logic	Output Fact(s)
1	• MPD Card Number in Discrepancy Narrative • Sixth Position of JCN is Alphabetic Character	OR	Maintenance is Scheduled
2	• Maintenance is Scheduled	NOT	Maintenance is Unscheduled
3	• JCN in Corrective Action Field	THEN	Inspection has a Finding
4	• No JCN in Corrective Action Field	THEN	No Defect
5	• Inspection has a Finding	NOT	No Defect
6	• Maintenance is Scheduled • Inspection has a Finding	AND	This is a Scheduled Defect
7	• JCN in Corrective Action Field	NOT	No JCN in Corrective Action Field
8	• Maintenance is Unscheduled • Type 1 or 2 How Malfunction Code • No JCN in Corrective Action	AND	This is an Unscheduled Defect
9	• "A" or "C" When Discovered Code (Indicates Air and Ground Abort Respectively)	THEN	Operational Abort
10	• "A" or "C" When Discovered Code	NOT	Not an Operational Abort

To visualize Table 3's rules, K-MEDE also produces an inference network based on the user defined facts and logic. K-MEDE's OO Application Program Interface leverages Python's data visualization capabilities to interactively plot facts and logic as edges and nodes respectively. Figure 27 illustrates this inference network to trace K-MEDE's functionality and map its expert system behavior. Rules 3, 5, 6 are expanded to show the conditional logic (red nodes) and facts (blue edges) to infer a maintenance action resulting in a scheduled finding (i.e., defect). Appendix C contains the full-size inference network produced by K-MEDE.

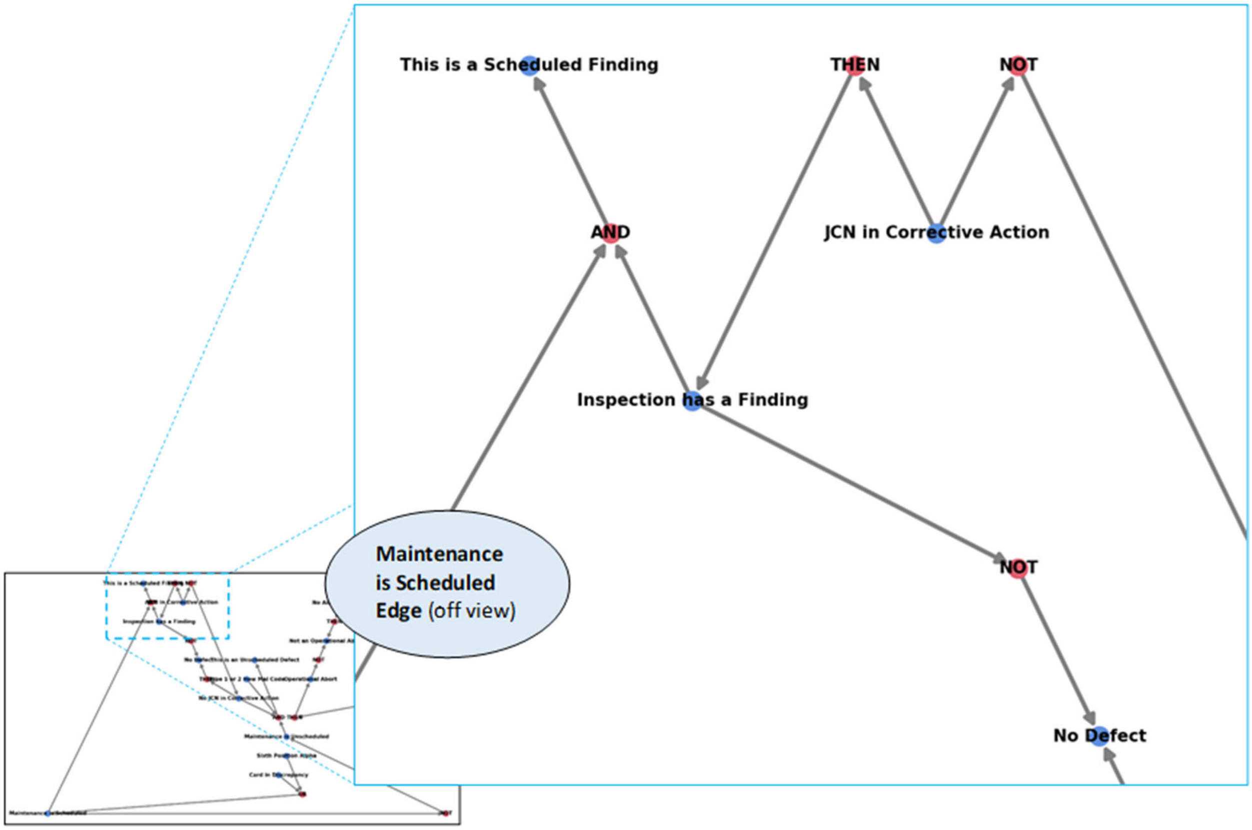

Figure 27: K-MEDE Inference Network with Expanded Rule Set

5.1.2.3. KC-46A Decision Support Applications Conclusion

CAT and K-MEDE condition KC-46A maintenance data to evaluate and report a maintenance task's R&M performance. Managing this R&M performance serves as the foundation of KC-46A maintenance program decision-making. Once this foundation is established, more advanced tools such as SASMO, optimization techniques (e.g., evolutionary algorithms), and maintenance strategies (e.g., condition based maintenance (CBM)) can be applied. Thus, CAT and K-MEDE serve as rule-based expert sub-systems in the proposed KC-46A maintenance program decision-making framework detailed in Section 5.1.3.

5.1.3. Proposed KC-46A Maintenance Program Decision-Making Framework

As discussed in Section 4.3, ESE and decision support methods are implemented via a decision-making framework intended to support the KC-46A SPO in maintenance program enhancements. This framework serves as the beginning of an engineering data package and is notionally demonstrated on 43 KC-46A A-check maintenance tasks previously identified for R&M improvements. The proposed framework is illustrated in Figure 28 and described in Sections 5.1.3.1 and 5.1.3.2 with its use case demonstrated in Section 5.1.3.3 and provided in Appendix D. Section 5.1.3.4 concludes this section with a summary of the framework and its background.

5.1.3.1. Framework Overview

The proposed KC-46A maintenance program decision-making framework shown in Figure 28 is organized by columns to illustrate the heuristic decision process, decision logic, and prescribed response for the KC-46A CASS program. The blue heuristic decision process includes decisions, drawn as diamonds in the process map, regarding the compliance, effectiveness, and optimality of a maintenance task. The decision logic, shown in the green column and rectangular shapes for "no" decisions, answers the heuristics to proceed to the next decision step for "yes" answers or stop and execute the response for "no" answers. The proposed responses are listed in ovals in the yellow column and correspond to an enhancement for the evaluated maintenance task based on the heuristics.

After responding with any enhancement, the maintenance task's performance is re-assessed by starting at the beginning of the heuristic decision process. Similarly, if all of the heuristics are answered "yes," then the task is not considered for an enhancement since it is compliant, effective, and optimized; it is only recommended that its performance continue to be monitored under the KC-46A CASS program by restarting the heuristic decision process.

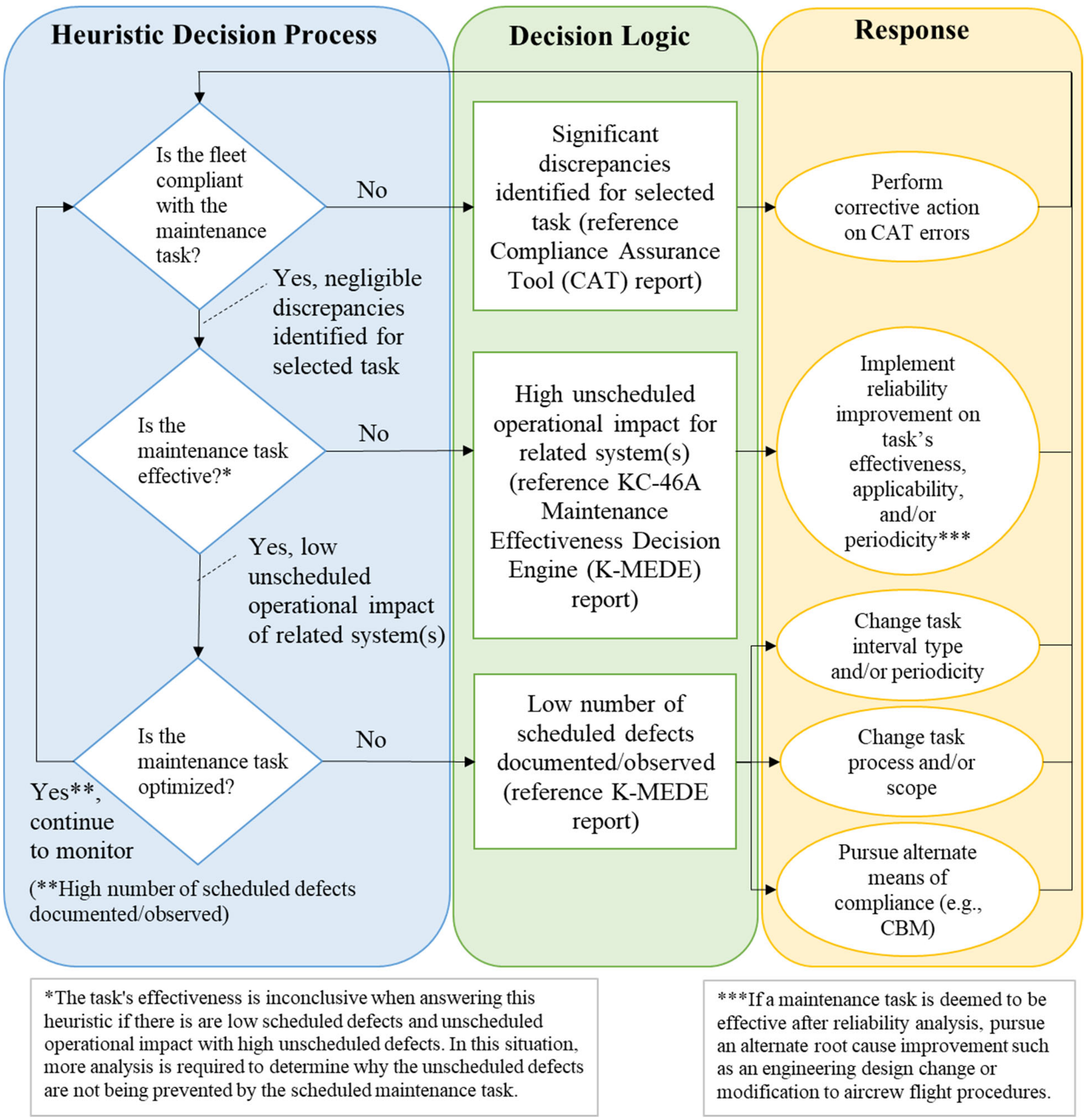

Figure 28: Proposed KC-46A Maintenance Program Decision-Making Framework

5.1.3.2. Decision-Making Algorithm

Stepping through the framework in more detail and tracing it to Table 1, the first heuristic asks "Is the fleet compliant with the maintenance task?" which corresponds to Rule Number 1 in Table 1. This compliance heuristic is answered by assessing the severity of discrepancies produced by CAT for the selected maintenance task[19]. If the discrepancies are significant, respond by performing corrective actions on the CAT errors via a KC-46A organizational process such as the CRB. If the discrepancies are not significant, proceed to the next heuristic which corresponds to the first premise for Rules 2 through 5 in Table 1.

The next heuristic asks "Is the maintenance task effective?" and corresponds to Rule Number 2 in Table 1. The decision logic answers this heuristic "no" if there is a high unscheduled operational impact for system(s) related to the scheduled maintenance task[20]. In response to an ineffective task (thus proving the second premise true for Rule 2), the KC-46A SPO is recommended to implement a reliability improvement on the task's effectiveness, applicability, and/or periodicity[21]. It is important to note, as indicated by the three asterisks on the reliability improvement response oval, that if a task is deemed to be effective after a formal reliability analysis, then an alternate root cause may need to be improved such as an engineering design change of the system or modification of aircraft flight procedures. These improvements are considered outside the primary responsibility of the maintenance program and are recommended to be performed via alternate decision criteria.

Additionally, as identified by the single asterisk in the effectiveness decision diamond, if there is a low operational impact of the task's related system(s), low scheduled defects, and a high number of unscheduled defects for a maintenance task, then more analysis is required to determine why the high number of unscheduled defects are not being prevented by the scheduled task. This

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[19] Based on the variability, sensitivity, and criticality of these compliance discrepancies, it is recommended that this step remain a manual human assessment when executing this framework. Reference the CAT error report in Appendix D for this characterization.

[20] Referencing the K-MEDE output will assist in determining and quantifying a "high" versus "low" operational impact.

[21] An example of an effectiveness improvement is increasing the durability of the material used in the task (e.g., better paint or corrosion prevention compound). Improving a task's applicability could entail performing a more in depth detailed visual inspection versus a general visual inspection based on the defects found. Improving the task's periodicity typically de-escalates (i.e., reduces in length) the task's schedule performance interval.

situation corresponds to Rule 3 in Table 1 and proves both of its premises true. Otherwise, low operational impact from a task's unscheduled defects indicate an effective maintenance task and the framework proceeds to the next decision heuristic asking "Is the maintenance task optimized?". Rule 4 in the inference table captures this decision criteria to show that the maintenance task is effective and warrants further evaluation.

Advancing to the final heuristic in the decision process, a maintenance task is considered optimized if there are a high number of scheduled defects documented/observed in the K-MEDE report. This is illustrated by the two asterisks in Figure 28's respective decision diamond and proves all the clauses true for Rule 5 in Table 1. Upon this final decision, the framework recommends to continue monitoring the task's performance via the KC-46A CASS program to conduct trend analysis on its compliance, effectiveness, and optimality using the proposed decision-making framework.

Alternately, if a low number of scheduled maintenance defects are observed by referencing the K-MEDE report, then the final clause of Rule 5 is proved false and the task is classified as "Effective but not Optimized" (i.e., Rule 4 in the inference table). Upon this determination, the researcher recommends the following responses:

1. **Change task interval type and/or periodicity:** This response entails changing the task interval's parameter (i.e., calendar days, flight hours, or flight cycles) to one that's more appropriate in detecting failures during task execution. An example of this for a landing gear servicing task, such as a lubrication, would be: changing from the task's interval from calendar days to flight cycles. Lubricating the landing gear is assumed to be more dependent on landing cycles versus calendar days, thus, landing cycles is the more appropriate task interval to detect servicing requirements for the landing gear.

Additionally, changing the task's periodicity (i.e., the frequency the task is completed) may present more defects during the scheduled maintenance task. Decreasing the frequency of the task by extending its completion interval is referred to as escalation and is an effective way to reduce maintenance costs and human error during task execution.

2. **Change task process and/or scope:** Another option to improve the scheduled task's performance in detecting discrepancies is to change the process or scope required to complete the task. Changing the task's process requires adding, deleting, or modifying the specific steps taken during task execution. An example of this would be: requiring a detailed visual inspection versus a less intensive general visual inspection of a specific aircraft zone in an attempt to detect more discrepancies. Changing the scope of the task in this case would be increasing the size of the zone inspected during the task.
3. **Pursue an alternate means of compliance:** In light of the increasing trend in aviation using CBM, optimizing a maintenance task via an alternate means of compliance is highly sought after by industry and the USAF. Essentially, CBM leverages sensor data to only perform the scheduled maintenance task based on evidence of need. Thus, the condition of the system of interest for a particular task produced a condition triggering a maintenance action. This condition can be considered a defect the task would address thus increasing the number of scheduled maintenance defects. Further expanding this approach, Blond et al. discuss applications of Comparative Vacuum Monitoring sensors on structural components as a potential starting point to advance CBM for the KC-46A [78].

Executing one of these responses ultimately returns us to the beginning of the decision-making framework to continue evaluating a maintenance task's performance via the KC-46A CASS program.

5.1.3.2.1. Decision-Making Parameterization

To execute the framework's decision logic in determining the high/low classification of attributes, the effectiveness and optimality of a maintenance task is parameterized based on notional reliability, maintainability, and availability metrics. If implemented, the proposed thresholds would need to be formalized based on KC-46A operational/readiness requirements and engineering analysis. The effectiveness and optimality metrics reflect the KC-46A sustainment enterprise's RAM-C performance and are summarized in Table 4 with an example threshold included for each metric.

Table 4: Generic Decision-Making Parameter Selection Summary

Heuristic Performance Category	Decision Logic Category	RAM-C Category	Metric	Example Threshold
Effectiveness	Unscheduled Defects	Reliability	Count of Defects	High > 10 > Low
			Mean Time Between Failure	High < 7 Calendar Days > Low
			Ratio to Scheduled Defects	High > 0.1 > Low
		Maintainability	Total and Mean Repair Times (Non-Mission Capable (NMC) Hours)	High > 75 (total) or 7.5 (mean) > Low
			Total and Mean Repair Times (Partial Mission Capable (PMC) Hours)	High > 25 (total) or 2.5 (mean) > Low
	Operational Impact	Operational Availability	Mean Annual NMC/PMC Hours per Aircraft	High > 100 (NMC) or 75 (PMC) > Low
			Mean Annual NMC/PMC Percent Decrease per Aircraft	High > 1.14 (NMC) or 0.86 (PMC) > Low
		Operational Reliability	Count of Annual Ground Aborts per Aircraft	High > 1 > Low
			Count of Annual In-Flight Aborts per Aircraft	High > 1 > Low
Optimality	Scheduled Defects	Reliability	Count of Defects	High > 10 > Low
			Mean Time Between Failure	High < 7 Calendar Days < Low
			Ratio to Unscheduled Defects	High > 10 > Low
		Maintainability	Total and Mean Repair Times (Non-Mission Capable (NMC) Hours)	High > 75 (total) or 7.5 (mean) > Low
			Total and Mean Repair Times (Partial Mission Capable (PMC) Hours)	High > 25 (total) or 2.5 (mean) > Low

5.1.3.3. Framework Demonstration

To demonstrate how Figure 28's decision-making framework would be applied to the 43 A-check tasks previously identified for R&M improvements, four decision-support components comprise the background logic supporting the framework. They quantify the ordinal quality attributes listed in the framework to create Boolean logic for a task's compliance, effectiveness, and optimality. The components' algorithms ingest CAT and K-MEDE data (i.e., preliminary conclusions drawn from conditioned KC-46A maintenance data), performs various reliability, maintainability, operational analyses to measure a maintenance task's RAM-C performance in accordance with CASS program guidance, and classifies the task's compliance, effectiveness, and optimality based on its Maintenance Steering Group Third Edition (MSG-3)[22] defined Failure Effects Category (FEC) [79].

The components include:

1. **Current State Decision-Making Tool:** This was the decision support tool utilized by the KC-46A CASS Office in 2022. It is based on the KC-46A maintenance program increasing its annual aircraft utilization (i.e., increasing the number of planned flight hours each year), comparison to the B767 commercial MRB Report intervals, and identification of identical tasks. This tool analyzes a subset of 43 A-Check maintenance tasks, as discussed in Section 4.3.3, to justify their adjustment to Boeing. The KC-46A CASS Office indicated a comprehensive R&M analysis was not completed on all tasks due to ongoing efforts with Boeing to repackage the KC-46A A-check and the lack of a standardized USAF methodology to complete such analyses [23, 33]. The incomplete R&M related columns of the tool reflect this decision-making current state with the two examples from the tool's contents summarized in Table 5.

[22] MSG-3 is the industry standard used to develop an aircraft's scheduled maintenance requirements. It is a decision-logic process published by the Air Transport Association of America to develop maintenance tasks and intervals acceptable to regulatory authorities (i.e., FAA), operators (i.e., USAF), and manufacturers (i.e., Boeing). MSG-3 defines an aircraft's failure modes based on its detectability and criticality to determine the appropriate type of scheduled maintenance task (e.g., general visual inspection, operational check, replacement) [75].

Table 5: Current State Decision-Making Tool Overview

Maintenance Task Number	Maintenance Task Description	FEC	Current KC-46A CMPD Interval	Commercial B767 MRB Report Interval	MRB Report Calendar Conversion[23]	R&M Analysis and Justification
21-120-00-01	Fan Fault Circuit Inspection	9 (Hidden, Non-Safety)	16 Months	6,000 Flight Hours	8 Years	Incomplete
25-170-00-01	Aft Entry/Service Door Escape Slide Bottles Visual Examination	8 (Hidden, Safety)	2 Months	750 Flight Hours	1 Year	Delete this A-check task as it is inspected during pre and post-flight inspection.

2. **Proposed Decision-Making Tool:** This is the application of the proposed decision-making framework. It is intended to advance the current state decision-making tool by including the maintenance tasks' compliance, effectiveness, and optimality criteria and recommending a response to improve the task's performance. The additional columns added in the proposed decision-making tool are color coded to highlight their improvement in supporting the R&M analysis/justification of the current decision-making tool. They are provided in Table 6 to incorporate the decision-making framework's heuristics in evaluating a KC-46A maintenance task's performance. Two examples are also provided to demonstrate the tool's user interface as an expert system.

[23] This column contains the equivalent MRB Report calendar day interval based on the annual expected flight hours for the KC-46A. While the researcher could not identify specifically where it was included in the R&M analyses/justification columns of the current state decision-making tool, the researcher added to this table based on correspondence with the KC-46A CASS office in which the conversion was cited as a significant factor influencing CMPD interval changes.

Table 6: Proposed Decision-Making Tool Additional Columns

Column Title	Compliance Check	Effective?	Optimized?	Recommended Response
Example 1	Fail	NA	NA	Perform corrective action on CAT errors.
Example 2	Pass	Yes	No	Change task interval/process/scope or pursue AMOC.

3. **FEC Decision-Making Parameter Selection:** Expanding on Table 4's Generic Decision-Making Parameter Selection Summary, this is the proposed decision-making parameter selection worksheet to classify a task's RAM-C attributes as high or low based on its MSG-3 FEC. For the two tasks listed above, their FEC is 8 (hidden safety) and 9 (hidden economic). Notional thresholds for each FEC is listed in Table 7 to parameterize the effectiveness and optimality of each task.

Table 7: FEC Parameter Selection Worksheet

Effectiveness Parameter Selection	(i.e., number of unscheduled defects and operational impact)					
	FEC					
	8 (hidden safety)			**9** (hidden economic)		
Unscheduled Defects Parameter	High	Low	Threshold	High	Low	Threshold
Reliability Metrics						
Count of Defects	>	<	10	>	<	25
Mean Time Between Failure (MTBF) (calendar days)	>	<	7	>	<	14
Mean Time Between Failure (MTBF) (flight hours)	>	<	15	>	<	30
Mean Time Between Failure (MTBF) (flight cycles)	>	<	5	>	<	10
Ratio to Scheduled Defects (count of unscheduled defects per scheduled defect)	>	<	0.1	>	<	1
Maintainability Metrics						
Total Repair Time (All Repairs)	>	<	100	>	<	100
Mean Time To Repair (MTTR) (All Repairs) (Hours)	>	<	10	>	<	10
Total Repair Time (NMC Repairs) (Hours)	>	<	75	>	<	75
MTTR (NMC Repairs) (Hours)	>	<	7.5	>	<	7.5
Total Repair Time (PMC Repairs) (Hours)	>	<	25	>	<	25
MTTR (PMC Repairs) (Hours)	>	<	2.5	>	<	2.5
Operational Impact Parameter						
Operational Availability						
Mean annual NMC hours per aircraft	>	<	100	>	<	100
Mean annual NMC % decrease per aircraft	>	<	1.14%	>	<	1.14%
Mean annual PMC hours per aircraft	>	<	75	>	<	75
Mean annual PMC % decrease per aircraft	>	<	0.86%	>	<	0.86%
Operational Reliability Metrics						
Count of annual ground aborts per aircraft	>	<	1	>	<	1
Count of annual in-flight aborts per aircraft	>	<	1	>	<	1

Optimality Parameter Selection

(i.e., number of scheduled defects)

	FEC					
	8 (hidden safety)			**9** (hidden economic)		
Scheduled Defects Parameter	High	Low	Threshold	High	Low	Threshold
Reliability Metrics						
Count of Defects	>	<	10	>	<	25
Mean Time Between Failure (MTBF) (calendar days)	>	<	7	>	<	14
Mean Time Between Failure (MTBF) (flight hours)	>	<	15	>	<	30
Mean Time Between Failure (MTBF) (flight cycles)	>	<	5	>	<	10
Ratio to Unscheduled Defects (count of scheduled defects per unscheduled defect)	>	<	10	>	<	1
Maintainability Metrics						
Total Repair Time (All Repairs)	>	<	100	>	<	100
Mean Time To Repair (MTTR) (All Repairs) (Hours)	>	<	10	>	<	10
Total Repair Time (NMC Repairs) (Hours)	>	<	75	>	<	75
MTTR (NMC Repairs) (Hours)	>	<	7.5	>	<	7.5
Total Repair Time (PMC Repairs) (Hours)	>	<	25	>	<	25
MTTR (PMC Repairs) (Hours)	>	<	2.5	>	<	2.5

4. **Example Maintenance Task:** This is the example template for a maintenance task's performance data to inform the Proposed Decision-Making Tool. It contains notional detailed analysis and visualization of the compliance, effectiveness, and optimality of a selected maintenance task. It also contains additional information to inform CASS analysis and decision-making such as the interval comparison to an optimized commercial B767 maintenance task based on the discussion in Section 3.3. The performance parameters can be set to the default thresholds from the generic decision-making parameter selection summarized in Table 7 or customized based on the specific maintenance task. Key information included in the example maintenance task analysis includes the following:

   i. **Task Information:** MPD number, task description, FEC, interval type/periodicity
   ii. **Customized Decision-Making Parameter Selection Table** (if selected versus generic parameters)
   iii. **Task Performance Summary:** compliance, effectiveness, and optimality performance and trending behavior
   iv. **<u>Compliance</u> Summary, Details, and Trend:** Derived from the CAT report
   v. **<u>Effectiveness</u> Summary, Details, and Trend:** Derived from the K-MEDE report
   vi. **<u>Optimality</u> Summary, Details, and Trend:** Derived from the K-MEDE report

Appendix D contains the complete details of the proposed KC-46A maintenance program decision-making framework components. They demonstrate how the framework classifies a

KC-46A maintenance task as compliant, effective, and optimized as a rule-based expert system[24]. The classification and its supporting logic recommend a response to the KC-46A CASS program to improve a maintenance task's RAM-C performance. It also serves as an engineering data package for the KC-46A SPO to justify maintenance task improvements to the B767 ISC.

5.1.3.4. Framework Conclusion

Section 5.1.3.1's framework proposes the heuristics, decision logic, and recommended responses for the KC-46A SPO to address ESE derived gaps in KC-46A maintenance program decision-making. Closing these gaps seeks to improve the performance of the KC-46A sustainment enterprise in achieving RAM-C objectives when producing mission capable aircraft. Section 5.1.3.2 details the algorithms used to process the heuristics of the framework and the parameterization of its supporting decision logic. Section 5.1.3.3 provides a use case of this framework for the KC-46A CASS program to improve the performance of 43 A-check maintenance tasks. The framework is demonstrated via four components including the current state and proposed decision making tool, generic decision-making parameter selection, and an example maintenance task. These components encompass an engineering data package for the KC-46A SPO to standardize its CASS program analysis and maintenance program recommendations to the B767 ISC (i.e., the FAA, Boeing, and other B767 operators) in accordance with its CDA sustainment strategy.

5.2. Focus Group Results

5.2.1. Introduction

To evaluate the proposed decision-making framework and supporting documents presented in Section 5.1, the researcher conducted a focus group of KC-46A sustainment SMEs to produce

[24] The researcher notes that this framework's approach to the 43 maintenance tasks is demonstrated in these sections but the result of applying the framework to the tasks is not included as it is beyond the scope of this research.

consensus on the framework's application in KC-46A maintenance program management decisions. An interaction analysis of the focus group using the methods described in [80] determined that the framework does improve KC-46A maintenance program decision-making if properly integrated with ESE factors of the KC-46A sustainment enterprise. These results informed adoption and scaling recommendations in Section 5.3 and a complete overview of the focus group is provided in Appendix E.

5.2.2. Planning and Execution

5.2.2.1. Planning

The researcher planned the focus group to be in-person at GTRI's Dayton, Ohio Field Office where the KC-46A SPO is located. He recruited six participants from the KC-46A SPO, AFLCMC/EZP, Booz Allen Hamilton's PFMT team, and AFLCMC's Rapid Sustainment Office. The researcher planned to moderate the focus group according to the following agenda:

- Welcome, overview, and instructions (15 minutes)
- Proposed decision-making framework tutorial (30 minutes)
    - In addition to a live demonstration of the framework on the selected maintenance tasks using an Excel spreadsheet, the researcher disseminated the framework to participants prior to the focus group. Appendix D contains this content provided to the focus group.
- Focus group discussion (60 minutes)
- Focus group conclusion (15 minutes)

During the focus group discussion, the researcher planned to facilitate discussion among the participants to answering the following questions:

1. Are there current shortfalls in making reliability and maintainability (R&M) decisions for KC-46 maintenance tasks?
2. How would the proposed KC-46A maintenance program decision-making framework be used in R&M management decisions?
3. Is this an improvement to current state?
4. What barriers (i.e., technical, regulatory, financial, policy) do you expect the proposed framework face if implemented?
5. What is the cost/benefit of the framework?

To analyze the participant's discussion in answering these questions, the researcher used Liamputtong's group components of what, who, and how to categorize 12 aspects of interaction for analysis [80]. These analysis results were planned to provide the focus group's evaluation of the framework's impact on KC-46A decision-making.

5.2.2.2. Execution

During the focus group's execution, two participants from AFLCMC/EZP (Participant #1) and Booz Allen Hamilton (Participant #2) participated synchronously and the researcher consulted with the KC-46A SPO (Participant #3) asynchronously. The researcher demonstrated each element of the framework on a large screen to address the participant's questions and comments. After the tutorial was completed, the researcher asked the participants the research questions to encourage their discussion in evaluating the framework. The researcher also consulted with Participant #3 from the KC-46A SPO to respond to Participant #1 and #2's synchronous discussion of the framework.

The researcher used Liamputtong's 12 aspects of interaction to analyze the participant's discussion with this method and its results included in Table 8. Regarding the "what" components produced by the focus group, participants agreed that a standardized decision-making framework, such as the one proposed in this research and illustrated in Figure 28, is needed in the KC-46A CASS program to consistently evaluate the maintenance program's R&M performance. The group also identified a need to automate and report the framework's performance metrics (i.e., Key Performance Indicators (KPIs)) to support KC-46A maintenance program management decisions. In contrast, group consensus was not achieved in deciding what organization in the KC-46A sustainment enterprise is responsible to develop and implement this framework. Additional disagreement among participants included how to condition the data and measure the R&M performance of a maintenance task. The final "what" aspects analyzed during the focus group related to contradictions, common experiences, and new insights and are included in Table 8. Focus group components "Who" and "How" are included in Table 8 and shaded blue and red respectively. "Who" interaction aspects detail the organizations represented in the focus group, specifically AFLCMC/EZP (Participant #1), Booz Allen Hamilton (Participant #2) who manages PFMT, and a KC-46A SPO representative (Participant #3). Interpersonal dynamics of participants are included in the "How" component to analyze the group's communication. These interactions identified the focus group's organizational response to the proposed framework and began to demonstrate the cultural risks described in Section 4.2.2.3.

Table 8: KC-46A Decision Making Framework Focus Group Interaction Analysis [Adapted from 80]

Group component	Aspect of interaction for analysis	Analysis Results
What?	What topics/opinions produced agreement?	The group agreed that a standardized framework is needed to identify the R&M performance of individual maintenance tasks as well as the maintenance program as a whole. Additionally, automating and reporting the framework's KPIs is needed to prescribe and support decision-making in the KC-46A maintenance program.
	What statements seemed to evoke conflict?	Disagreement occurred in how to implement such framework and who is responsible for its implementation. Organizational responsibilities/conflicts we're discussed among the KC-46A SPO, AFLCMC/EZP, and Booz Allen Hamilton as the PFMT provider. Additionally, how to condition the data and measure a maintenance task's R&M performance produced disagreement.
	What were the contradictions in the discussion?	Contradictions existed in that a need for the framework was agreed upon but the need to identify how/who should execute and implement it was not agreed upon. Additionally, the KC-46A CASS TO states the existing PFMT infrastructure shall implement the framework but the requirement is not formalized elsewhere to resource it properly.
	What common experiences were expressed?	Common experiences included ad hoc and manual execution of the framework's functions, reactive management to maintenance task performance, and lack of enterprise consensus on how to perform R&M analysis on maintenance programs.

	Did the collective interaction generate new insights or precipitate an exchange of information among participants?	Yes. The participants better understood the proposed framework and began to discuss how the KC-46A SPO, AFLCMC/EZP, Booz Allen Hamilton, and GTRI would implement it.
Who?	Whose interests were being represented in the group?	Due to limited attendance, only AFLCMC/EZP (Participant #1) and Booz Allen Hamilton (Participant #2) interests we're being represented. Given the close working relationship with the KC-46A SPO, the participants voiced the SPO's interests as well.
	Were alliances formed among group members?	Yes. Alliances between Participants #1 and #2 formed in agreeing that the KC-46A SPO needed to lead the implementation of this framework for the KC-46A.
	Was a particular member or viewpoint silenced?	The KC-46A SPO CASS office was not present and did not challenge Participant #2 on the framework being specific to the KC-46A. In a follow-on conversation with the KC-46A SPO, the representative indicated that this type of framework should be standardized across R&M management for every weapon system AFLCMC/EZP supports and is thus their responsibility to implement it.
How?	How closely did the group adhere to the issues presented for discussion?	The group moderately adhered to the issues for discussion and was able to discuss each issue at varying lengths.
	How did group members respond to the ideas of others?	Participants positively responded to each other to constructively build the conversation.
	How did the group resolve disagreements?	Disagreements were resolved by identifying follow-on actions to answer questions and determine next steps.
	How were non-verbal signs and behaviors used to contribute to the discussion?	Body language was used to facilitate transitions between discussion issues and indicate consensus/disagreement with other's statements.

5.2.3. Findings and Conclusions

The focus group was designed and executed to evaluate the proposed KC-46A maintenance program decision-making framework and produce consensus amongst KC-46A sustainment SMEs. Key takeaways extracted from Table 8's results include:

- The proposed framework is an improvement in capturing the complex decision-making of the KC-46A maintenance program. Participant #2 from Booz Allen Hamilton stated "My programmers and data scientists could implement this (framework) in PFMT right now if it was a formal requirement." Participant #2's statement indicates that PFMT has the technical capabilities to incorporate the framework's functionality and that Booz Allen Hamilton would do so if an organization from the KC-46A sustainment enterprise directed them to develop it.
- While technical capabilities exist to orchestrate the data and execute the framework's functionality, organizational barriers are most significant in developing and maintaining the framework in a DSS (as described in Section 4.2.2). Referring to these KC-46A sustainment enterprise bureaucratic challenges, Participant #1 from AFLCMC/EZP voiced "This is great…ask the KC-46A SPO who would be responsible to implement it?" This finding highlights the need for robust ESE in implementing decision-support methods in KC-46A maintenance program decision-making.
- There is a recognition that PFMT is intended to be the authoritative DSS for the KC-46A CASS program as per the TO, but the current state CASS program meets the FAA's intent and the KC-46A sustainment enterprise is facing higher priority challenges as the weapon system is acquired and fielded. Thus, there lacks an

immediate impetus to implement the framework presenting temporal constraints on its adoption.

These conclusions represent the voice of the focus group to aid in answering Research Question 3 regarding how ESE and decision support methods would be implemented to advance KC-46A maintenance program decision-making. The result is that the framework advances the state of the art in this field. The researcher includes these results in adoption and scaling recommendations described in Section 5.3.

5.3. Recommended Adoption and Scaling

To adopt and scale the proposed decision-making framework for the KC-46A maintenance program presented in Section 5.1, a programmatic and technical roadmap is recommended to determine the cost, schedule, and system performance requirements expected by the KC-46A sustainment enterprise. Programmatic plans include project management related activities, acquisition and contracting actions, and organizational and process viewpoints prescribed by ESE. Technical roadmapping captures more of ESE's information viewpoints to drive the development and application of the expert system into PFMT. Technical plans and activities include requirements engineering, capability analysis, and data orchestration to properly engineer PFMT into a knowledge based system.

KC-46A sustainment enterprise adoption of the proposed decision-making framework is largely contingent on the business need identified by maintenance program stakeholders. As described by Dr. Steven Conrad in his lecture on expert systems, applying the proposed framework to improve decision-making addresses many of the business needs faced by the KC-46A sustainment enterprise including a shortage of expertise and high cost of recruiting/training R&M analysts, documented examples of good decision-making available from commercial B767 operators, and heuristic rather than algorithmic procedures in KC-46A maintenance program decision-making [81]. Coupled with the cost/benefit analysis performed in Sections 4.1 and 4.2, the framework is one element of an enterprise solution that may begin to improve KC-46A sustainment.

To realize this capability in PFMT or another enterprise DSS, the researcher proposes formally initiating acquisition and contracting processes to pursue the framework's application. A collaborative effort among the KC-46A SPO, AMC, and AFLCMC/EZP is recommended to achieve the cross-functional buy-in needed from the primary decision-makers in the KC-46A maintenance program. This team should act as the KC-46A sustainment enterprise executive steering committee to fund the framework's requirement and implement it via an improved KC-46A maintenance program delivered to O/D-level maintenance units. The CRB should continue to provide feedback to this group as the CASS program's primary control mechanism on the implementation of the framework to achieve business objectives.

A Project Management Plan (PMP) should address the execution of this framework's application to include the scope, schedule, and budget of the effort. The programmatic roadmap is included in the PMP to plan/schedule stakeholder's responsibilities to drive the framework's development. Executing the PMP should capture many of the organizational and process views required to successfully implement the framework and improve KC-46A maintenance program decision-making.

Unlike the PMP serving as the vehicle for programmatic roadmapping activities, technical roadmapping should be accomplished primarily via the Systems Engineering Master Plan (SEMP). The SEMP should dictate which system development methodology (e.g., waterfall, spiral, or agile development) the enterprise steering committee will use to plan the expert system's requirements, development, test/evaluation, and release. The SEMP should also include the framework's concept of operations, data plan, security concept of operations, and lifecycle management plan to inform stakeholders of changes to their technical activities. While a complete PMP and SEMP is beyond the scope of this research, they are critical requirements to roadmap the programmatic and technical steps needed to adopt and scale the proposed decision-making framework in the KC-46A sustainment enterprise.

5.4. Conclusion

Research Question 3 asks "How would ESE and decision support methods be implemented to advance KC-46A maintenance program decision-making?" This question was answered through three research tasks which propose the decision-making framework to implement ESE and decision support methods (Section 5.1), evaluate the framework via a focus group to establish its improvement to the state of the art (Section 5.2), and recommend programmatic and technical roadmapping activities (specifically the PMP and SEMP respectively) to adopt and scale the framework in the KC-46A sustainment enterprise (Section 5.3).

Table 1's inference table serves as the expert system by applying the FAA decision criteria in Figure 4 and inference model shown in Appendix A's OV-5b. Coupled with the CAT and K-MEDE decision support tools produced during related research efforts, these expert sub-systems collectively prototype a knowledge engine to apply decision support methods in PFMT. The framework proposed in Figure 28 incorporate ESE methods to employ this knowledge engine in KC-46A maintenance program decision-making.

A focus group of KC-46A maintenance SMEs produced agreement in describing the proposed framework's improvement to current R&M analysis and decision-making in the KC-46A CASS program. A shared concern among participants was which organization in the KC-46A sustainment enterprise would resource, develop, and implement the framework. In observing the shared responsibility among the KC-46A SPO, AMC, and AFLCMC/EZP for the KC-46A maintenance program, the researcher recommends these organizations lead the programmatic and technical roadmapping to address this concern in the KC-46A sustainment enterprise.

In conclusion answering Research Question 3, the researcher determined that a decision-making framework including an inference table and various expert sub-systems is recommended to advance KC-46A maintenance program decision-making via ESE and decision support methods. Upon a focus group's positive evaluation of Figure 28's proposed framework, a PMP and SEMP will roadmap the programmatic and technical activities required to implement the framework in KC-46A maintenance program decision-making.

Research contributions achieved by answering Research Question 3 include roadmapping programmatic and technical changes to improve the KC-46A sustainment enterprise via the weapon system's maintenance program. Additionally, a novel application of PFMT as a DSS develops new understandings to gain consensus on KC-46A sustainment enterprise management decisions. Encoding expert KC-46A sustainment knowledge and programming the rules, premises, and attributes of the KC-46A maintenance program provides a tool to the KC-46A CASS program to more rapidly analyze and improve the RAM-C performance of KC-46A maintenance tasks.

CHAPTER 6: RESEARCH CONTRIBUTIONS

Research contributions from the proposed KC-46A maintenance program decision-making framework include fundamental research in the field of ESE and applied research in the field of USAF acquisitions and sustainment. Specific contributions include the following:

1. The first specific applications of ESE to a DoD maintenance program. These disciplines advance the state of the art through their focus on the KC-46A sustainment enterprise and its maintenance program as an industrial enterprise system. The author's review of ESE related literature does not identify any specific use case of a DoD maintenance program in the field. The proposed framework incorporates critical ESE viewpoints to synchronize decision-making in the KC-46A sustainment enterprise when pursuing maintenance task improvements. The researcher's ESE products in the research (i.e., MBSE diagrams) serve as the beginning of a reference architecture for DoD sustainment stakeholders to evaluate the RAM-C performance of a maintenance program.
2. Regarding applied research contributions to USAF acquisitions and sustainment, the researcher applied novel decision support methods to develop new understandings and gain consensus on KC-46A sustainment enterprise management decisions. Encoding expert KC-46A sustainment knowledge and programming the rules, premises, and attributes of the KC-46A maintenance program enhances KC-46A CASS program performance to more rapidly improve maintenance tasks based on operational data.
3. Lastly, the author roadmapped technical and programmatic changes to improve the KC-46A sustainment enterprise via the weapon system's maintenance program. This provides sustainment stakeholders options to enhance the KC-46A sustainment enterprise

by identifying resource requirements and value system impacts associated with the recommendations.

These contributions and supporting research for this framework are published in the following key delivered products and peer-reviewed publications:

1. Blond, K., et al., *Adapting Commercial Best Practices to the KC-46A Maintenance Program Final Report*. 2022, Georgia Tech Research Institute. [72]
    - The researcher authored this key delivered product for the KC-46A SPO as part of the contracted study he co-led at GTRI described in Section 1.5.
2. Blond, K., A. Clark, and T. Bradley. *A Decision-Making Framework for the KC-46A Maintenance Program*. in *2023 Annual Reliability and Maintainability Symposium (RAMS)*. 2023. [3]
3. Blond, K., S. Conrad, and T. Bradley, *Enterprise Systems Engineering and Decision Support Applications to the KC-46A Maintenance Program*, in *Military Operations Reserach Journal*. 2023, Military Operations Research Society. [82]
4. Blond, K., et al., *Comparative Vacuum Monitoring Solutions to Advance U.S. Air Force KC-46A Condition Based Maintenance Plus*. 2023, Multidisciplinary Digital Publishing Institute: Aerospace. [78]
5. Blond, K., et al., *Adapting Commercial Best Practices to U.S. Air Force Maintenance Scheduling.* Aerospace, 2023. **10**(1). [83]
6. Thompson, N., et al. *MBSE Applications to Optimize Predictive Maintenance Scheduling in Military Aviation*. in *IEEE Aerospace Conference*. 2023. Big Sky, Montanta: IEEE. [58]

7. Blond K., M. Xu, *Classifying Historical Airworthiness Directives to Inform Military Aircraft Maintenance Strategies and Sensor Solutions*, in *Military Operations Research Society 91st Symposium*. 2023: West Point, NY. [84]
8. Spexet, A., et al., *The Connected Hangar: Ubiquitous Computing and Aircraft Maintenance*, in *Adjunct Proceedings of the 2022 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. 2023, Association for Computing Machinery: Cambridge, United Kingdom. p. 118–120. [85]

CHAPTER 7: CONCLUSIONS

7.1. Dissertation Summary

This research evaluates ESE and decision support methods to advance KC-46A maintenance program management. To assess ESE and decision support applications, qualitative and quantitative research methods developed a technical and programmatic solutions for KC-46A sustainment enterprise stakeholders. Specifically, a decision-making framework is proposed to analyze KC-46A maintenance data and recommend reliability and maintainability improvements for specific maintenance tasks. The framework serves as an enterprise-level decision support tool to advance the KC-46A SPO in maintenance program decision-making with regulatory (i.e., FAA) and industry (i.e., Boeing) enterprise actors.

Technical and programmatic implementation plans are provided to navigate ESE complexities of the KC-46A sustainment enterprise. MBSE is also employed to map the KC-46A maintenance program as an industrial enterprise system. A focus group of KC-46A sustainment SMEs evaluated these research products to determine they advance the state of the art in KC-46A maintenance program decision-making. Lastly, multiple peer reviewed publications document these research contributions in applying ESE and decision support methods to the sustainment of a DoD weapon system.

7.1.1. Chapter Summaries

Chapter 1 introduces the KC-46A, its sustainment enterprise, and its maintenance program. It details how the KC-46A is the USAF's newest aerial refueling tanker, a CDA of the B767, and how the KC-46A's sustainment strategy maximizes participation in B767 industry. The researcher asserts that the KC-46A's current underperformance in RAM-C sustainment metrics is primarily governed by decision-making in the KC-46A maintenance program. A literature review of decision-making to improve KC-46A sustainment enterprise performance in meeting these RAM-C objectives provides the state of the art. A research approach is proposed using ESE and decision support methods to address gaps observed in the current state.

Chapter 2 details research questions to answer using various methods aligned to research tasks. The first research question investigates the current-state of decision-making in the KC-46A maintenance program that ESE and decision support methods can address. The result is the enterprise context of KC-46A maintenance program decision-making including a KC-46A sustainment enterprise system definition using ESE frameworks (Section 3.1), definition of KC-46A maintenance program relationships and decision-making across ESE's organizational, operational, and information views (Section 3.2), and comparison to a commercial B767 operator (Section 3.3). The second research question develops a business case analysis to implement ESE and decision support methods in the KC-46A maintenance program. The resulting answer includes ESE and decision support opportunities (Section 4.1), costs/barriers (Section 4.2), and methods of implementation (Section 4.3). Lastly, the third research question details how ESE and decision support methods are implemented to advance KC-46A maintenance program decision-making. The results include a proposed decision-making framework for the CASS Maintenance Effectiveness Module in PFMT (Section 5.1), a focus group's evaluation of the framework (Section 5.2), and programmatic and technical recommendations to adopt and scale the framework in the KC-46A sustainment enterprise (Section 5.3).

Chapter 3 is titled "KC-46A Maintenance Program Decision-Making Background" and begins with an overview of KC-46A maintenance program management decisions in relation to B767 industry activity (e.g., ISC, MRB). A triangle enterprise model of the KC-46A sustainment enterprise and its higher-level enterprises in the USAF is presented to bound its spheres of control and influence. The focus of decision-making to improve KC-46A sustainment enterprise performance is determined to be the exchange of industry requirements and operational feedback between the KC-46A SPO and the FAA and Boeing. MBSE diagrams provide detailed context of KC-46A maintenance program interactions within the enterprise to identify and justify improvements to maintenance tasks via this operational feedback. Finally, a comparison to a leading B767 commercial operator contrasts enterprise decisions to optimize Boeing's B767 maintenance program for the KC-46A and commercial operator.

Chapter 4 builds a business case for implementing ESE and decision support methods in the KC-46A maintenance program. First, the chapter details opportunities for these methods to close gaps related to the CRB's information viewpoint and PFMT CASS module that serves as the DSS for the CRB. Business resource costs associated with addressing these gaps are estimated to be hundreds of thousands of dollars and one to two years for development and implementation. Technical, business, and cultural barriers are analyzed to determine ESE related risks are higher in probability and severity of occurrence over technical risks. To effectively navigate these opportunities, costs, and risks, Section 4.3 provides the context, scope, and processes to implement ESE and decision support methods in KC-46A maintenance program decision-making.

Chapter 5 proposes ESE and decision support applications to the KC-46A maintenance program. Specifically, the application is a framework for an expert system knowledge engine in PFMT's CASS Maintenance Effectiveness Module. The framework includes heuristics, decision logic, and recommended responses for the KC-46A CASS program to evaluate and improve the RAM-C performance of scheduled maintenance tasks in the KC-46A maintenance program. The framework's inference table enables chaining algorithms to derive conclusions from a task's attributes regarding compliance, effectiveness, and optimality. A focus group evaluated the framework on a subset of maintenance tasks to determined it does advance KC-46A maintenance program decision-making if properly implemented in an ESE context. The chapter concludes by recommending a PMP and SEMP to adopt and scale the framework in the KC-46A sustainment enterprise.

Chapter 6 describes this dissertations research contributions and provides a list of supporting publications. Fundamental research in the field of ESE and applied research in the field of USAF acquisitions and sustainment is discussed. Specific contributions include the first application of ESE to a DoD maintenance program, novel applications of decision support methods to derive new understandings of KC-46A sustainment enterprise behavior, and programmatic and technical methods to improve KC-46A sustainment enterprise performance via the weapon system's maintenance program. Publications related to this research include a GTRI final report delivered to the KC-46A SPO, journal paper, conference proceedings, and other supporting publications.

7.2. Future Work

The future work of this framework is categorized by its development, extensibility, and influence on DoD and private sector sustainment communities. First, future work related to the proposed framework's technical development will seek to mature the framework into a complete DSS in PFMT's Maintenance Effectiveness Module. This development would formalize the parameterization of KC-46A maintenance task performance by the CASS program, programming the chaining methods, inference logic, and data visualization of this expert system, and integrating it as the knowledge engine component in PFMT's Maintenance Effectiveness Module. Additionally, DoDAF models would be matured in parallel to engineer the system. These models also facilitate the framework's application to other DoD weapon systems and begin to establish a reference architecture for evaluating the RAM-C performance of a scheduled maintenance task.

Regarding the framework's extensibility, these research results are planned to extend to the E-4B sustainment enterprise via a research contract between GTRI and the E-4B SPO. The USAF's E-4B is a Boeing 747-200 CDA that serves as the National Airborne Operations Center in the case of a national emergency or destruction of ground command and control centers [86]. The E-4B has been in service since 1974 and is also underperforming in its RAM-C sustainment metrics [14, 86]. Applying the proposed framework to the E-4B maintenance program will identify R&M improvements for specific tasks. Their impact on the E-4B's RAM-C performance will assist in measuring the success of the framework's application. The recommended improvements will also be evaluated against previous efforts by the E-4B SPO to determine how to best approach these sustainment challenges.

Lastly, this research contributes to the knowledge base of DoD and private sector sustainment communities through its applications of ESE and decision support disciplines in the domain of asset sustainment. The researcher plans to socialize these applications with commercial B767 operators, DoD logistics directorates, and other industries involved in the sustainment of vehicle fleets. A specific focus will be made on characterizing the relationships between RAM-C attributes and their impact on sustainment enterprise outputs to support operational requirements. This is intended to influence sustainment communities by engineering the decision-making of their enterprise interactions related to R&M. To help disseminate this research across sustainment communities, the researcher plans to include this in GTRI's Digital Sustainment Strategy which seeks to develop an authoritative digital engineering taxonomy for a system's operations and sustainment phase of its lifecycle.

REFERENCES

1. Maggiulli, N., *The Liabilities of Success*, in *Of Dollars and Data*. 2023.
2. *Boeing's KC-46A Pegasus Aerial Refueling Aircraft*. [cited 2021 December 8]; Available from: https://www.airforce-technology.com/projects/kc-46-aerial-refuelling-aircraft-us/.
3. Blond, K., A. Clark, and T. Bradley. *A Decision-Making Framework for the KC-46A Maintenance Program*. in *2023 Annual Reliability and Maintainability Symposium (RAMS)*. 2023.
4. *KC-46A Pegasus Air Force Fact Sheet*. April 2019 [cited 2021 December 8]; Available from: https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104537/kc-46a-pegasus/.
5. Donald, D. *KC-46 Tanker Gains FAA Approval*. 2018 [cited 2021 December 8]; Available from: https://www.ainonline.com/aviation-news/defense/2018-09-06/kc-46-tanker-gains-faa-approval.
6. GAO, *KC-46 Tanker Modernization - Program Cost is Stable, but Schedule May Be Further Delayed*. 2018.
7. GAO, *KC-46 Tanker - Air Force Needs to Mature Critical Technologies in New Aerial Refueling System*. 2022.
8. *AFI 62-601 USAF Airworthiness*, Secretary of the Air Force. Division, Editor. 2010.
9. GAO, *KC-46 Tanker Modernization - Aircraft Delivery Has Begun, but Deficiencies Could Affect Operations and Will Take Time to Correct*. 2019.
10. Low, M.S., *Impact of Decision Criteria on Federal Aviation Administration Certification of Military Commercial Derivative Aircraft*. 2012.
11. OSD, *Condition Based Maintenance Plus (CBM+) Guidebook.pdf*. 2008.

12. *Defense Acquisition Guidebook, Chapter 3*, D.A. University, Editor. 2020.

13. Retrieval, D.A.M.I., *KC-46A Tanker Modernization Acquisition Report (As of FY21 Budget.* 2019.

14. Cohen, R. and S. Losey. *US Air Force fleet's mission-capable rates are stagnating. Here's the plan to change that.* 2022 [cited 2022 March 13]; Available from: https://www.airforcetimes.com/news/your-air-force/2022/02/14/us-air-force-fleets-mission-capable-rates-are-stagnating-heres-the-plan-to-change-that/#:~:text=Mission%2Dcapable%20rates%2C%20the%20main,point%20in%20nearly%20a%20decade.

15. Giachetti, R.E., *Design of enterprise systems; theory, architecture, and methods*. 2010, Ringgold, Inc: Portland.

16. Dabney, T., et al., *Critical Systems Engineering Perspectives for the Development and Implementation of Enterprise Health Management Solutions*, in *DSTO International Conference on Health & Usage Monitoring*, A.F.A.I.A. Congress, Editor. 2011.

17. Martin, J., D. Fairley, and B. Lawson, *Enterprise Systems Engineering.* The Guide to the Systems Engineering Body of Knowledge (SEBoK), 2021. **v. 2.5**.

18. National Research Council, *Examination of the U.S. Air Force's aircraft sustainment needs in the future and its strategy to meet those needs*. 2011, Washington, D.C: National Academies Press.

19. AF/A4, *Sustainment Strategy Framework Implementation Plan*. 2020.

20. *Air Force Instruction 21-103 Equipment Inventory, Status and Utilization Reporting*, U.S.A. Force, Editor. 2020.

21. Boeing, *Maintenance Planning Document*. 2021.

22. Kelly, D., *KC-46A Maintenance Planning Sub-IPT Lead* K. Blond, Editor. 2021.

23. Osborn, R., *KC-46A CASS Program Manager* K. Blond, Editor. 2022.

24. FAA, *AC_120-17B - Reliability Program Methods - Standards for Determining Time Limitations* 2018.

25. B767 Commercial Operator, *Maintenance Programs A-Check Escalation Presentation* 2022. This presentation was a key delivered product to the KC-46A SPO by the B767 Commercial Operator who participated in the GTRI research study co-led by the dissertation's author.

26. Kaplun, N., *KC-46A Task Escalation Project*. 2020.

27. Tsiatsis, V., et al., *Chapter 11 - Industrial Automation*, in *Internet of Things (Second Edition)*, V. Tsiatsis, et al., Editors. 2019, Academic Press. p. 249-256.

28. Lasi, H., et al., *Industry 4.0.* Business & information systems engineering, 2014. **6**(4): p. 239-242.

29. Zhang, W., D. Yang, and H. Wang, *Data-Driven Methods for Predictive Maintenance of Industrial Equipment: A Survey.* IEEE systems journal, 2019. **13**(3): p. 2213-2227.

30. Ortiz, E.M., et al. *Multi Source Data Integration for Aircraft Health Management*. 2008. IEEE.

31. Gröger, C., *Building an Industry 4.0 Analytics Platform.* Datenbank-Spektrum, 2018. **18**(1): p. 5-14.

32. Böhmann, T., J.M. Leimeister, and K. Möslein, *Service Systems Engineering: A Field for Future Information Systems Research.* Business & information systems engineering, 2014. **6**(2): p. 73-79.

33. Bowers, R., *KC-46A Lifecycle Management Subject Matter Expert*, K. Blond, Editor. 2022.

34. Garrett, C., *USAF Digital Campaign*. 2021, USAF/AFMC.

35. Deng, Q., B.F. Santos, and W.J.C. Verhagen, *A novel decision support system for optimizing aircraft maintenance check schedule and task allocation.* Decision Support Systems, 2021. **146**.

36. Mallidis, I., et al., *A Goal Programming-Based Methodology for Machine Learning Model Selection Decisions: A Predictive Maintenance Application.* Mathematics (Basel), 2021. **9**(19): p. 2405.

37. Hu, Y., et al., *Reinforcement learning-driven maintenance strategy: A novel solution for long-term aircraft maintenance decision optimization.* Computers & industrial engineering, 2021. **153**: p. 107056.

38. Koornneef, H., W.J.C. Verhagen, and R. Curran, *A web-based decision support system for aircraft dispatch and maintenance.* Aerospace, 2021. **8**(6): p. 154.

39. Liu, Y., et al., *The design and simulation of an autonomous system for aircraft maintenance scheduling.* Computers & Industrial Engineering, 2019. **137**: p. 106041.

40. Dinis, D., A. Barbosa-Póvoa, and Â.P. Teixeira, *A supporting framework for maintenance capacity planning and scheduling: Development and application in the aircraft MRO industry.* International Journal of Production Economics, 2019. **218**: p. 1-15.

41. B767 Commercial Operator. *CASS and Reliability Programs Presentation*. in *B767 Reliability and Maintenance Programs Overview*. 2022. This presentation was a key delivered product to the KC-46A SPO by the B767 Commercial Operator who participated in the GTRI research study co-led by the dissertation's author.

42. Bousdekis, A., D. Apostolou, and G. Mentzas, *Predictive Maintenance in the 4th Industrial Revolution: Benefits, Business Opportunities, and Managerial Implications.* IEEE engineering management review, 2020. **48**(1): p. 57-62.

43. Tien, J.M. and D. Berg, *A case for service systems engineering.* Journal of systems science and systems engineering, 2003. **12**(1): p. 13-38.

44. Rizzo, S., K. Blond, and M. Covey, *C-5M Inspection Development Framework and Kitting Pathfinder Outbrief*. 2021. This presentation was a key delivered product to the C-5M SPO from a previous GTRI study the dissertation's author co-led.

45. Covey, S.R. and J.C. Collins, *The 7 habits of highly effective people : powerful lessons in personal change*. 25th anniversary edition. ed. Seven habits of highly effective people. 2013, New York, NY: Simon & Schuster.

46. Rouse, W.B., *Enterprises as systems: Essential challenges and approaches to transformation.* Systems engineering, 2005. **8**(2): p. 138-150.

47. Rouse, W.B., *A theory of enterprise transformation.* Systems engineering, 2005. **8**(4): p. 279-295.

48. *Boeing 767 Airplane Deliveries Report*. 2021.

49. Troux, *Metamodeling and Modeling with Troux Semantics, version 9.5.* 2015.

50. *Department of the Air Force Structure*. 2020 [cited 2021 December 15]; Available from: https://www.airforcemag.com/app/uploads/2020/06/Structure.pdf.

51. *Air Force Sustainment Center Fact Sheet*. 2021 [cited 2021 December 15]; Available from: https://www.afsc.af.mil/About-Us/.

52. *Air Force Acquisition Homepage*. 2021 [cited 2021 December 15]; Available from: https://ww3.safaq.hq.af.mil/.

53. Griffith, E. *Achieving Art of the Possible Results Presentation*. in *DoD Maintenance Symposium*. 2017. SAI International.

54. *Air Force Lifecycle Management Center - About Us*. 2021 [cited 2021 December 15]; Available from: https://www.aflcmc.af.mil/WELCOME/About-Us/.

55. Paulsen, C., et al., *Criticality Analysis Process Model*, in *Prioritizing Systems and Components*. 2018, National Institute of Standards and Technology.

56. Chief Information Officer, *Protection of Mission Critical Functions to Achieve Trusted Systems and Networks (TSN)*, D.o. Defense, Editor. 2018, Undersecretary of Defense Research and Engineering.

57. Conley, S., A. Himshoot, and E. Tilden, Maintenance *Planning Compliance Assurance Tool Presentation* 2022, Georgia Tech Research Institute. This presentation was a key delivered product to the KC-46A SPO from the GTRI research team the dissertation's author co-led.

58. Thompson, N., et al. *MBSE Applications to Optimize Predictive Maintenance Scheduling in Military Aviation*. in *IEEE Aerospace Conference*. 2023. Big Sky, Montana: IEEE.

59. Thompson, N. and K. Blond, *Measuring Maintenance Effectiveness: A Model Based Approach*. 2022, Georgia Tech Research Institute. This presentation was an internal GTRI product that directly supported the contracted study between the KC-46A SPO and GTRI research team that the dissertation's author co-led.

60. Ead, J., *B767 Commercial Operator Reliability Playbook*. 2019. This presentation was a key delivered product to the C-5M SPO from a previous GTRI study with the B767 Commercial Operator that the dissertation's author co-led.

61. Blond, K., E. Klein, and S. Knight, *Adapting Commercial Best Practices Beyond C-5M Reliability Programs: Inspection Development Framework and Kitting Final Outbrief*. 2019. This presentation was a key delivered product to the C-5M SPO from a previous GTRI study the dissertation's author co-led.

62. B767 Commercial Operator Analysis and Performance Office, *Planning Transparency: High Priority versus High Risk.* 2019. This presentation was a key delivered product to the C-5M SPO from a previous GTRI study with the B767 Commercial Operator that the dissertation's author co-led.

63. B767 Commercial Operator Analysis and Performance Office, *Risk Calculation Summary*. 2019. This presentation was a key delivered product to the C-5M SPO from a previous GTRI study with the B767 Commercial Operator that the dissertation's author co-led.

64. B767 Commercial Operator, *OEM MRBR Revision Process*. 2022. This presentation was a key delivered product to the KC-46A SPO by the B767 Commercial Operator who participated in the GTRI research study co-led by the dissertation's author.

65. Tilden, E., et al., *KC-46A Maintenance Program Commercial Benchmark*. 2022. This presentation was a key delivered product to the KC-46A SPO from the GTRI research team the dissertation's author co-led.

66. FAA, *Advisory Circular 121-22C - Maintenance Review Boards, Maintenance Type Boards, and OEM/TCH Recommended Maintenance Procedures*, FAA, Editor. 2012.

67. Tilden, E., et al., *KC-46A Maintenance Scheduling Commercial Benchmark*. 2022. This presentation was a key delivered product to the KC-46A SPO from the GTRI research team the dissertation's author co-led.

68. B767 Commercial Operator, *KC-46 Reliability & Maintenance Programs Overview*. 2022. This presentation was a key delivered product to the KC-46A SPO by the B767 Commercial Operator who participated in the GTRI research study co-led by the dissertation's author.

69. AFLCMC/WKC Weapon System Program Office, *Technical Order 00-25-266-KC46: Continuing Analysis and Surveillance System (CASS) Program Standard Procedures Manual*, USAF, Editor. 2020.

70. FAA, *Advisory Circular 120-79A - Developing and Implementing an Air Carrier Continuing Analysis and Surveillance System*, D.o. Transportation, Editor. 2013.

71. Petruschell, R.L., G.K. Smith, and T.F. Kirkwood, *Using the Air Force Maintenance Data Collection System Data to Identify Candidates for Improvement in Reliability and Maintainability,* 1987, RAND.

72. Blond, K., et al., *Adapting Commercial Best Practices to the KC-46A Maintenance Program Final Report*. 2022, Georgia Tech Research Institute. This presentation was a key delivered product to the KC-46A SPO from the GTRI research team the dissertation's author co-led.

73. Borky, J.M. and T.H. Bradley, *Effective Model-Based Systems Engineering*. 2018: Springer International Publishing.

74. Conrad, S., *Week 5 - Introduction to nonlinear multiobjective optimization*. 2022, Colorado State University.

75. McLoughlin, B., F. Doulatshahi, and J. Onorati, *Improving Maintenance Programs Through Statistical Analysis* in *AERO*. 2011, Boeing Commercial Airplanes: Seattle, Washington. p. 28.

76. Lockie, S. and S. Rockloff, *Decision frameworks: assessment of the social aspects of decision frameworks and development of a conceptual model*. 2005: CRC Coastal Zone Estuary and Waterway Management.

77. Conrad, S., *Week 10 - Knowledge representation methods - Inferencing*. 2022, Colorado State University.

78. Blond, K., et al., *Comparative Vacuum Monitoring Solutions to Advance U.S. Air Force KC-46A Condition Based Maintenance Plus*. Aerospace, 2023. **10**(7).

79. SKYbrary Aviation Safety *Maintenance Steering Group-3 (MSG-3)*. 2023.

80. Liamputtong, P., *Focus Group Methodology: Principles and Practice*. 2011, SAGE Publications Ltd: London.

81. Conrad, S., *Week 9 - Risk and Uncertainty Continued -Expert System*. 2022, Colorado State University.

82. Blond, K., S. Conrad, and T. Bradley, *Enterprise Systems Engineering and Decision Support Applications to the KC-46A Maintenance Program*, in *Military Operations Research Journal*. 2023, Military Operations Research Society.

83. Blond, K., et al., *Adapting Commercial Best Practices to U.S. Air Force Maintenance Scheduling.* Aerospace, 2023. **10**(1).

84. Xu, M. and K. Blond, *Classifying Historical Airworthiness Directives to Inform Military Aircraft Maintenance Strategies and Sensor Solutions*, in *Military Operations Research Society 91st Symposium*. 2023: West Point, NY.

85. Spexet, A., et al., *The Connected Hangar: Ubiquitous Computing and Aircraft Maintenance*, in *Adjunct Proceedings of the 2022 ACM International Joint Conference on*

Pervasive and Ubiquitous Computing. 2023, Association for Computing Machinery: Cambridge, United Kingdom. p. 118–120.

86. Air Force Global Strike Command Public Affairs Office. *USAF E-4B Fact Sheet*. 2023 [cited 2023 June 5, 2023]; Available from: https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104503/e-4b/.

APPENDIX A: MAINTENANCE DECISION-MAKING DETAILED MODELS

Source: Thompson, N. and K. Blond, *Measuring Maintenance Effectiveness: A Model Based Approach*. 2022, Georgia Tech Research Institute. This presentation was an internal GTRI product that directly supported the contracted study between the KC-46A SPO and GTRI research team that the dissertation's author co-led. [59]

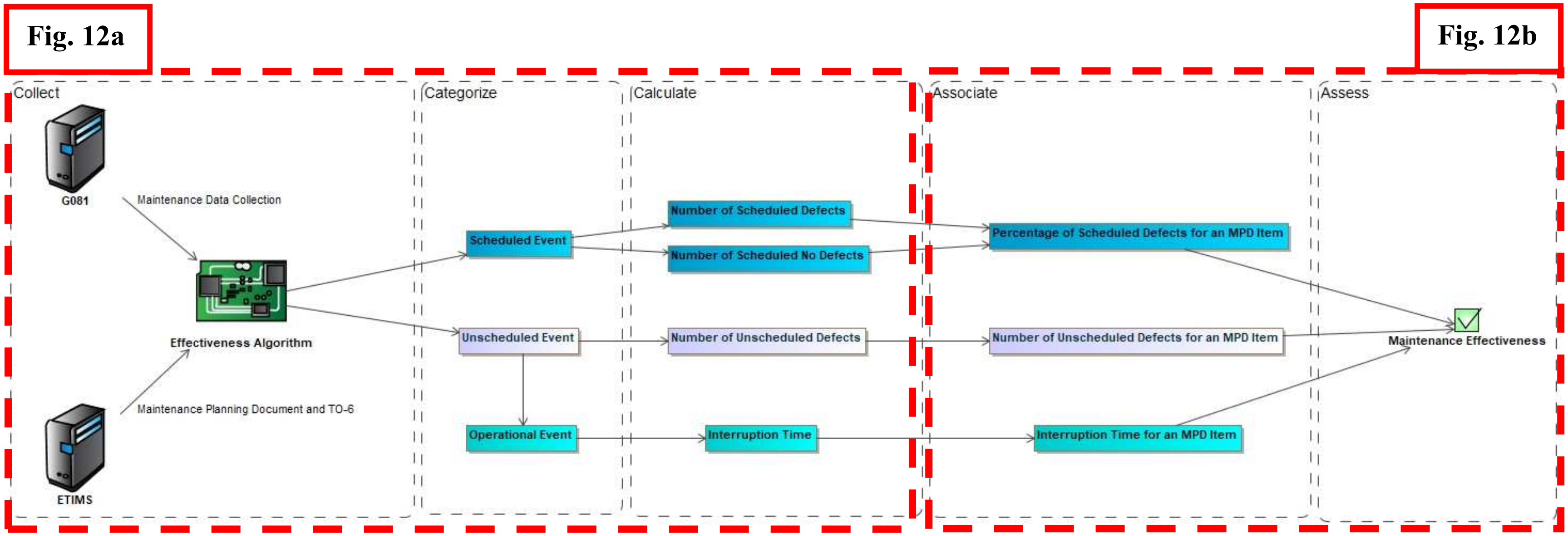


Figure 29: Maintenance Task Evaluation OV-1

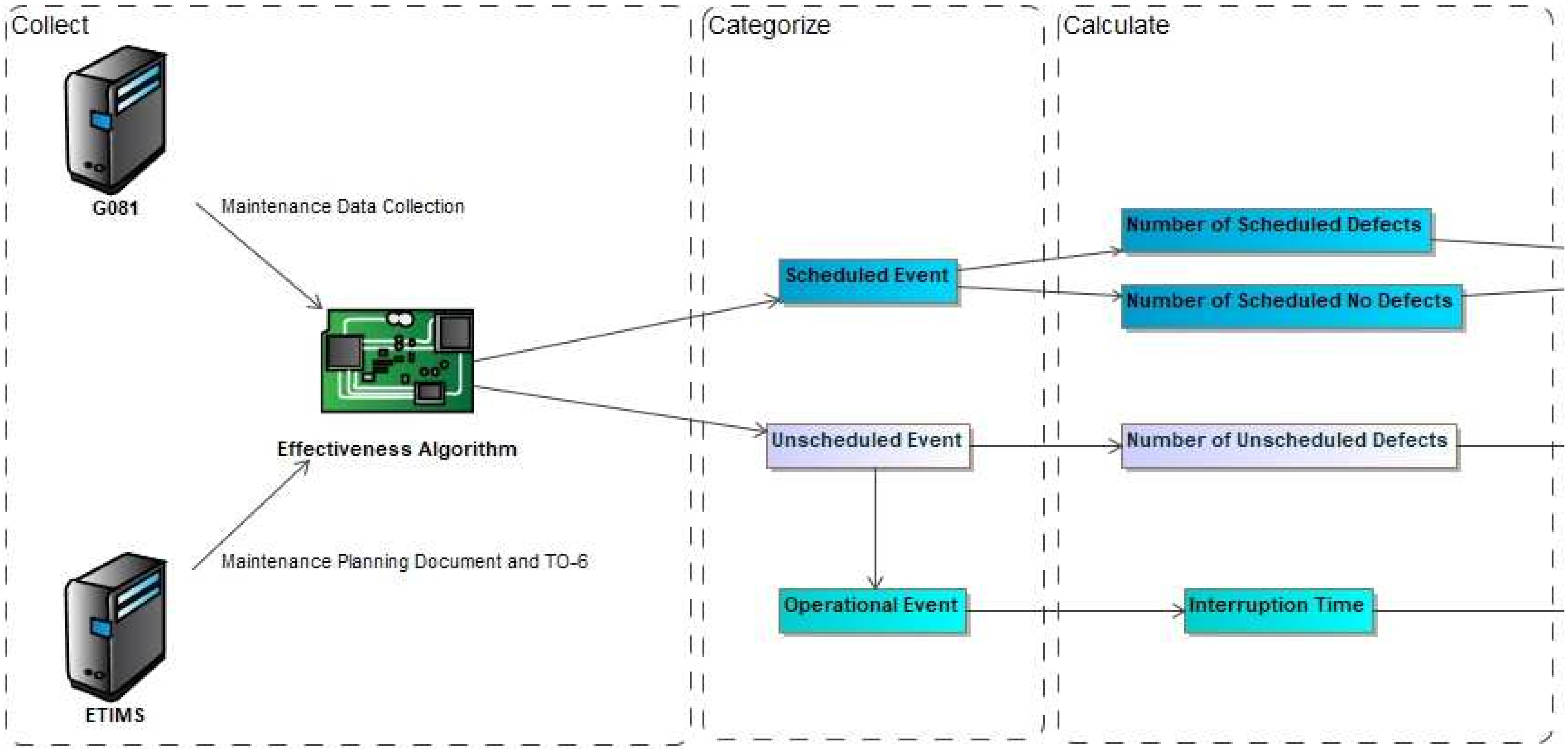


Figure 30a: Maintenance Task Evaluation OV-1 Collect, Categorize, and Calculate Stages

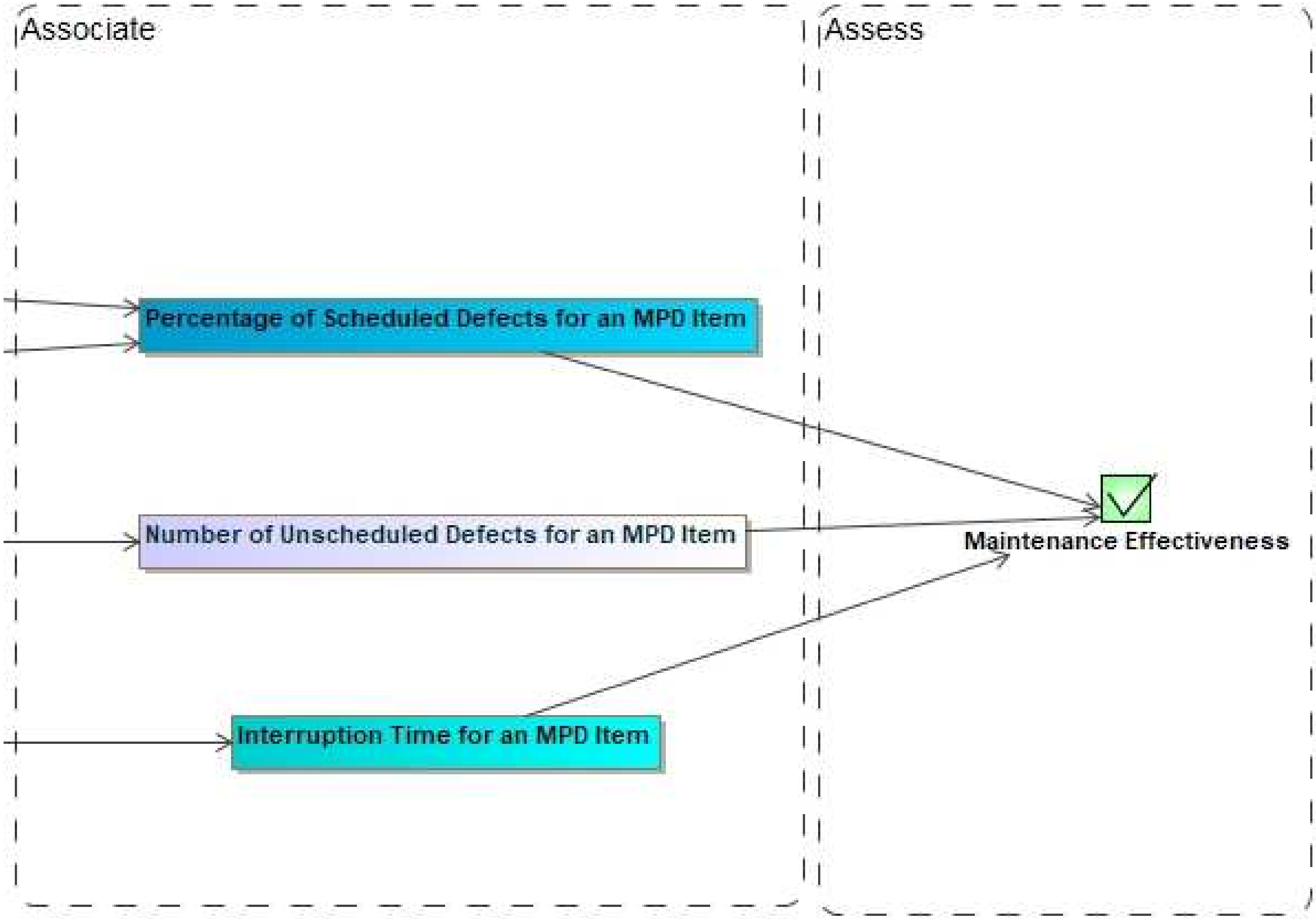


Figure 31b: Maintenance Task Evaluation OV-1 Associate and Assess Stages

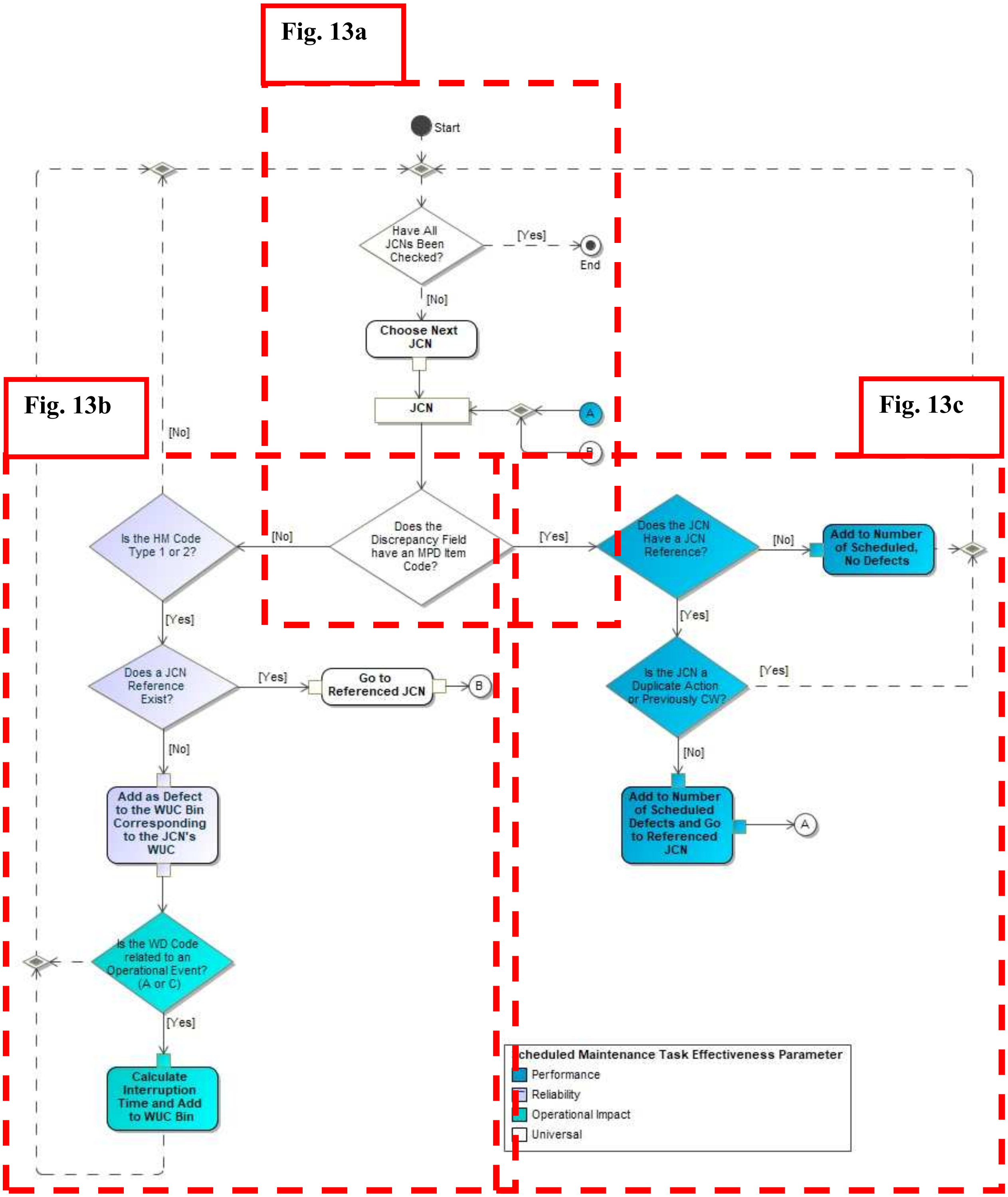


Figure 32: OV-1 Categorize and Calculate Stage Decision Tree

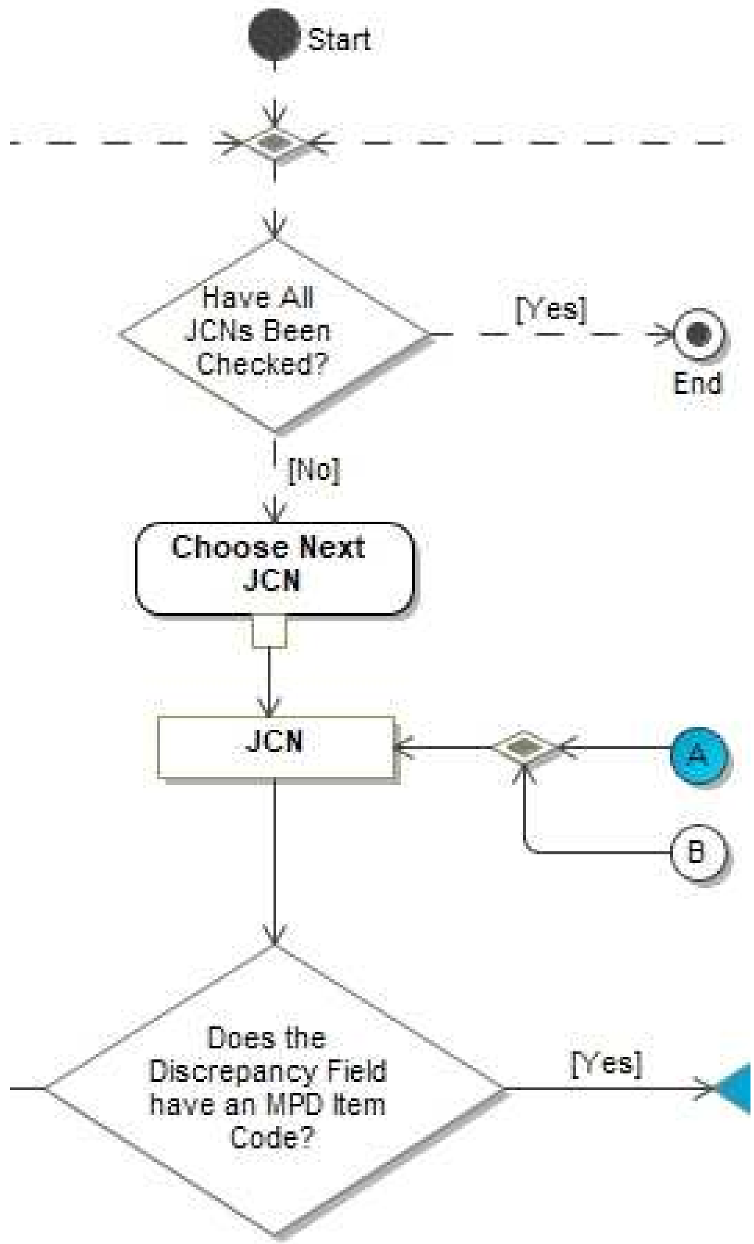


Figure 33a: OV-1 Categorize and Calculate Stage Decision Tree Control Chain

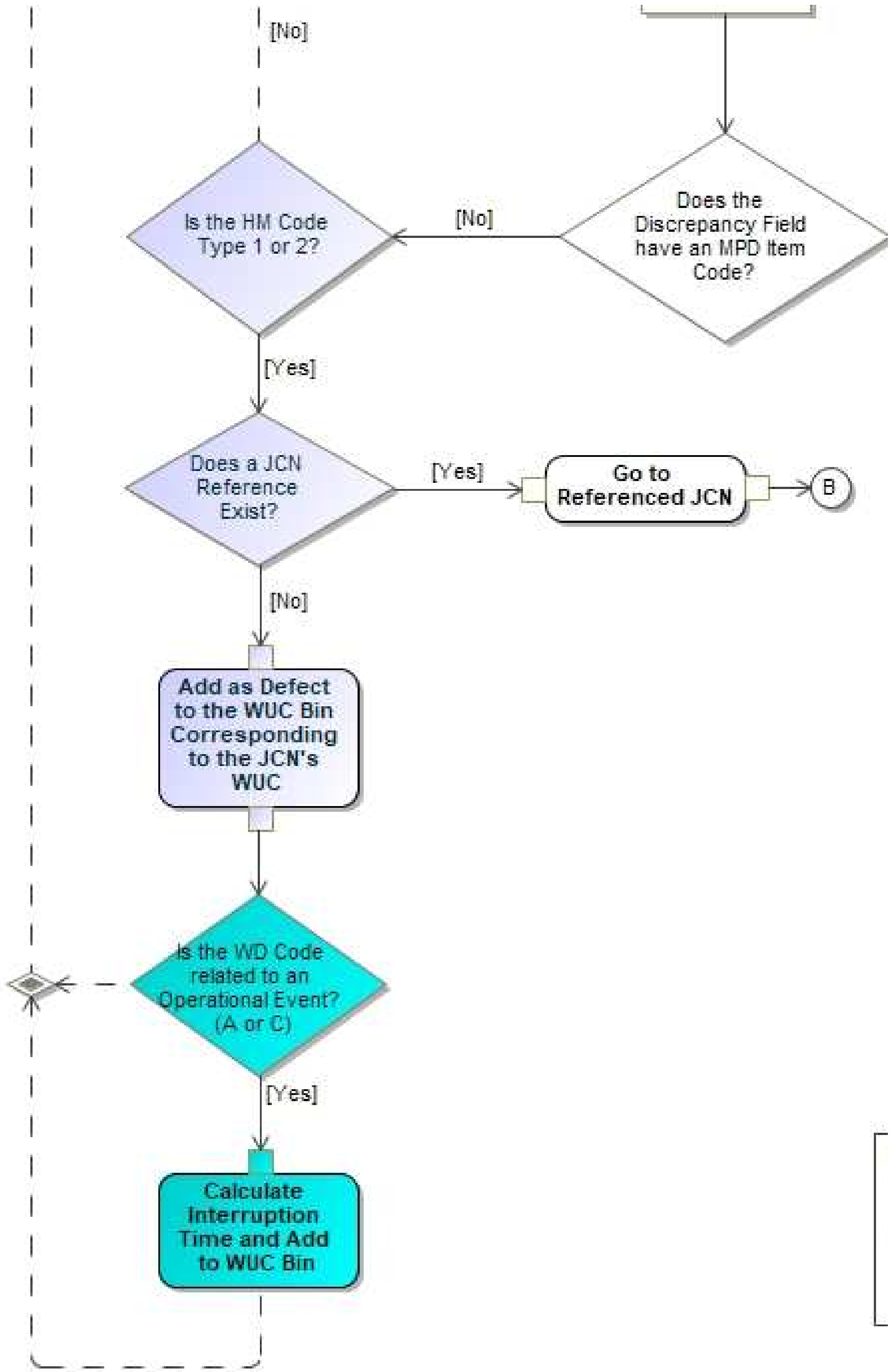


Figure 34b: OV-1 Categorize and Calculate Stage Decision Tree Unscheduled Defect and Operational Impact Query

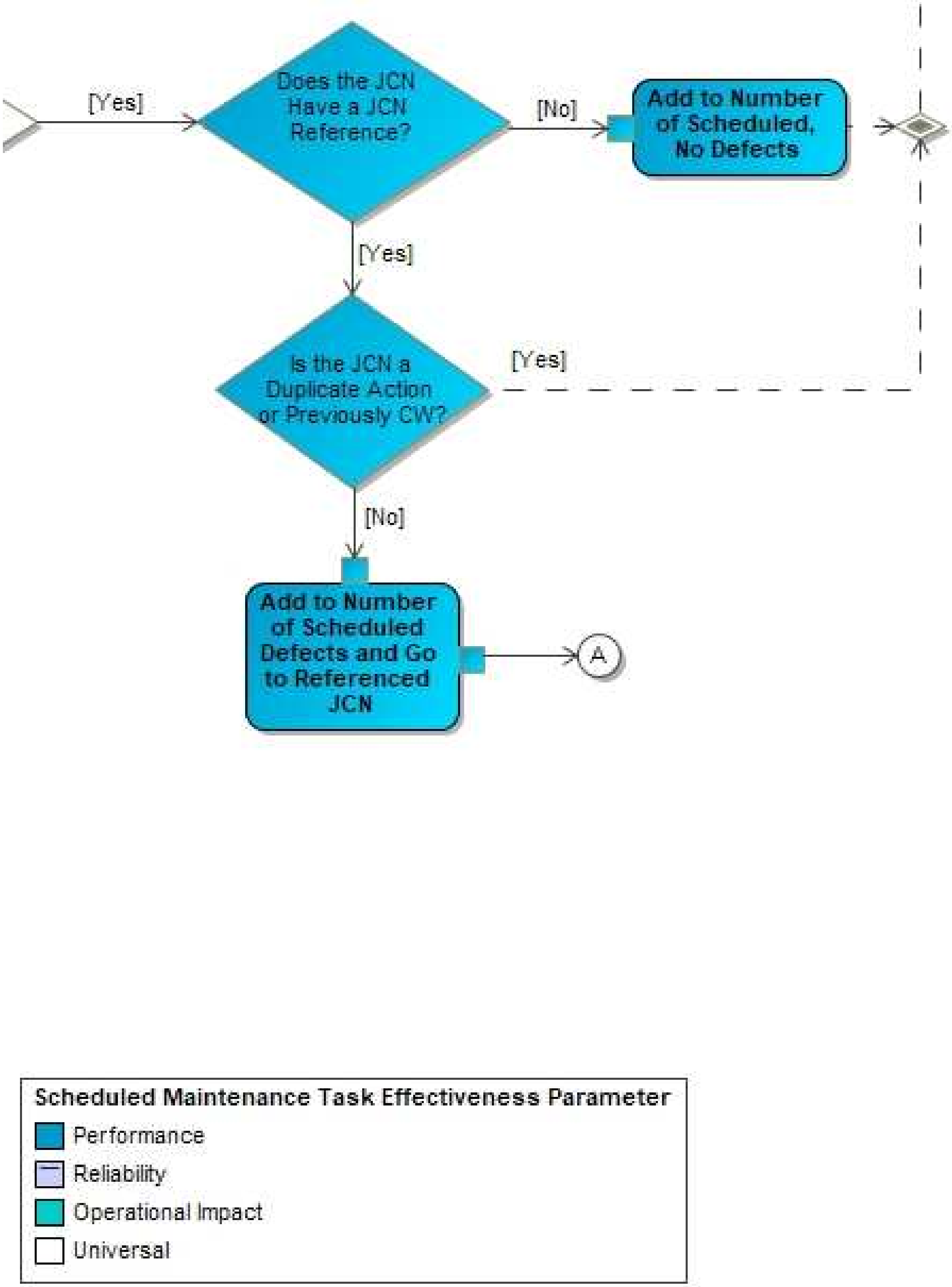


Figure 35c: OV-1 Categorize and Calculate Stage Decision Tree Scheduled Defect Query

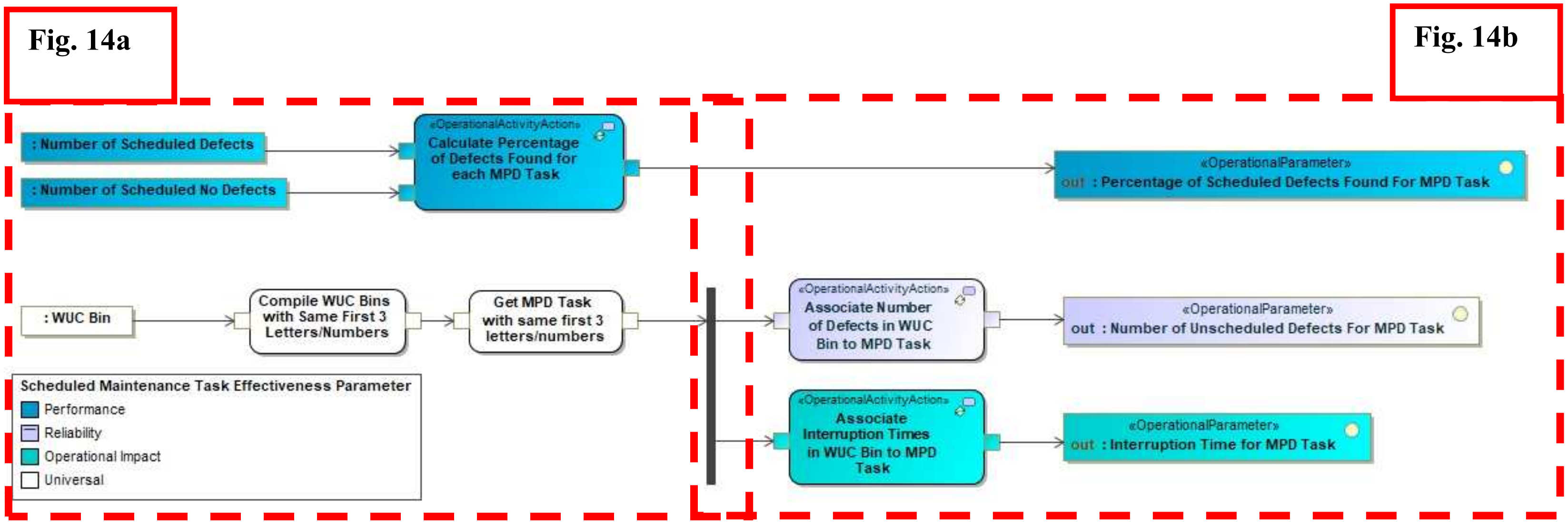


Figure 36: OV-1 Associate Stage Decision Process

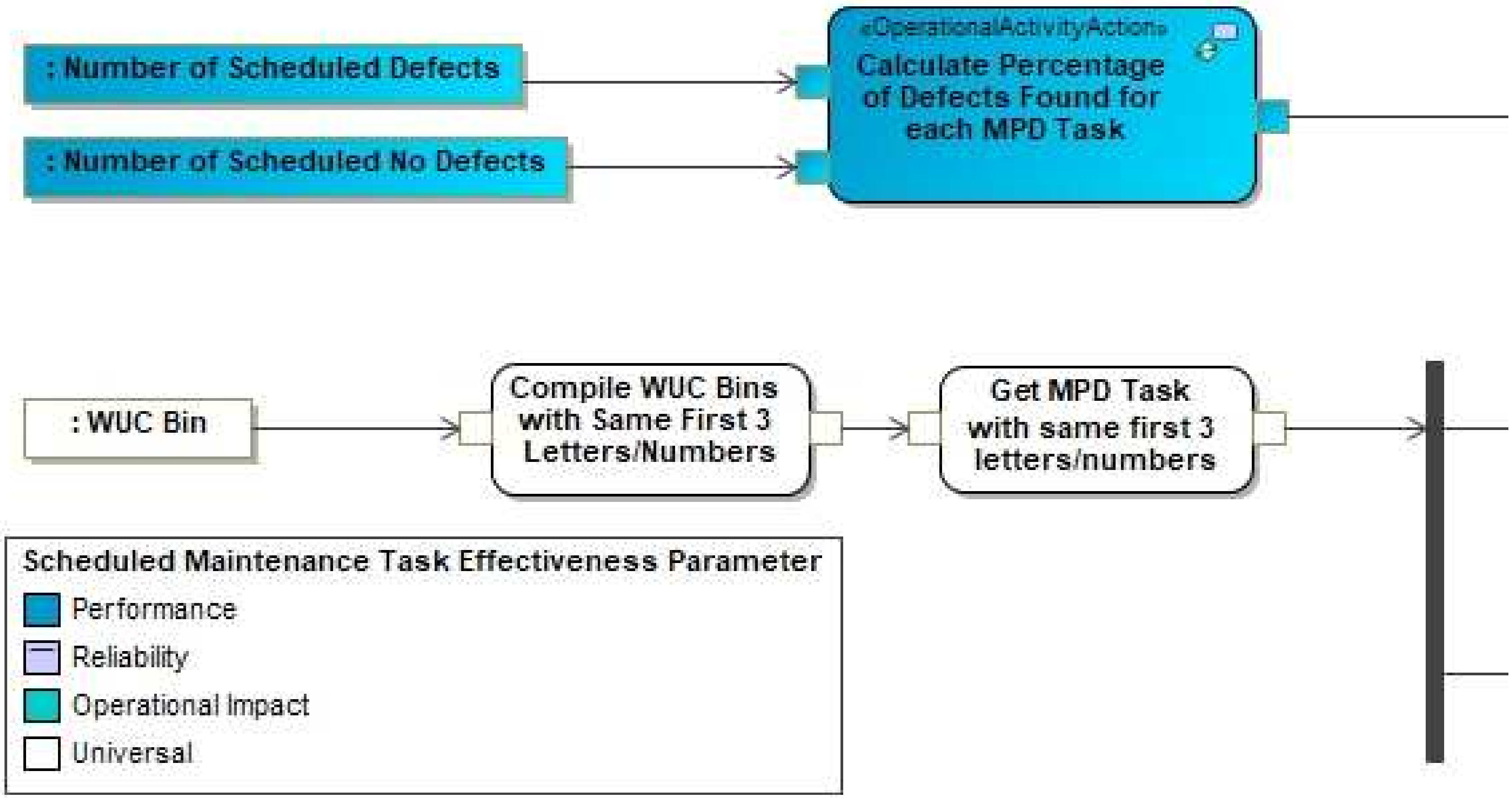


Figure 37a: OV-1 Associate Stage Scheduled Defect Calculation and Unscheduled Defect Task Association

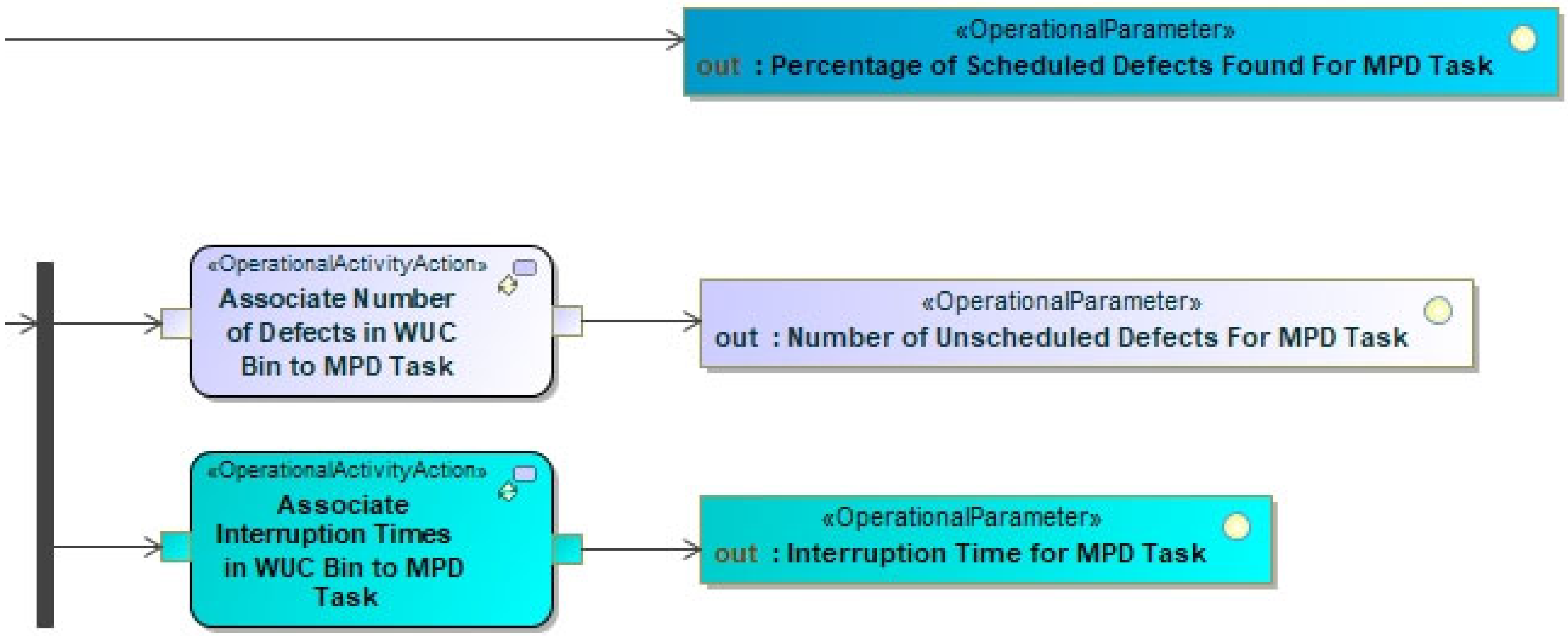


Figure 38b: OV-1 Associate Stage Unscheduled Defect and Operational Impact Calculation

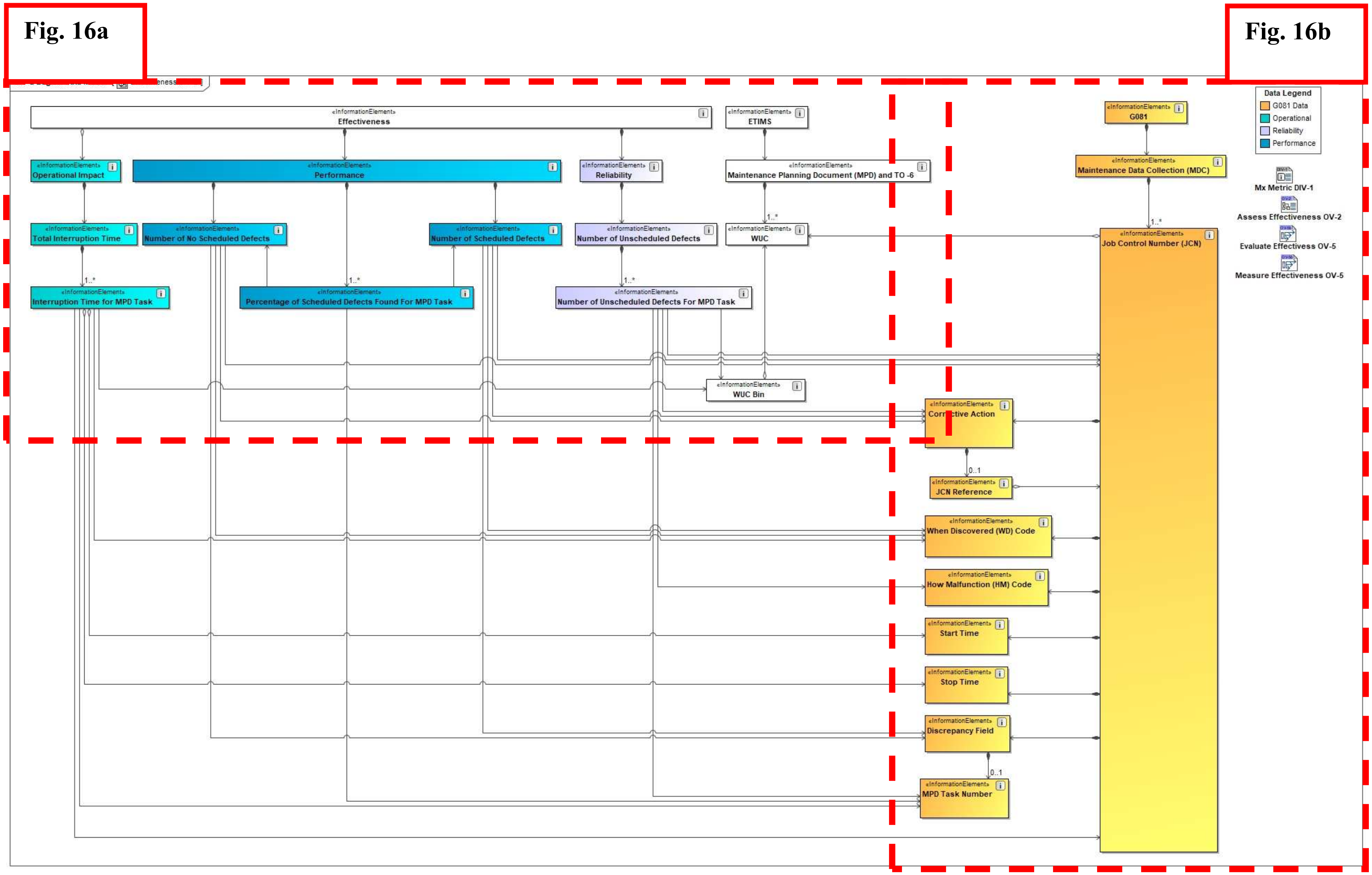


Figure 39: Maintenance Program Decision-Making Logical Data Model (DIV-2)

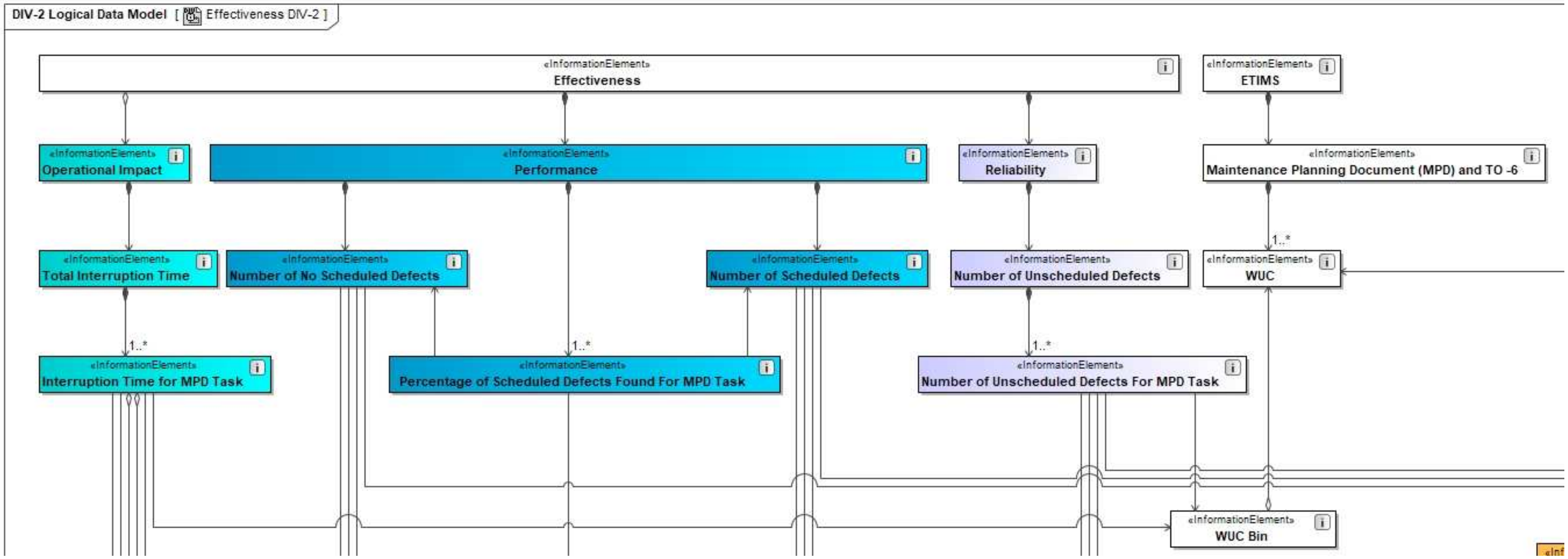


Figure 40a: Maintenance Program Decision-Making Parameters Logical Data Model (DIV-2)

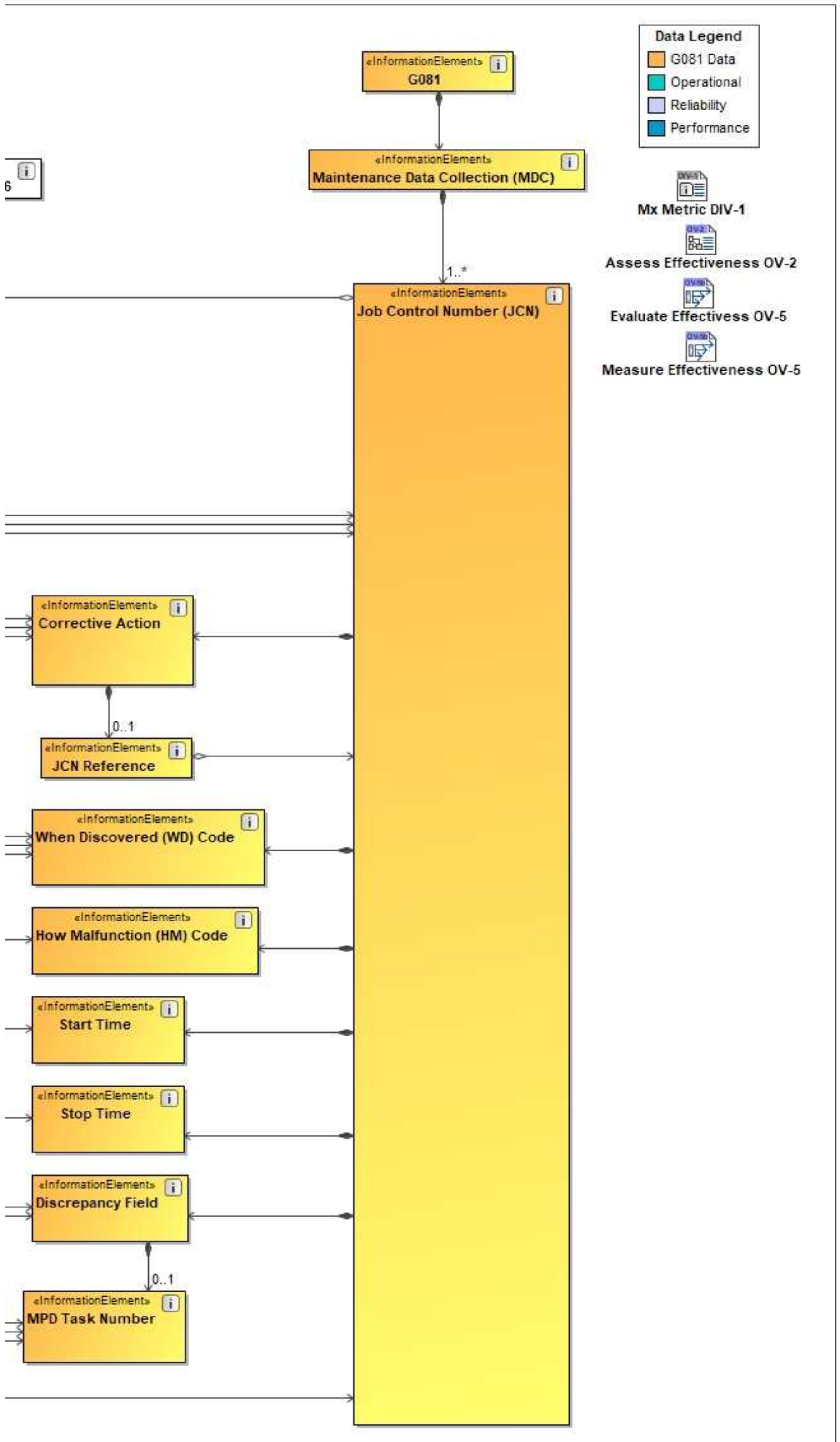
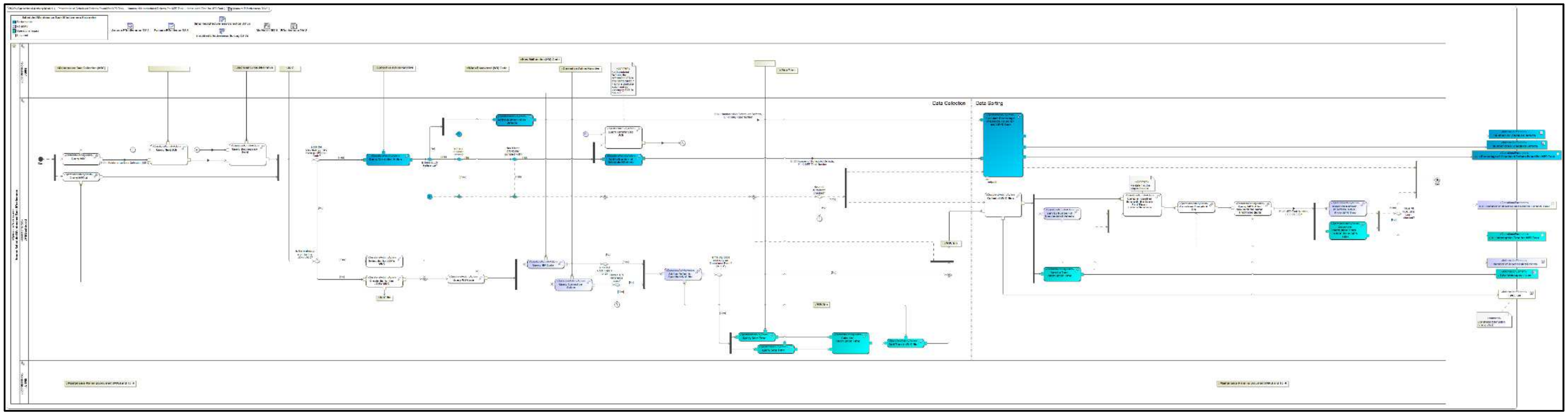
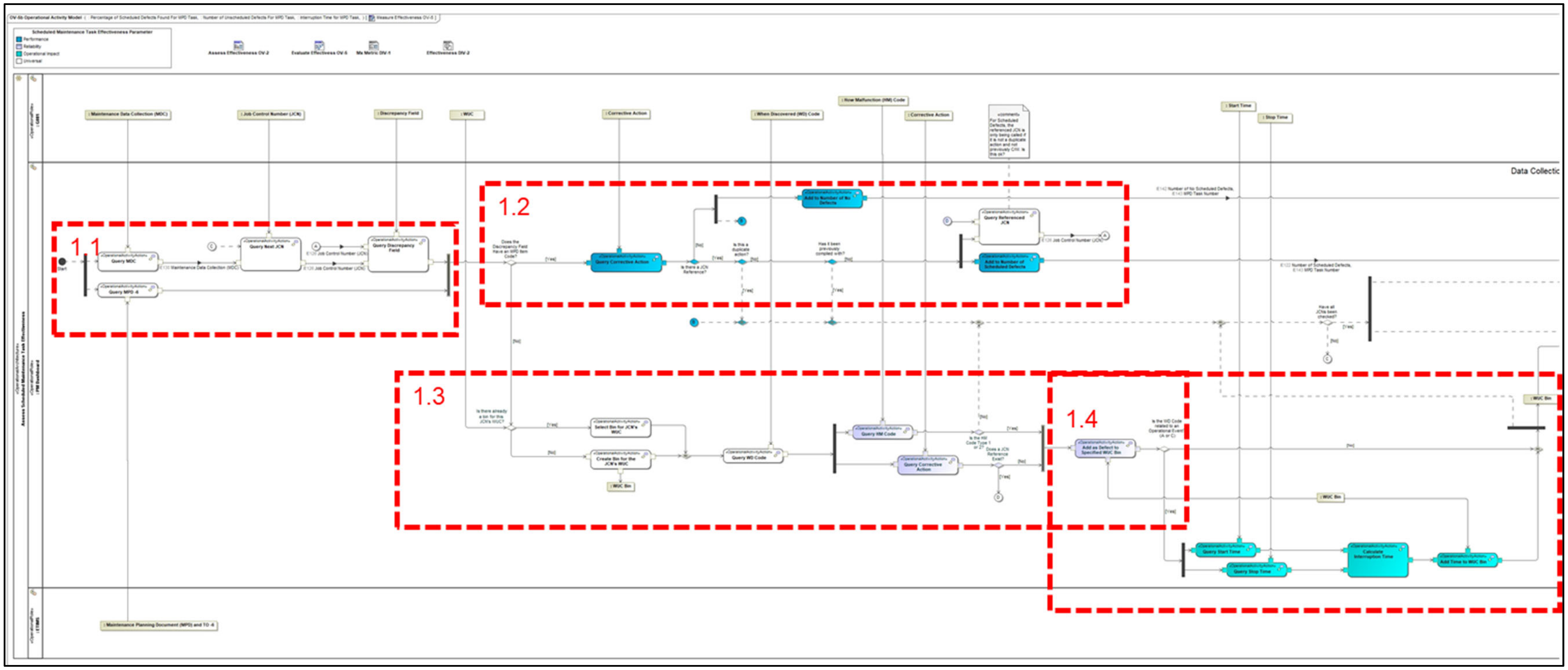


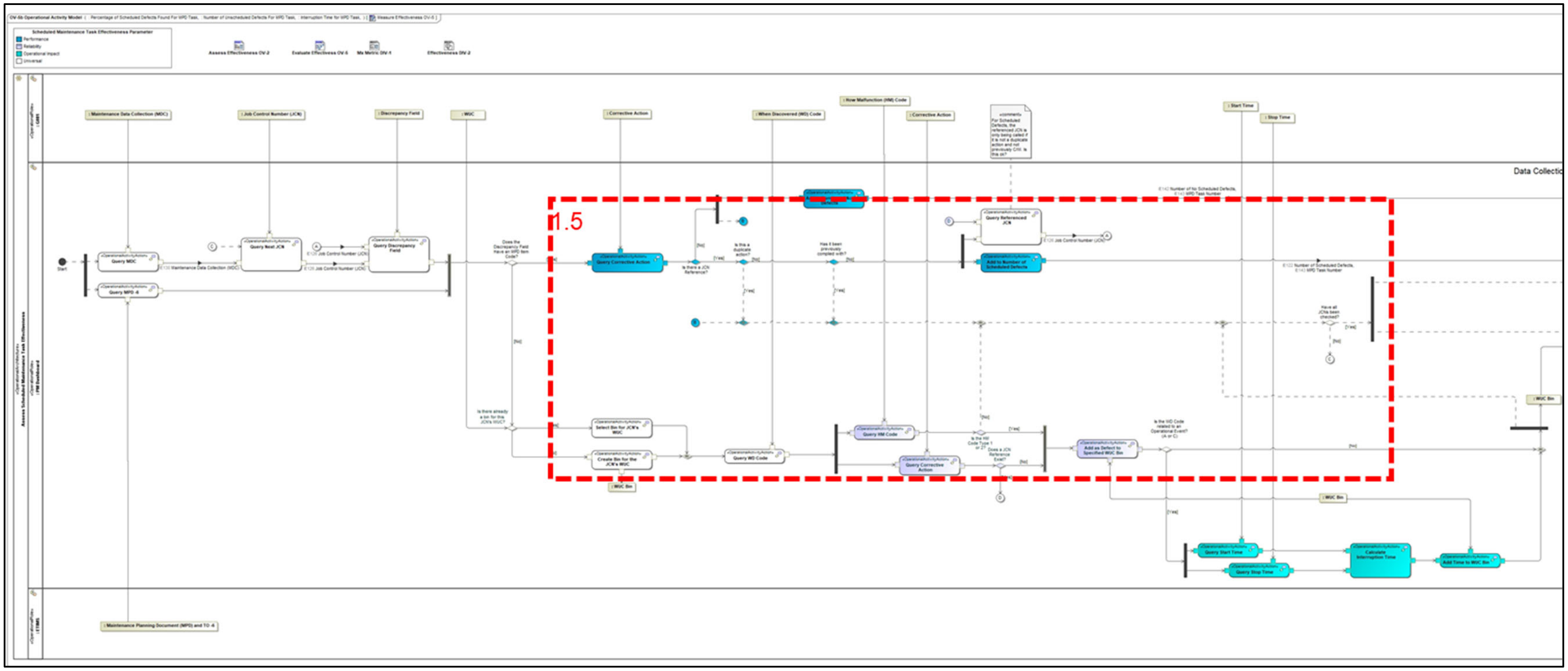
Figure 41b: Maintenance Program Decision-Making G081 Maintenance Data Logical Data Model (DIV-2)

Operational Activity Model (OV-5b) Full

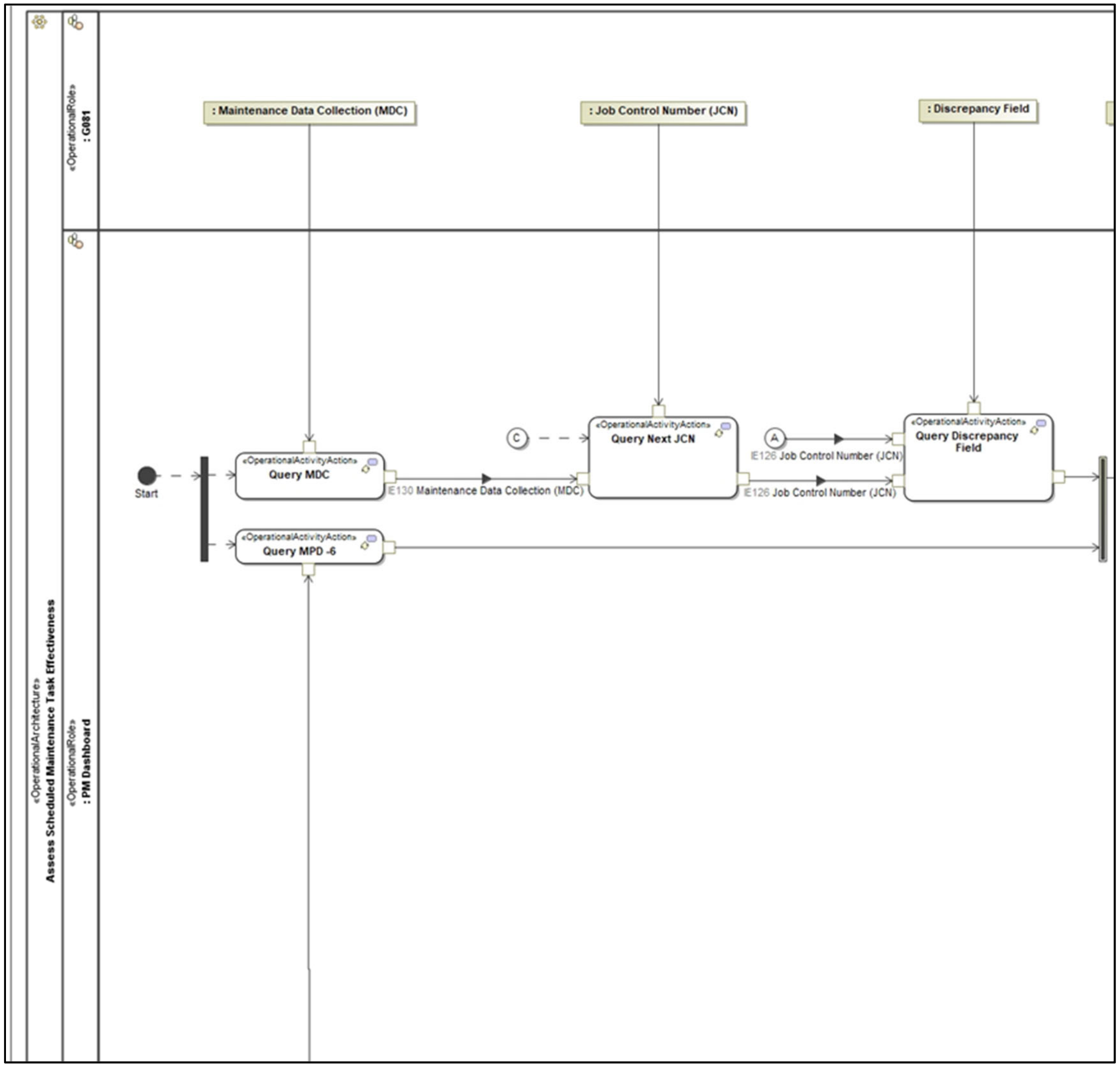


OV-5b Collection 1: Measuring Maintenance Effectiveness

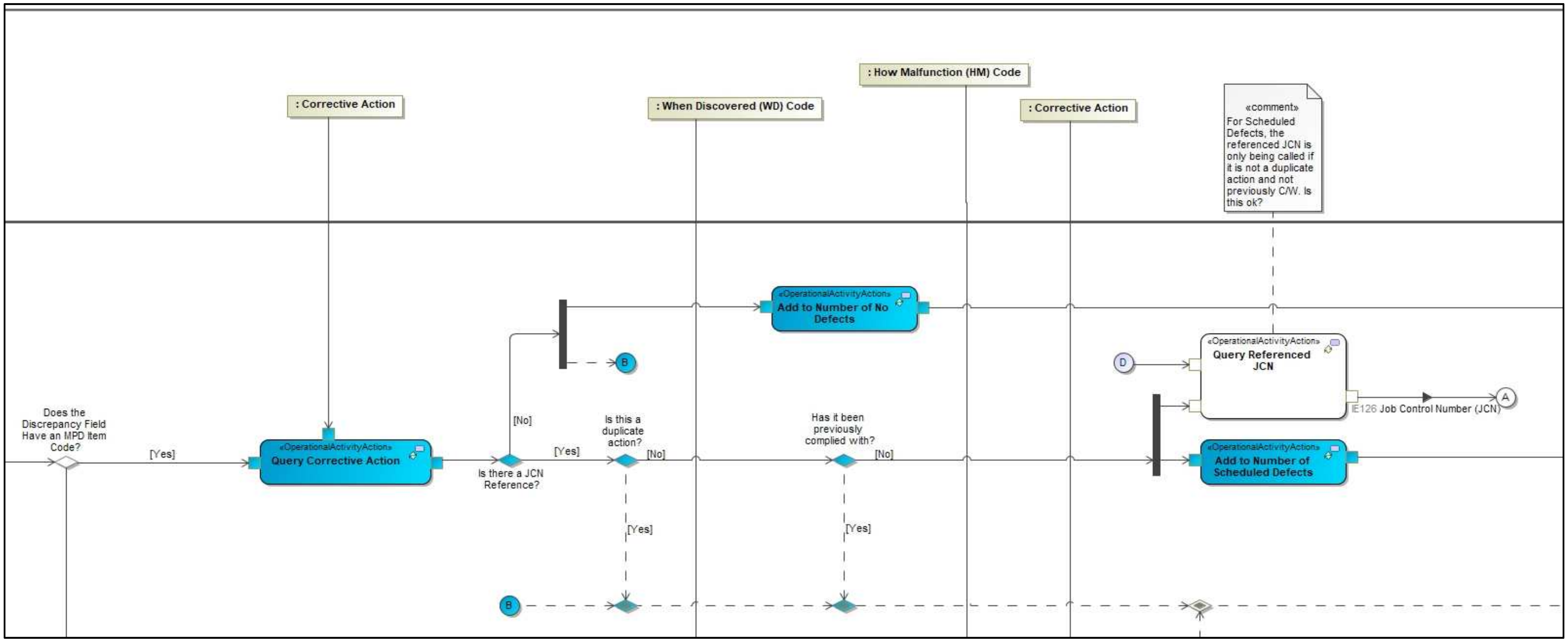



1.5
Data Collectio

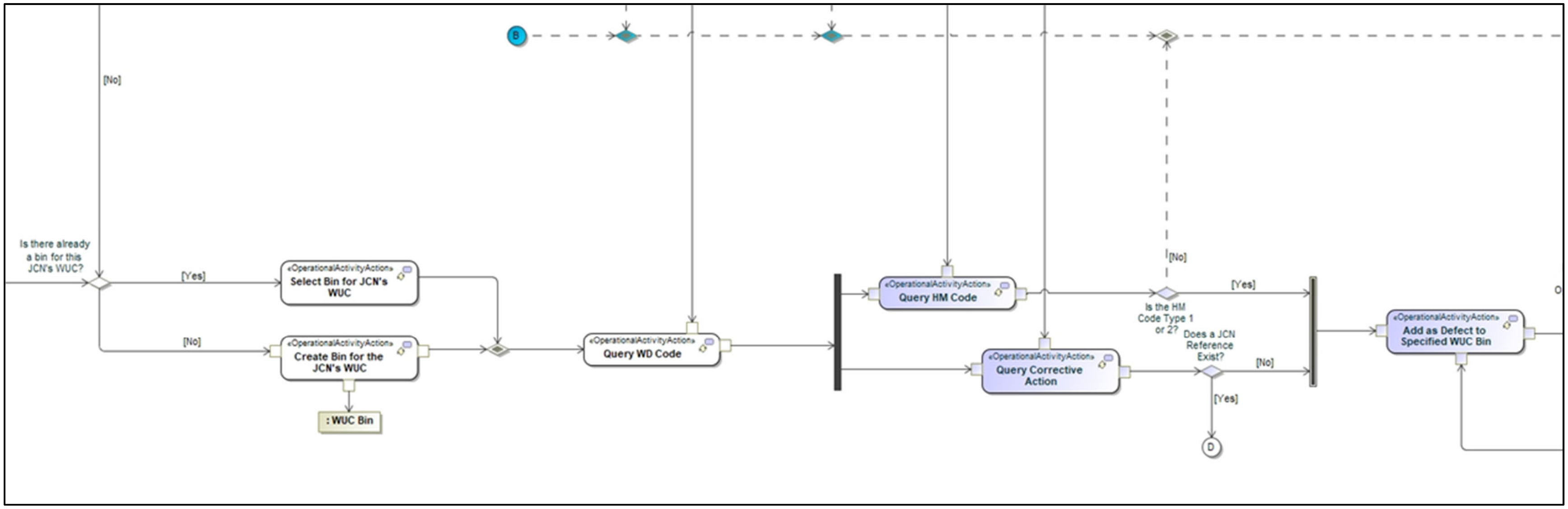
OV-5b Step 1.1: Query Data



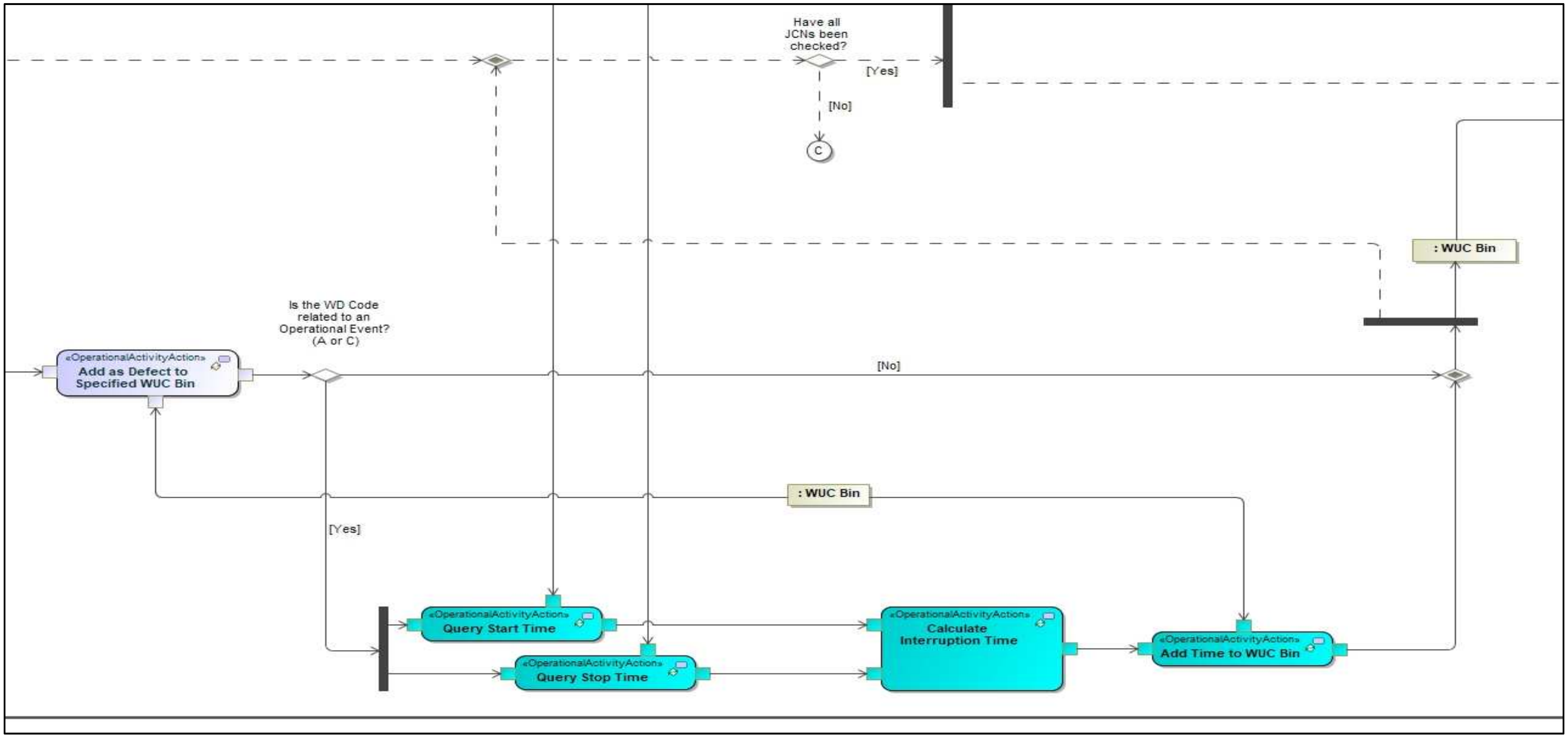
OV-5b Step 1.2: Find Scheduled Defects



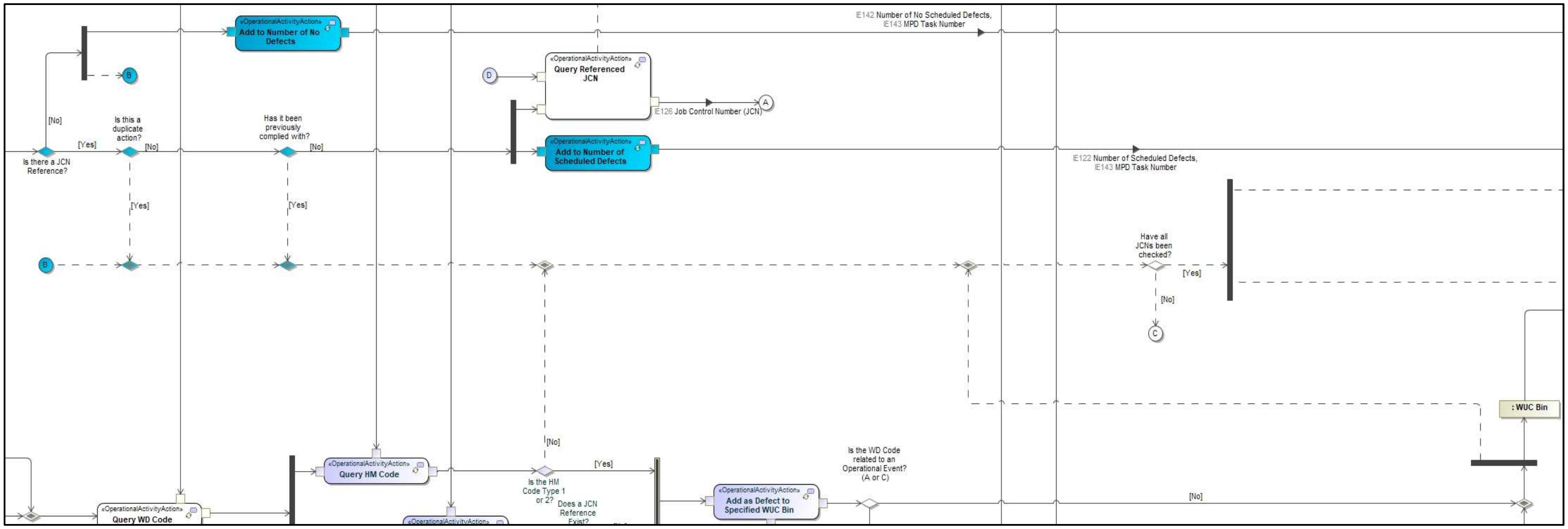
OV-5b Step 1.3: Find Unscheduled Defects



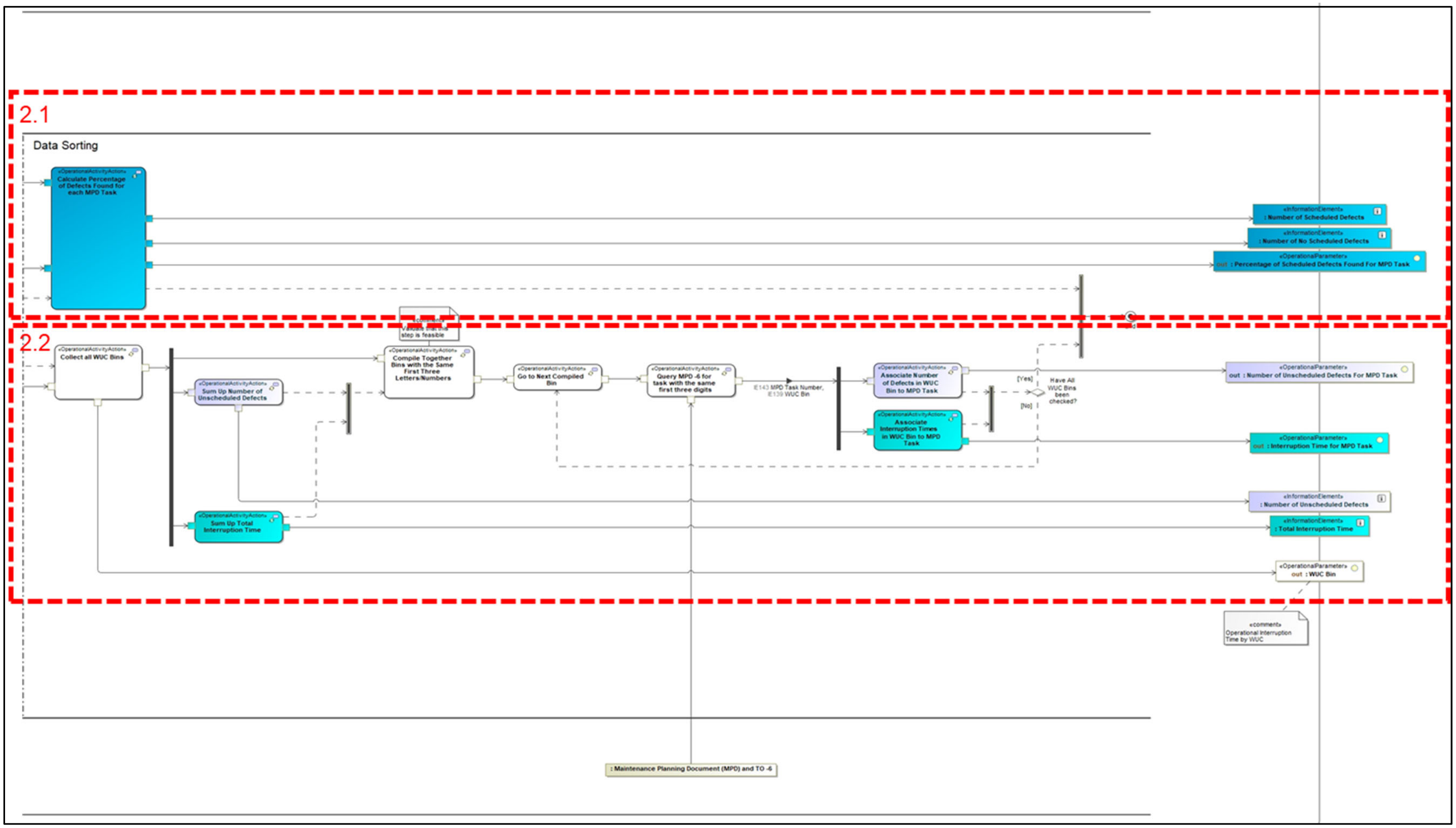
OV-5b Step 1.4: Determine Operational Impact



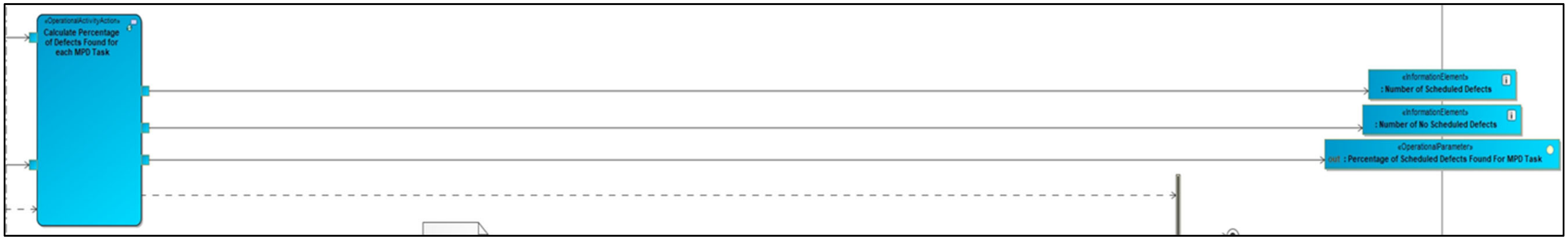
OV-5b Step 1.5: Control Chain



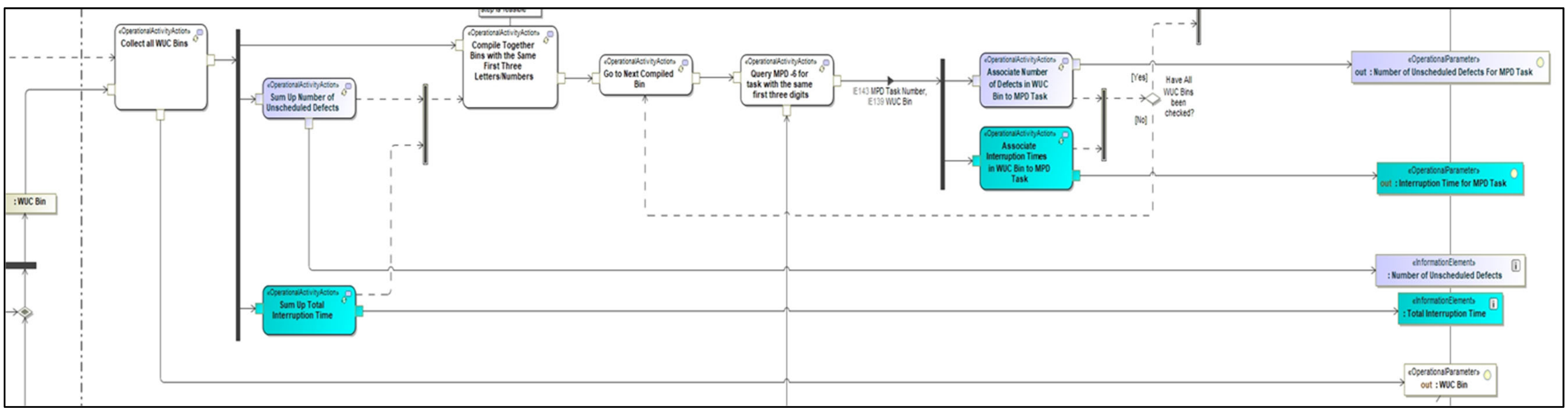
OV-5b Collection 2: Data Sorting



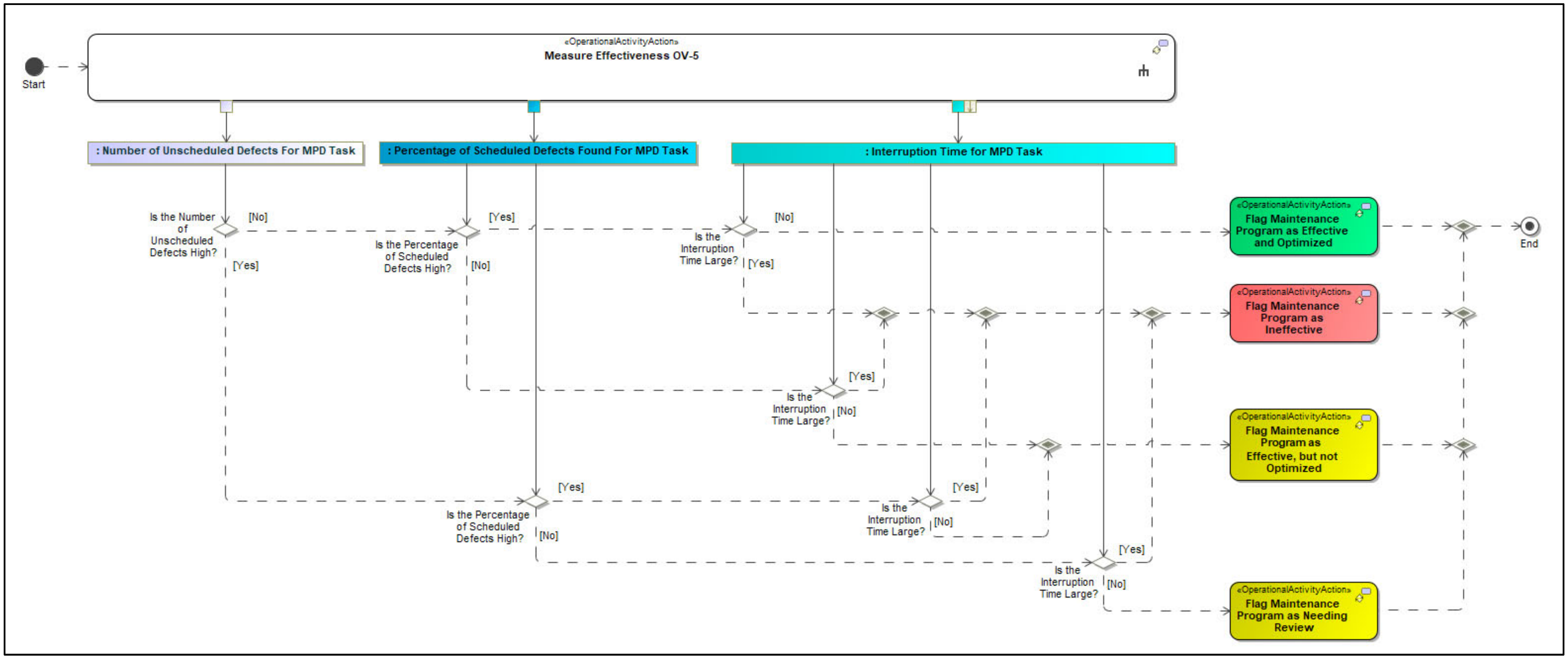
OV-5b Step 2.1: Process Scheduled Events



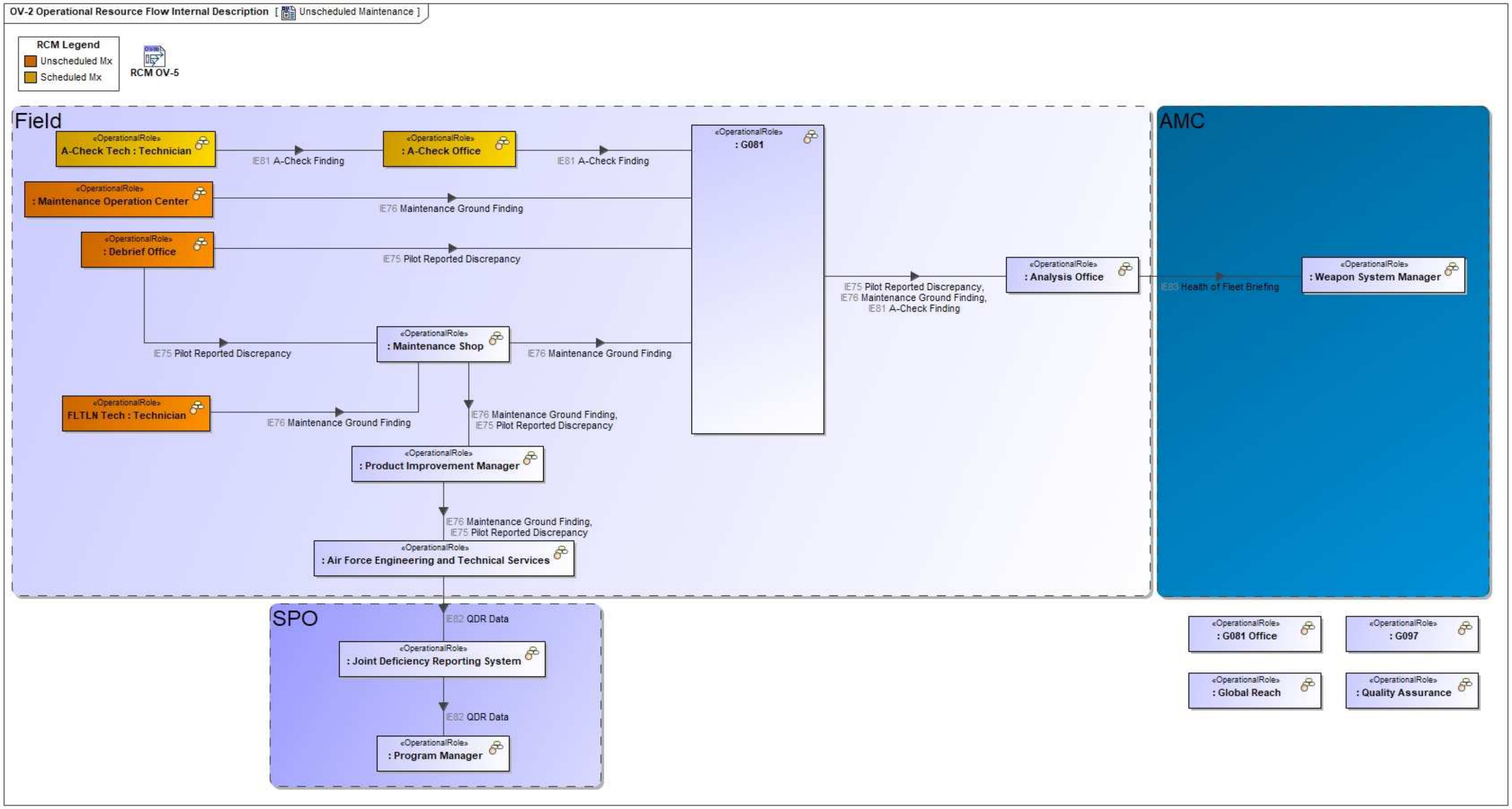
OV-5b Step 2.2: Process Unscheduled Events



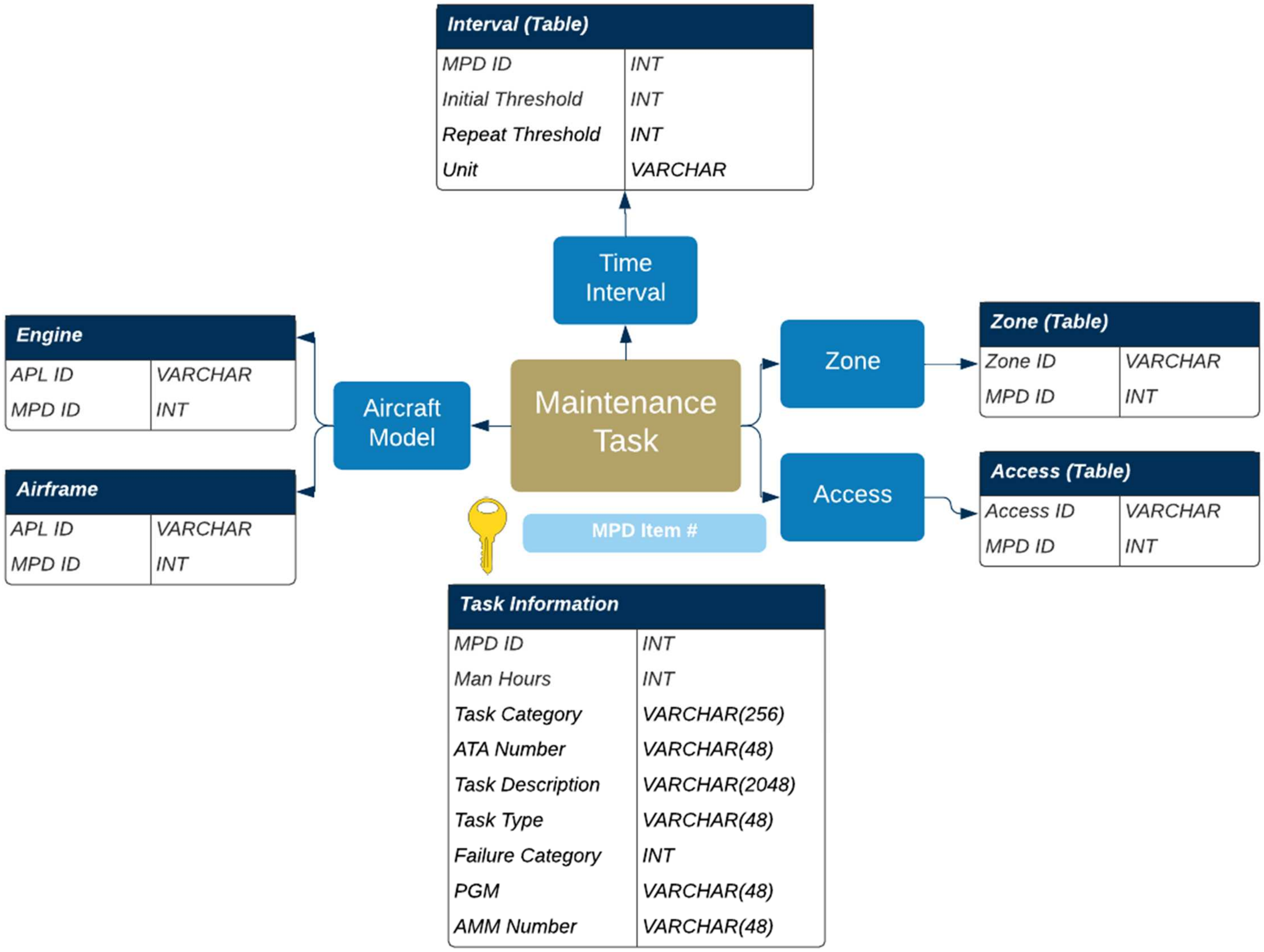
OV-5b Extension: Evaluate Maintenance Effectiveness Decision Tree



Operational Resource Flow Description (OV-2)



KC-46A Maintenance Task Entity Relationship Diagram



APPENDIX B: CASS PERFORMANCE INFERENCE TABLE FORWARD AND BACKWARD CHAINING EXAMPLE

Forward and backward chaining is the process of drawing concluisons from rules and/or sets of intermediate or final facts. They are search strategies to perform inferencing as an expert system's knowledge processing element. Forward chaining is a data driven control and search method to infer conclusions from facts in an expert system. Backward chaining is a goal driven control and search method to infer facts from conclusions.

The below forward and backward chainging algorithms are demonstrated for a notional KC-46A maintenace task has the following facts and conclusions regarding it CASS performance:

- Facts (used as inputs in forward chaining):
    - The KC-46A sustainment enterprise is <u>complaint</u> with the task (Rule 1)
    - The task's unscheduled defects have a <u>low operational impact</u> (Rule 2)
    - The task has a <u>low number of unscheduled defects</u> (Rules 3 and 4)
    - The task has a <u>high number of scheduled defects</u> (Rule 5)
- Conclusions (used as inputs in backward chaining):
        - The task's CASS performance is:
            - Compliant,
            - Effective, and
            - Optimized.

Forward Chaining Algorithm

1. The task's fact **"**KC-46A sustainment enterprise is <u>complaint</u> with the task" is related to its "Compliance" attribute which is recorded in the Attribute Queue. Active rules are scanned and marked to query their respective free clauses. Since all rules are still active, they are all marked and their premises related to the compliance attribute are determined to be true or false. Rule 1's premise that "The KC-46A Sustainment Enterprise is <u>NOT compliant</u> with the maintenance task" is proven false by this fact and thus the rule is discarded.

   The first clause for Rules 2 – 5 is proven true since "the KC-46A sustainment enterprise is <u>compliant</u> with the maintenance task." Thus the first premise for Rules 2 – 5 ("evaluate task for effectiveness) is proven true and the rule's status remains active. The inference table's working memory is updated to show Compliance = Yes. Since the "evaluate task for effectiveness" premise requires additional facts beyond the task's compliance criteria, proceed to the next attribute.

Rule Number and Description	Rule Status	Premise Clause Number and Description	Clause Status
1. IF the KC-46A sustainment enterprise is <u>NOT compliant</u> with a maintenance task,	Discarded Marked	1. THEN the task is not compliant AND perform corrective action on compliance discrepancies.	1. False Clause
2. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is high,**	Active Marked Triggered	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task is ineffective AND requires a reliability improvement.	1. True Clause 2. Free Clause

3. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a high number of unscheduled maintenance defects,** **AND there is a low number of scheduled maintenance defects,**	Active Marked Triggered	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task requires more analysis to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.	1. True Clause 2. Free Clause
4. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a low number of unscheduled maintenance defects** **OR there is high number of unscheduled maintenance defects AND there is a high number of scheduled maintenance defects,**	Active Marked Triggered	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality.	1. True Clause 2. Free Clause
5. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low** **AND there is a low number of unscheduled maintenance defects** **AND a high number of scheduled maintenance defects,**	Active Marked Triggered	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality. 3. THEN the task is optimized AND continue to monitor.	1. True Clause 2. Free Clause 3. Free Clause
Attribute Queue 1. Compliance (Rule 1)		**Working Memory** 1. Compliance = Yes	

2. The task's next facts are "unscheduled defects have a low operational impact" and there are a "low number of unscheduled defects." These are related to its "Effectiveness" attribute which is recorded next in the Attribute Queue. Rule 1 is discarded and thus unmarked so it is not queried. The free clauses in Rules 2 – 5 are scanned to be proven true or false by these facts. The second clauses of Rules 2 and 3 are proven false and the rules are discarded. The second clause of Rules 4 and 5 are proven true and proceed with the corresponding premise of "the task is effective AND evaluate for optimality". Since all of Rule 4's clauses are proven true, its status is set as triggered and fired and the rule will be unmarked since there are no clauses to be queried. The working memory is now updated to show the task as compliant and effective.

Rule Number and Description	Rule Status	Premise Clause Number and Description	Clause Status
1. IF the KC-46A sustainment enterprise is <u>NOT compliant</u> with a maintenance task,	Discarded Unmarked	1. THEN the task is not compliant AND perform corrective action on compliance discrepancies.	1. False Clause
2. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is high,**	Discarded Marked Triggered	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task is ineffective AND requires a reliability improvement.	1. True Clause 2. False Clause
3. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task:	Discarded Marked Triggered	1. THEN the task is compliant AND evaluate task for effectiveness.	1. True Clause 2. False Clause

AND the operational impact of unscheduled defects is low, **AND there is a high number of unscheduled maintenance defects,** **AND there is a low number of scheduled maintenance defects,**		2. THEN the task requires more analysis to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.	
4. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a low number of unscheduled maintenance defects** **OR there is high number of unscheduled maintenance defects AND there is a high number of scheduled maintenance defects,**	Active Marked Triggered Fired	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality.	1. True Clause 2. True Clause
5. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low** **AND there is a low number of unscheduled maintenance defects** **AND a high number of scheduled maintenance defects,**	Active Marked Triggered	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality. 3. THEN the task is optimized AND continue to monitor.	1. True Clause 2. True Clause 3. Free Clause
Attribute Queue 1. Compliance (Rule 1) 2. Effectiveness (Rules 2 – 4)		**Working Memory** 1. Compliance = Yes 2. Effective = Yes	

3. The task's final fact is that it has "a high number of scheduled defects" which is related to the task's optimality listed in the attribute queue. Rules 1 – 4 are unmarked as all of their clauses are proven true or false. The final clause for Rule 5 is proven true thus proceed with the corresponding premise that "the task is optimized AND continue to monitor." Rule 5 is marked as triggered and fired and update the working memory accordingly.

Rule Number and Description	Rule Status	Premise Clause Number and Description	Clause Status
1. IF the KC-46A sustainment enterprise is <u>NOT compliant</u> with a maintenance task,	Discarded Unmarked	1. THEN the task is not compliant AND perform corrective action on compliance discrepancies.	1. False Clause
2. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is high,**	Discarded Unmarked	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task is ineffective AND requires a reliability improvement.	1. True Clause 2. False Clause
3. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a high number of unscheduled maintenance defects,** **AND there is a low number of scheduled maintenance defects,**	Discarded Unmarked	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task requires more analysis to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.	1. True Clause 2. False Clause

4. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a low number of unscheduled maintenance defects** **OR there is high number of unscheduled maintenance defects AND there is a high number of scheduled maintenance defects,**	Active Unmarked Triggered Fired	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality.	1. True Clause 2. True Clause
5. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low** **AND there is a low number of unscheduled maintenance defects** **AND a high number of scheduled maintenance defects,**	Active Marked Triggered Fired	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality. 3. THEN the task is optimized AND continue to monitor.	1. True Clause 2. True Clause 3. True Clause
Attribute Queue 1. Compliance (Rule 1) 2. Effectiveness (Rules 2 – 4) 3. Optimality (Rule 5)		**Working Memory** 1. Compliance = Yes 2. Effective = Yes 3. Optimized = Yes	

Using forward chaining with the facts provided for this task, inference table concludes that the task is compliant, effective, and optimized. Additionaly, Rule 5's final premise recommends that the KC-46A CASS program continues to monitor the task's performance. Lastly, note that if there were a low number of scheduled defects, Rule 5 regarding the task's optimality would be false and only Rule 4 would fire. This would infer that the task is complaint, effective, but not optimized.

Backward Chaining Algorithm

1. Using the conclusions that the notional KC-46A maintenance task being evlauated is compliant, effective, and optimized (i.e., Rule 5's premises), the algorithm first lists those conclusions in a goal table instead of attribute queue in the inference table. All rules are set to active and all clauses are free to be queried. The working memory is cleared and inference table is set up to execute backward chaining.

Rule Number and Description	Rule Status	Premise Clause Number and Description	Clause Status
1. IF the KC-46A sustainment enterprise is <u>NOT compliant</u> with a maintenance task,	Active	1. THEN the task is not compliant AND perform corrective action on compliance discrepancies.	1. Free Clause
2. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is high,**	Active	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task is ineffective AND requires a reliability improvement.	1. Free Clause 2. Free Clause
3. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a high number of unscheduled maintenance defects,** **AND there is a low number of scheduled maintenance defects,**	Active	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task requires more analysis to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.	1. Free Clause 2. Free Clause

4. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a low number of unscheduled maintenance defects** **OR there is high number of unscheduled maintenance defects AND there is a high number of scheduled maintenance defects,**	Active	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality.	1. Free Clause 2. Free Clause
5. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low** **AND there is a low number of unscheduled maintenance defects** **AND a high number of scheduled maintenance defects,**	Active	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality. 3. THEN the task is optimized AND continue to monitor.	1. Free Clause 2. Free Clause 3. Free Clause
Goal Table 1. Compliant (Rule 1) 2. Effective (Rules 2 – 4) 3. Optimized (Rule 5)		**Working Memory**	

2. The rules are then evaluated to determine the unknow fact of the unscheduled defect's operational impact (i.e., high or low). Knowing the conclusion that the task is effective, evaluate the free premise clauses related to the effectiveness attribure. In doing so, Rule 2's second premise clause is proven false and discard the rule. The second clause for Rules 4

and 5 are proven true and the rules are triggered. The working memory is updated with the established fact that the unscheduled defect's operational impact is low.

Rule Number and Description	Rule Status	Premise Clause Number and Description	Clause Status
1. IF the KC-46A sustainment enterprise is <u>NOT compliant</u> with a maintenance task,	Active	1. THEN the task is not compliant AND perform corrective action on compliance discrepancies.	1. Free Clause
2. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is high,**	Discard	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task is ineffective AND requires a reliability improvement.	1. True Clause 2. False Clause
3. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a high number of unscheduled maintenance defects,** **AND there is a low number of scheduled maintenance defects,**	Active Triggered	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task requires more analysis to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.	1. True Clause 2. Free Clause
4. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low,**	Active Triggered	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality.	1. Free Clause 2. True Clause

AND there is a low number of unscheduled maintenance defects **OR there is high number of unscheduled maintenance defects AND there is a high number of scheduled maintenance defects,**			
5. IF the KC-46A sustainment enterprise is <u>compliant</u> with a maintenance task: **AND the operational impact of unscheduled defects is low** **AND there is a low number of unscheduled maintenance defects** **AND a high number of scheduled maintenance defects,**	Active Triggered	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality. 3. THEN the task is optimized AND continue to monitor.	1. Free Clause 2. True Clause 3. Free Clause
Goal Table 1. Compliant (Rule 1) 2. Effective (Rules 2 – 4) 3. Optimized (Rule 5)		**Working Memory** 1. The task's unscheduled defects have a low operational impact (Rule 2)	

3. In discarding Rule 2 and triggering Rules 3 – 5, the table also infers that the task can only be evaluated for efectiveness if it is compliant (as also stated in the conclusion). Thus, Rule 1's premise clause is proven false and it is discarded. The first premise for Rules 3, 4, and 5 are proven true and the working memory is updated with the established fact that the KC-46A sustainment enterprise is compliant with the maintenance task. Rule 4 is fired since all of its premise clauses

are proven true. Proceed until all rules are fired or discarded in order to establish the complete facts of the maintenance task based in the conclusion's classification.

Rule Number and Description	Rule Status	Premise Clause Number and Description	Clause Status
1. IF the KC-46A sustainment enterprise is NOT compliant with a maintenance task,	Discard	1. THEN the task is not compliant AND perform corrective action on compliance discrepancies.	1. False Clause
2. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is high,**	Discard	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task is ineffective AND requires a reliability improvement.	1. True Clause 2. False Clause
3. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a high number of unscheduled maintenance defects,** **AND there is a low number of scheduled maintenance defects,**	Active Triggered	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task requires more analysis to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.	1. True Clause 2. Free Clause
4. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low,**	Active Triggered Fired	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality.	1. True Clause 2. True Clause

AND there is a low number of unscheduled maintenance defects **OR there is high number of unscheduled maintenance defects AND there is a high number of scheduled maintenance defects,**			
5. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low** **AND there is a low number of unscheduled maintenance defects** **AND a high number of scheduled maintenance defects,**	Active Triggered	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality. 3. THEN the task is optimized AND continue to monitor.	1. True Clause 2. True Clause 3. Free Clause
Goal Table 1. Compliant (Rule 1) 2. Effective (Rules 2 – 4) 3. Optimized (Rule 5)		**Working Memory** 1. The task's unscheduled defects have a low operational impact (Rule 2) 2. The KC-46A sustainment enterprise is complaint with the task (Rule 1)	

4. Next, evaluate the rules to determine the unknown fact of the number of unscheduled defects. Knowing the conclusion that the task is optimized, the free premise clauses related to the optimality attribure are evaluated. In doing so, Rule 5's final premise clause is proven true which fires the rule. The working memory is updated with the established facts that the task has a low number of unscheduled defects and high number of scheduled defects. These facts prove Rule 3's second clause false thus discarding the rule.

Rule Number and Description	Rule Status	Premise Clause Number and Description	Clause Status
1. IF the KC-46A sustainment enterprise is NOT compliant with a maintenance task,	Discard	1. THEN the task is not compliant AND perform corrective action on compliance discrepancies.	1. False Clause
2. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is high,**	Discard	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task is ineffective AND requires a reliability improvement.	1. True Clause 2. False Clause
3. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a high number of unscheduled maintenance defects,** **AND there is a low number of scheduled maintenance defects,**	Discard	1. THEN the task is compliant AND evaluate task for effectiveness. 2. THEN the task requires more analysis to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.	1. True Clause 2. False Clause
4. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low,** **AND there is a low number of unscheduled maintenance defects**	Active Triggered Fired	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality.	1. True Clause 2. True Clause

OR there is high number of unscheduled maintenance defects AND there is a high number of scheduled maintenance defects,			
5. IF the KC-46A sustainment enterprise is compliant with a maintenance task: **AND the operational impact of unscheduled defects is low** **AND there is a low number of unscheduled maintenance defects** **AND a high number of scheduled maintenance defects,**	Active Triggered Fired	1. THEN the task is compliant AND evaluate task for effectiveness 2. THEN the task is effective AND evaluate for optimality. 3. THEN the task is optimized AND continue to monitor.	1. True Clause 2. True Clause 3. True Clause
Goal Table 1. Compliant (Rule 1) 2. Effective (Rules 2 – 4) 3. Optimized (Rule 5)		**Working Memory** 1. The task's unscheduled defects have a low operational impact (Rule 2) 2. The KC-46A sustainment enterprise is complaint with the task (Rule 1) 3. The task has a low number of unscheduled defects (Rules 3 and 4) 4. The task has a high number of scheduled defects (Rule 5)	

Now, all rules are discarded or fired based on the conclusions/goals that the evaluated KC-46A maintenance task is compliant, effective, and optimized. Using backward chaining, the same facts are established from forward chaining which are:

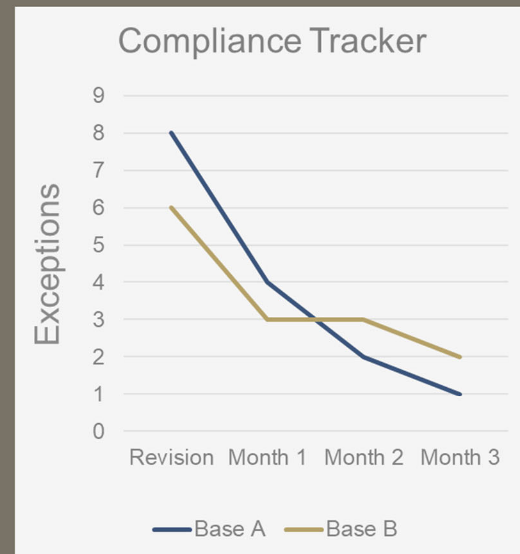
- The KC-46A sustainment enterprise is complaint with the task (Rule 1)

- The task’s unscheduled defects have a low operational impact (Rule 2)
- The task has a low number of unscheduled defects (Rules 3 and 4)
- The task has a high number of scheduled defects (Rule 5)

Compliance Assurance Tool (CAT) Sample Report

Base	Error Type	Description
Base A	Extra MPD	Task CC-032-00-02 is in the A-check, but not the -6.
Base B	Missing MPD	Task 12-123-46-01 is missing from the A-check package.
Base B	Incorrect Interval	Task 22-444-00-01 has an interval of 8 MO, which has been revised to 1 YR.
⋮		⋮

Error Type category can be changed as required



KC-46A Maintenance Effectiveness Decision Engine (K-MEDE) Sample Report

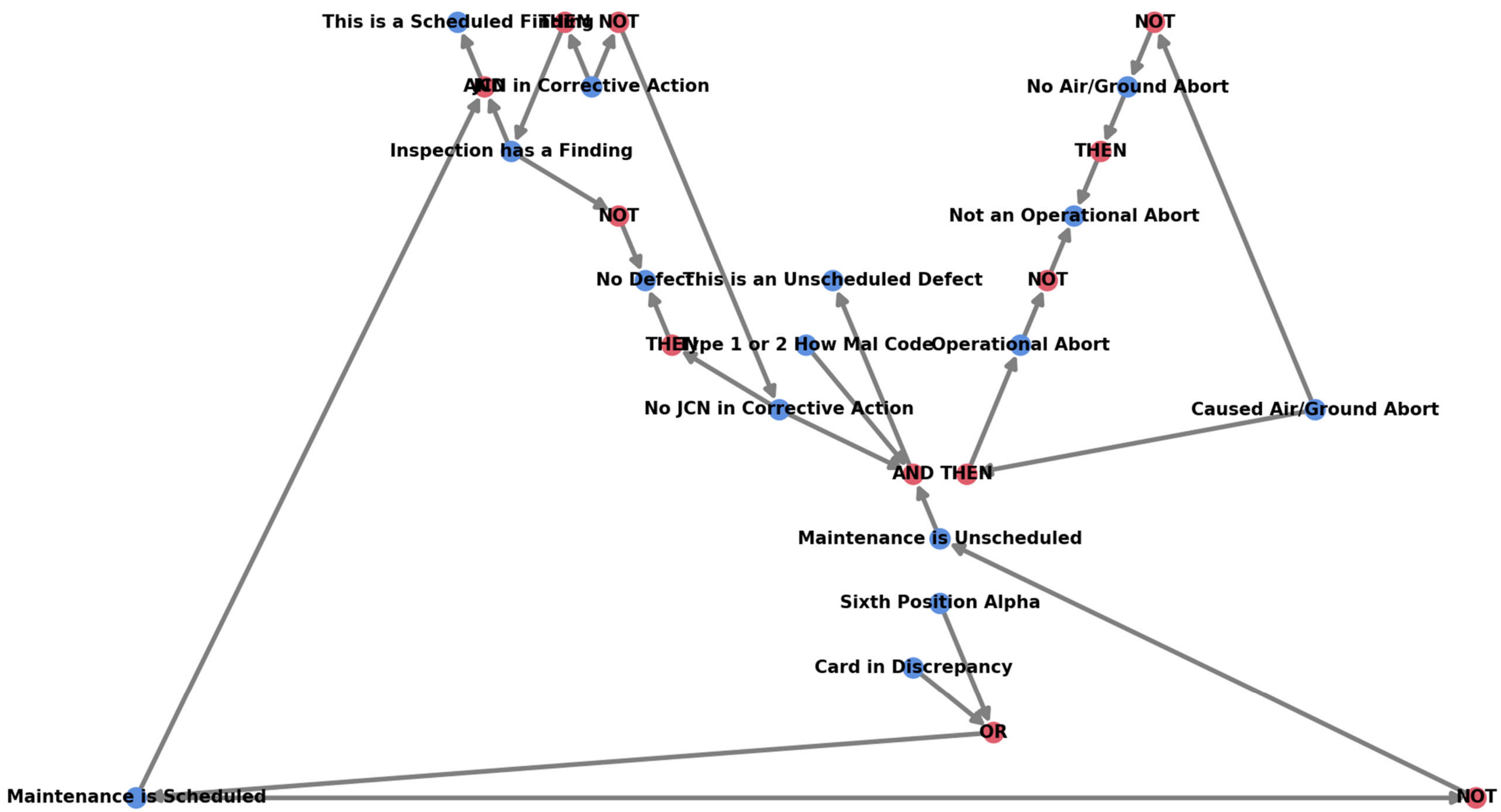
Scheduled Findings

Task	WUC	Count	Findings	Frequency	Median Man Hours	Mean Man Hours	Unscheduled Defect Count
21-120-00-01 Fan Fault Circuits	04999	44	3	6.8%	7.5	6.5	0
29-025-00-01 Left Hyd EDP / ACMP Case Drain Filter	45ALB	49	2	4.1%	0.3	0.3	0
28-100-00-01 Body Tank Refueling Isolation Valve	46PR0	89	3	3.4%	0.1	0.3	1

Unscheduled Findings

WUC	Task	Count	Findings	Frequency	Median Man Hours	Mean Man Hours	Scheduled Defect Count
45ANA – Filter Element	29-040-00-01 Ctr Hyd ACMP / ADP Case Drain Filter	5	3	60%	0.2	0.6	0
47BA0 – O2 Cylinder (TCI)	35-004-46-01 O2 Bottle A-check	18	7	39%	0.5	0.6	2
47AC0 – Pressure Transducer	35-010-00-01 Crew O2 Press Transducer	7	2	29%	7.8	7.8	0

K-MEDE Inference Network



APPENDIX D: PROPOSED KC-46A MAINTENANCE PROGRAM DECISION MAKING FRAMEWORK APPLICATION

The following displays the Excel spreadsheet tabs that comprised framework's application and were evaluated by KC-46A SMEs during the focus group. The Excel spreadsheet file can be made available upon request to the author.

Front Matter Tab

Content: This document contains the proposed decision-making framework for the KC-46A maintenance program in the following tabs:

> **Background:** Information supporting the development of the proposed framework.

> **Proposed Framework:** An overview of the decision-making (DM) steps, logic, and recommended response when evaluating a KC-46A maintenance task's performance.

> **Current State DM Tool:** This is the decision support tool provided to the author by the KC-46A Continued Analysis and Surveillance System (CASS) Office on September 20, 2022. It is based on the KC-46A maintenance program increasing its annual aircraft utilization (i.e., moving from 489 to 700 flight hours per year), comparison to the Maintenance Review Board Report (MRBR) intervals, and identification of identical tasks. This tool analyzes a subset of 43 A-Check maintenance tasks to justify their adjustment to Boeing. The KC-46A CASS Office indicated all tasks were not analyzed due to Boeing repackaging the KC-46A A-check.

> **Proposed DM Tool:** This is the application of the proposed DM framework. It is intended to advance the current state DM tool by including the compliance, effectiveness, and optimality criteria of maintenance tasks and recommending a response to improve the task's performance.

> **DM Parameter Selection:** This is the proposed DM selection parameters to quantify the effectiveness and optimality of a maintenance tasked based on notional reliability, maintainability, and availability metrics. These notional thresholds are categorized by the Maintenance Steering Group Third Edition's (MSG-3) Failure Effects Category (FEC) and would need to be formalized based on KC-46A operational/readiness requirements and engineering analysis if implemented.

> **Example Maintenance Task:** This is the example template for a maintenance task's performance data to inform the Proposed DM Tool. It contains notional detailed analysis and visualization of the compliance, effectiveness, and optimality of a selected maintenance task. It also contains additional information to inform CASS analysis and decision making such as the interval comparison to an optimized commercial B767 maintenance task.

Background Tab

The following background items inform the proposed decision-making framework and are provided here for reference.

1. FAA decision criteria to determine the effectiveness and optimality of a systems/powerplant maintenance task.

	Low **Number of Unscheduled Maintenance Defects**		***High*** **Number of Unscheduled Maintenance Defects**	
	Low Impact on Operations	*High* Impact on Operations	*Low* Impact on Operations	*High* Impact on Operations
Low **Number of Scheduled Defects**	Effective but not optimized	Ineffective	More analysis required to determine effectiveness	Ineffective
High **Number of Scheduled Defects**	Effective and optimized	Ineffective	Effective but not optimized	Ineffective

Adapted From: FAA. "AC 120-17B - Reliability Program Methods - Standards for Determining Time Limitations," 2018, Table 5-2. Review of Systems/Powerplant Tasks.

Key Takeaways:

1. Any task which has a high impact on operations due to unscheduled maintenance is deemed ineffective
2. Low and high parameters must be defined for each maintenance task
   > Recommended to set thresholds based on MSG-3 Failure Effects Category (FEC)
   > Proposed Defect and Operational Parameters are found on the "Generic Parameter Selection" Tab

2. KC-46A and B767 Applications

KC-46A:

> The KC-46A Customized Maintenance Planning Document (CMPD) front matter states it is the USAF's "responsibility to justify an escalation of (maintenance) intervals and other time limitations to their regulatory authority based on substantiating operating experience."

> The KC-46A's Continued Analysis and Surveillance System (CASS) Technical Order (TO) 00-25-266-KC46 states "CASS Office analysts will continuously analyze KC-46 data in the Pegasus Fleet Management Tool (PFMT) to identify characteristics indicating a need for program adjustment, revision of operational or maintenance practices, or equipment improvement (i.e. modification)."

> PFMT is a decision support system capable of performing CASS functions via its Performance, Maintenance Effectiveness, and Reliability/Maintainability (R&M) modules but the author observs it is not currently being used to adjust maintenance tasks based on operational data. The current state DM tool is an example of how CASS and R&M analysis is observed to be performed outside of PFMT in an ad hoc and manual manner.

B767: A leading commercial operator demonstrated the DM process to optimize their maintenance program by significantly escalating hundreds of maintenance task intervals and achieve alternate means of compliance through structural health monitoring sensors (i.e., revising their maintenance practices).

3. GTRI's Compliance Assurance Tool (CAT) and KC-46A Maintenance Effectiveness Decision Engine (K-MEDE)

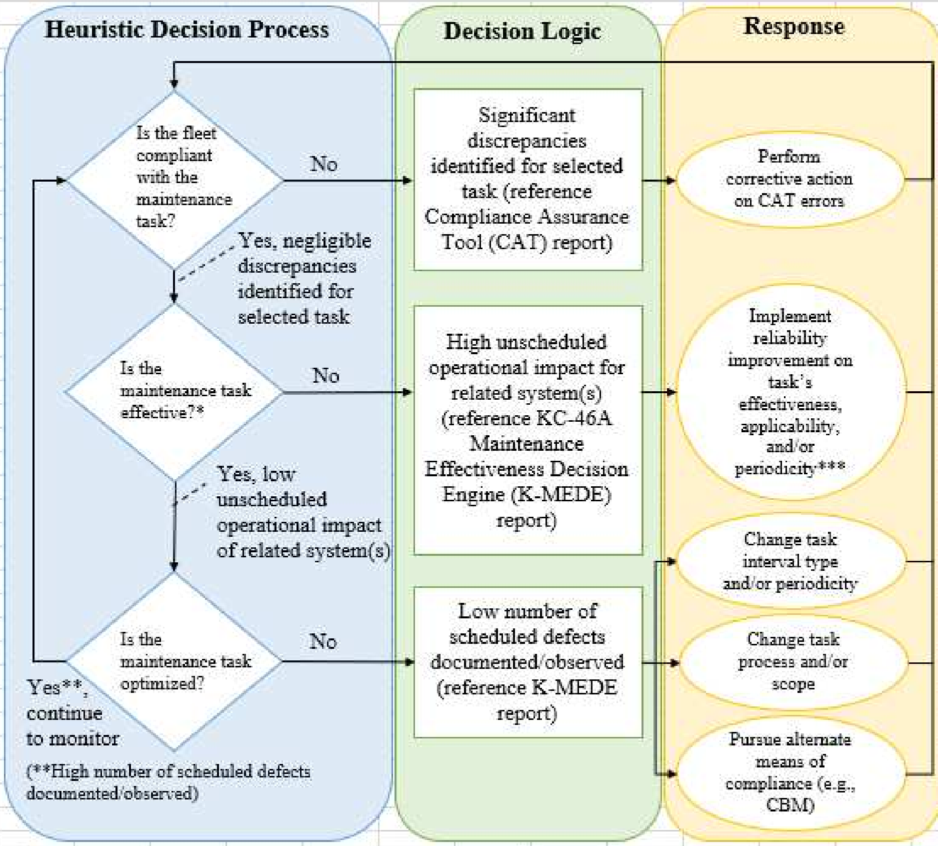
GTRI's CAT and K-MEDE are prototype rule-based expert systems developed under the research project titled "Adapting Commercial Best Practices to the KC-46A Maintenance Program." They produce semi-automated reports of suspected compliance discrepancies in the KC-46A maintenance program and scheduled/unscheduled defects for respective maintenance tasks.

CAT and K-MEDE execute conditional-logic algorithms to query and compare KC-46A maintenance data, the KC-46A CMPD, and the KC-46A scheduled maintenance requirements TO. While the project's research results indicated several inherent data limitations CAT and K-MEDE face, their outputs are demonstrated in the 'Example Maintenance Task' tab.

Lastly, opportunity exists to develop CAT and K-MEDE into expert system knowledge engines for the PFMT CASS modules (along with integrating Machine Learning solutions such as the Rapid Sustainment Office's Predictive Analytics and Decision Assistant (PANDA)).

Proposed Framework Tab

The framework below proposes the decision-making process to achieve a compliant, effective, and optimized maintenance program via CASS program responses for an evaluated maintenance task. In comparison to a decision support system such as PFMT, decision frameworks refer to the higher level principles, processes, and practices to proceed from information and desires to choices that inform actions and outcomes [1].



*The task's effectiveness is inconclusive when answering this heuristic if there is are low scheduled defects and unscheduled operational impact with high unscheduled defects. In this situation, more analysis is required to determine why the unscheduled defects are not being prevented by the scheduled maintenance task.

***If a maintenance task is deemed to be effective after reliability analysis, pursue an alternate root cause improvement such as an engineering design change or modification to aircrew flight procedures.

[1] Lockie, S., & Rockloff, S. (2005). *Decision frameworks: assessment of the social aspects of decision frameworks and development of a conceptual model.* CRC Coastal Zone Estuary and Waterway Management.

Current state Decision-Making Tool Tab

	Task Number	Task Description	FEC CODE CAT	CMPD Interval	MRBR Interval	R&M Analysis FH/FC	R&M Analysis CAL	R&M Rational	Boeing Adjust
1	21-120-00-01	Fan Fault Circuits	9	16 MO	6000 FH	2 Years (1C)	2 Years (1C)		
2	23-025-00-01	Audio Control Panel (ACP)	9	16 MO	6000 FH	8 Years (4C)	6 Years (3C)		
3	23-035-00-01	Voice Recorder - Self Test - Operation test	9	2 MO	750 FH	Pre-Launch Inspection	Pre-Launch Inspection	EZPR recommends moving this task to Pre-launch Inspection (PLI) because this is a critical failure item. Additionally, this task only requires 0.03 manhours (only 108 seconds) per the CMPD and the item is easily accessible.	
4	24-005-00-01	Engine 1 IDG QAD Coupling	6	1 YR	2250 FH				
5	24-005-00-02	Engine 2 IDG QAD Coupling	6	1 YR	2250 FH				
6	24-055-00-01	Hydraulic Motor Generator (HMG) - Operation test	9	2 MO	750 FH	Delete this A-check task	Delete this A-check task	This task is executed every time a Pre-Launch Inspection (PLI) occurs and is a true duplicate. Therefore the A-check task can be deleted.	
7	25-060-00-01	Lavatory Waste Compartment Doors	8	2 MO	1000 FH	16 Months (8A)	12 Months (6A)		
8	25-135-00-01	Off-Wing Slide Inflation Bottle - Visual examination	8	2 MO	750 FH	12 Months (6A)	8 Months (4A)		
9	25-170-00-01	Aft Entry/Service Door Esc Slide Bottles - Visual examination	8	2 MO	750 FH	Delete this A-check task	Delete this A-check task	The Aft entry/service door escape slide inflation bottle is inspected for proper pressure during Preflight/Basic Postflight (PR/BPO). This check is part of a more comprehensive PR/BPO task: Slide/raft (2) – Attached to the aft entry/service doors (Escape System Check - Inspection [※]). Therefore this A-check task can be deleted.	
10	26-055-00-01	Wheel Well Fire Detection System - Operation test	9	2 YR	750 FH	Delete this A-check task	Delete this A-check task	The wheel well fire detection system is already tested every preflight, as a part of the Automatic Fire/Overheat Logic Test System (AFOLTS) with Eng/APU/Cargo Test Switch Operational Test task. The FIRE/OVHT TEST pushbutton is pressed for seven seconds and the Engine Indication and Crew Alerting System (EICAS), red master warning light, and 'fire test in prog/ fire test pass' display for the duration of the test. Therefore, this preflight task includes all steps of the wheel well fire detection test, and the wheel well fire detection system operational test A-check task can be deleted.	

11	27-170-00-01 Left TE Flap Drive Mechanism	6	1 YR	4500 FH	2 Years (1C)	2 Years (1C)		
12	27-170-00-02 Right TE Flap Drive Mechanism	6	1 YR	4500 FH	2 Years (1C)	2 Years (1C)		
13	28-055-00-01 Body Tank Vent Isolation Valve	8	16 MO	6000 FH	8 Years (4C)	6 Years (3C)		
14	28-100-00-01 Body Tank Refueling Isolation Valve	8	8 MO	3000 FH	4 Years (1C)	2 Years (1C)		
15	29-025-00-01 Left Hydraulic EDP / ACMP Case Drain Filter	6	8 MO	3000 FH	4 Years (1C)	2 Years (1C)		
16	29-025-00-02 Right Hydraulic EDP / ACMP Case Drain Filter	6	8 MO	3000 FH	4 Years (1C)	2 Years (1C)		
17	29-040-00-01 Center Hydraulic ACMP / ADP Case Drain Filter	6	8 MO	3000 FH	4 Years (1C)	2 Years (1C)		
18	30-015-00-01 Pitot Static Probe Heat Annunciator - Operation test	9	2 MO	750 FH				
19	31-050-00-01 Landing Warning System - Operation test	8	2 MO	750 FH	12 Months (6A)	8 Months (4A)		
20	32-030-00-01 Left Main Gear Truck Pivot Pin	8	14 DY 50FC	14 DY 50FC	2 Months (1A)	2 Months (1A)		
21	32-030-00-02 Right Main Gear Truck Pivot Pin	8	14 DY 50FC	14 DY 50FC	2 Months (1A)	2 Months (1A)		
22	32-055-00-01 Nose Gear Extension and Retraction and Door Components	6,8	2 MO	1000 FH	4 Months (2A)	4 Months (2A)		
23	32-065-00-01 Left Gear Extension and Retraction and Door Components	6,8	2 MO	1000 FH	4 Months (2A)	4 Months (2A)		The interval for this task will be escalated by Boeing from 2 months to 4 months
24	32-065-00-02 Right Gear Extension and Retraction and Door Components	6,8	2 MO	1000 FH	4 Months (2A)	4 Months (2A)		The interval for this task will be escalated by Boeing from 2 months to 4 months
25	32-085-00-01 Right Main Gear Brakes - Detailed Visual Inspection	9	2 MO	100 FC	6 Months (3A)	4 Months (2A)		
26	32-085-00-02 Left Main Gear Brakes - Detailed Visual Inspection	9	2 MO	100 FC	6 Months (3A)	4 Months (2A)		
27	32-115-00-01 Parking Brake Accumulator - Servicing	8	2 MO	750 FH	Remove Task	Remove Task	This task is a true duplication of activity during BPO and should be removed The exact same task is performed as section 1.3 of BPO Servicing. While the BPO section states "if necessary", it does not provide criteria AND the only way to check the system is to depresurize the hydraulics which is the beginning of the referenced/linked task. The task then calls for servicing based on accumulator presure results and that is the same set of steps for BPO and A-check. Further investigation found no additional reasons to have a calendar based version of this check in addition to the frequently required in the BPO version.	
28	34-020-00-01 ADIRU Computers	9	4 MO	2000 FH	2 Years (1C)	2 Years (1C)		
29	35-004-46-01 Portable Oxygen Bottle A-check	8	4 MO	N/A	12 Months (6A)	8 Months (4A)		
30	35-010-00-01 Crew Oxygen Press Transducer/Indicator - Testing, Checking	8	2 MO	750 FH	12 Months (6A)	8 Months (4A)		
31	35-015-00-01 Crew Oxygen Mask/Regulator/Stowage box	8	4 MO	1500 FH	24 Months (1C)	18 Months (9A)		
32	35-025-00-01 Crew/Supernumerary Oxygen Masks	8	4 MO	1500 FH	24 Months (1C)	18 Months (9A)		
33	35-100-00-01 Supernumerary Oxygen System Pressure Indications	8	16 MO	6000 FH	8 Years (4C)	6 Years (3C)		
34	38-015-00-01 Vacuum Waste Sensor Control	9	8 MO	3000 FH	4 Years (1C)	2 Years (1C)		
35	52-085-00-01 Aft Cargo Door Operating Mechanism	9	8 MO	3000 FH	4 Years (1C)	2 Years (1C)		
36	71-135-00-01 Strut 1 Drain Inlets	9	1 YR	6000 FH 18 MO	18 Months (9A)	18 Months (9A)		
37	71-135-00-02 Strut 1 Drain Inlets	9	1 YR	6000 FH 18 MO	18 Months (9A)	18 Months (9A)		
38	72-125-00-01 Engine 1 - 1.6 Stage Compressor Rotor Blades	6	1 YR	2000 FH				
39	72-125-00-02 Engine 2 - 1.6 Stage Compressor Rotor Blades	6	1 YR	2000 FH				
40	72-210-00-01 Engine 1 Main Gearbox Housing	6	6 MO	6000 FH 18 MO	18 Months (9A)	18 Months (9A)		
41	72-210-00-02 Engine 2 Main Gearbox Housing	6	6 MO	6000 FH 18 MO	18 Months (9A)	18 Months (9A)		
42	72-215-00-01 Engine 1 Angle Gearbox Housing	6	6 MO	6000 FH 18 MO	18 Months (9A)	18 Months (9A)		
43	72-215-00-02 Engine 2 Angle Gearbox Housing	6	6 MO	6000 FH 18 MO	18 Months (9A)	18 Months (9A)		
	3. CAT FAILURE EFFECT CATEGORIES & REGULATORY REQUIREMENTS All tasks listed in this section have a "category" identification as follows: • 5 - Evident, Safety • 6 - Evident, Operational • 7 - Evident, Economic • 8 - Hidden, Safety • 9 - Hidden, Non-Safety • _ - A blank indicates this task is a non-MRB item or an ATA 20 task established via the Enhanced Zonal Analysis Process (EZAP), or the Lightning/HIRF MSG-3 analysis process (LHIRF).							

Proposed Decision-Making Tool

	Task Number Task Description	FEC CODE CAT	CMPD Inten	MRBR Interv	R&M Analysis FH/FC	R&M Analysis CAL	R&M Rational	Boeing Adjust	Compliance Check	Effective?	Optimized?	Recommended Response
1	21-120-00-01 Fan Fault Circuits	9	16 MO	6000 FH	2 Years (1C)	2 Years (1C)						
2	23-025-00-01 Audio Control Panel (ACP)	9	16 MO	6000 FH	8 Years (4C)	6 Years (3C)						
3	23-035-00-01 Voice Recorder - Self Test - Operation test	9	2 MO	750 FH	Pre-Launch Inspection	Pre-Launch Inspection	EZPR recommends moving this task to Pre-launch Inspection (PLI) because this is a critical failure item. Additionally, this task only requires 0.03 manhours (only 108 seconds) per the CMPD and the item is easily accessible.					
4	24-005-00-01 Engine 1 IDG QAD Coupling	6	1 YR	2250 FH								
5	24-005-00-02 Engine 2 IDG QAD Coupling	6	1 YR	2250 FH								
6	24-055-00-01 Hydraulic Motor Generator (HMG) - Operation test	9	2 MO	750 FH	Delete this A-check task	Delete this A-check task	This task is executed every time a Pre-Launch Inspection (PLI) occurs and is a true duplicate. Therefore the A-check task can be deleted.					
7	25-060-00-01 Lavatory Waste Compartment Doors	8	2 MO	1000 FH	16 Months (8A)	12 Months (6A)						
8	25-135-00-01 Off-Wing Slide Inflation Bottle - Visual examination	8	2 MO	750 FH	12 Months (6A)	8 Months (4A)						
9	25-170-00-01 Aft Entry/Service Door Esc Slide Bottles - Visual examination	8	2 MO	750 FH	Delete this A-check task	Delete this A-check task	The Aft entry/service door escape slide inflation bottle is inspected for proper pressure during Preflight/Basic Postflight (PR/BPO). This check is part of a more comprehensive PR/BPO task: Slide/raft (2) – Attached to the aft entry/service doors (Escape System Check - Inspection [※]). Therefore this A-check task can be deleted.					
10	26-055-00-01 Wheel Well Fire Detection System - Operation test	9	2 YR	750 FH	Delete this A-check task	Delete this A-check task	The wheel well fire detection system is already tested every preflight, as a part of the Automatic Fire/Overheat Logic Test System (AFOLTS) with Eng/APU/Cargo Test Switch Operational Test task. The FIRE/OVHT TEST pushbutton is pressed for seven seconds and the Engine Indication and Crew Alerting System (EICAS), red master warning light, and 'fire test in prog/ fire test pass' display for the duration of the test. Therefore, this preflight task includes all steps of the wheel well fire detection test, and the wheel well fire detection system operational test A-check task can be deleted.					
11	27-170-00-01 Left TE Flap Drive Mechanism	6	1 YR	4500 FH	2 Years (1C)	2 Years (1C)						
12	27-170-00-02 Right TE Flap Drive Mechanism	6	1 YR	4500 FH	2 Years (1C)	2 Years (1C)						
13	28-055-00-01 Body Tank Vent Isolation Valve	8	16 MO	6000 FH	8 Years (4C)	6 Years (3C)						
14	28-100-00-01 Body Tank Refueling Isolation Valve	8	8 MO	3000 FH	4 Years (1C)	2 Years (1C)						
15	29-025-00-01 Left Hydraulic EDP / ACMP Case Drain Filter	6	8 MO	3000 FH	4 Years (1C)	2 Years (1C)						
16	29-025-00-02 Right Hydraulic EDP / ACMP Case Drain Filter	6	8 MO	3000 FH	4 Years (1C)	2 Years (1C)						
17	29-040-00-01 Center Hydraulic ACMP / ADP Case Drain Filter	6	8 MO	3000 FH	4 Years (1C)	2 Years (1C)						
18	30-015-00-01 Pitot Static Probe Heat Annunciator - Operation test	9	2 MO	750 FH								
19	31-050-00-01 Landing Warning System - Operation test	8	2 MO	750 FH	12 Months (6A)	8 Months (4A)						
20	32-030-00-01 Left Main Gear Truck Pivot Pin	8	14 DY 50FC	14 DY 50FC	2 Months (1A)	2 Months (1A)						

21	32-030-00-02 Right Main Gear Truck Pivot Pin	8	14 DY 50FC	14 DY 50FC	2 Months (1A)	2 Months (1A)						
22	32-055-00-01 Nose Gear Extension and Retraction and Door Components	6,8	2 MO	1000 FH	4 Months (2A)	4 Months (2A)						
23	32-065-00-01 Left Gear Extension and Retraction and Door Components	6,8	2 MO	1000 FH	4 Months (2A)	4 Months (2A)		The interval for this task will be escalated by Boeing from 2 months to 4 months				
24	32-065-00-02 Right Gear Extension and Retraction and Door Components	6,8	2 MO	1000 FH	4 Months (2A)	4 Months (2A)		The interval for this task will be escalated by Boeing from 2 months to 4 months				
25	32-085-00-01 Right Main Gear Brakes - Detailed Visual Inspection	9	2 MO	100 FC	6 Months (3A)	4 Months (2A)						
26	32-085-00-02 Left Main Gear Brakes - Detailed Visual Inspection	9	2 MO	100 FC	6 Months (3A)	4 Months (2A)						
27	32-115-00-01 Parking Brake Accumulator - Servicing	8	2 MO	750 FH	Remove Task	Remove Task	This task is a true duplication of activity during BPO and should be removed The exact same task is performed as section 1.3 of BPO Servicing. While the BPO section states "if necessary", it does not provide criteria AND the only way to check the system is to depresurize the hydraulics which is the beginning of the referenced/linked task. The task then calls for servicing based on accumulator presure results and that is the same set of steps for BPO and A-check. Further investigation found no additional reasons to have a calendar based version of this check in addition to the frequently required in the BPO version.					
28	34-020-00-01 ADIRU Computers	9	4 MO	2000 FH	2 Years (1C)	2 Years (1C)						
29	35-004-46-01 Portable Oxygen Bottle A-check	8	4 MO	N/A	12 Months (6A)	8 Months (4A)						
30	35-010-00-01 Crew Oxygen Press Transducer/Indicator - Testing, Checking	8	2 MO	750 FH	12 Months (6A)	8 Months (4A)						
31	35-015-00-01 Crew Oxygen Mask/Regulator/Stowage box	8	4 MO	1500 FH	24 Months (1C)	18 Months (9A)						
32	35-025-00-01 Crew/Supernumerary Oxygen Masks	8	4 MO	1500 FH	24 Months (1C)	18 Months (9A)						
33	35-100-00-01 Supernumerary Oxygen System Pressure Indications	8	16 MO	6000 FH	8 Years (4C)	6 Years (3C)						
34	38-015-00-01 Vacuum Waste Sensor Control	9	8 MO	3000 FH	4 Years (1C)	2 Years (1C)						
35	52-085-00-01 Aft Cargo Door Operating Mechanism	9	8 MO	3000 FH	4 Years (1C)	2 Years (1C)						
36	71-135-00-01 Strut 1 Drain Inlets	9	1 YR	6000 FH 18 MO	18 Months (9A)	18 Months (9A)						
37	71-135-00-02 Strut 1 Drain Inlets	9	1 YR	6000 FH 18 MO	18 Months (9A)	18 Months (9A)						
38	72-125-00-01 Engine 1 - 1.6 Stage Compressor Rotor Blades	6	1 YR	2000 FH								
39	72-125-00-02 Engine 2 - 1.6 Stage Compressor Rotor Blades	6	1 YR	2000 FH								
40	72-210-00-01 Engine 1 Main Gearbox Housing	6	6 MO	6000 FH 18 MO	18 Months (9A)	18 Months (9A)						
41	72-210-00-02 Engine 2 Main Gearbox Housing	6	6 MO	6000 FH 18 MO	18 Months (9A)	18 Months (9A)						
42	72-215-00-01 Engine 1 Angle Gearbox Housing	6	6 MO	6000 FH 18 MO	18 Months (9A)	18 Months (9A)						
43	72-215-00-02 Engine 2 Angle Gearbox Housing	6	6 MO	6000 FH 18 MO	18 Months (9A)	18 Months (9A)						
	3. CAT FAILURE EFFECT CATEGORIES & REGULATORY REQUIREMENTS All tasks listed in this section have a “category” identification as follows: • 5 - Evident, Safety • 6 - Evident, Operational • 7 - Evident, Economic • 8 - Hidden, Safety • 9 - Hidden, Non-Safety • _ - A blank indicates this task is a non-MRB item or an ATA 20 task established via the Enhanced Zonal Analysis Process (EZAP), or the Lightning/HIRF MSG-3 analysis process (LHIRF).											

Generic Parameter Selection

Effectiveness Parameter Selection (i.e., number of unscheduled defects and operational impact)

	FEC														
	5 (evident safety)			**6** (evident operational)			**7** (evident economic)			**8** (hidden safety)			**9** (hidden economic)		
Unscheduled Defects Parameter	High	Low	Threshold	High	Low	Threshold	High	Low	Threshold	High	Low	Threshold	High	Low	Threshold
Reliability Metrics															
Count of Defects	>	<	10	>	<	25	>	<	25	>	<	10	>	<	25
Mean Time Between Failure (MTBF) (calendar days)	<	>	7	>	<	14	>	<	14	>	<	7	>	<	14
Mean Time Between Failure (MTBF) (flight hours)	<	>	15	>	<	30	>	<	30	>	<	15	>	<	30
Mean Time Between Failure (MTBF) (flight cycles)	<	>	5	>	<	10	>	<	10	>	<	5	>	<	10
Ratio to Scheduled Defects (count of unscheduled defects per scheduled defect)	>	<	0.1	>	<	1	>	<	1	>	<	0.1	>	<	1
Maintainability Metrics															
Total Repair Time (All Repairs)	>	<	100	>	<	100	>	<	100	>	<	100	>	<	100
Mean Time To Repair (MTTR) (All Repairs) (Hours)	>	<	10	>	<	10	>	<	10	>	<	10	>	<	10
Total Repair Time (NMC Repairs) (Hours)	>	<	75	>	<	75	>	<	75	>	<	75	>	<	75
MTTR (NMC Repairs) (Hours)	>	<	7.5	>	<	7.5	>	<	7.5	>	<	7.5	>	<	7.5
Total Repair Time (PMC Repairs) (Hours)	>	<	25	>	<	25	>	<	25	>	<	25	>	<	25
MTTR (PMC Repairs) (Hours)	>	<	2.5	>	<	2.5	>	<	2.5	>	<	2.5	>	<	2.5
Operational Impact Parameter															
Operational Availability															
Mean annual NMC hours per aircraft	>	<	100	>	<	100	>	<	100	>	<	100	>	<	100
Mean annual NMC % decrease per aircraft	>	<	1.14%	>	<	1.14%	>	<	1.14%	>	<	1.14%	>	<	1.14%
Mean annual PMC hours per aircraft	>	<	75	>	<	75	>	<	75	>	<	75	>	<	75
Mean annual PMC % decrease per aircraft	>	<	0.86%	>	<	0.86%	>	<	0.86%	>	<	0.86%	>	<	0.86%
Operational Reliability Metrics															
Count of annual ground aborts per aircraft	>	<	1	>	<	1	>	<	1	>	<	1	>	<	1
Count of annual in-flight aborts per aircraft	>	<	1	>	<	1	>	<	1	>	<	1	>	<	1

Optimality Parameter Selection (i.e., number of scheduled defects)

	FEC														
	5 (evident safety)			**6** (evident operational)			**7** (evident economic)			**8** (hidden safety)			**9** (hidden economic)		
Scheduled Defects Parameter	High	Low	Threshold	High	Low	Threshold	High	Low	Threshold	High	Low	Threshold	High	Low	Threshold
Reliability Metrics															
Count of Defects	>	<	10	>	<	25	>	<	25	>	<	10	>	<	25
Mean Time Between Failure (MTBF) (calendar days)	<	>	7	>	<	14	>	<	14	>	<	7	>	<	14
Mean Time Between Failure (MTBF) (flight hours)	<	>	15	>	<	30	>	<	30	>	<	15	>	<	30
Mean Time Between Failure (MTBF) (flight cycles)	<	>	5	>	<	10	>	<	10	>	<	5	>	<	10
Ratio to Unscheduled Defects (count of scheduled defects per unscheduled defect)	>	<	10	>	<	1	>	<	1	>	<	10	>	<	1
Maintainability Metrics															
Total Repair Time (All Repairs)	>	<	100	>	<	100	>	<	100	>	<	100	>	<	100
Mean Time To Repair (MTTR) (All Repairs) (Hours)	>	<	10	>	<	10	>	<	10	>	<	10	>	<	10
Total Repair Time (NMC Repairs) (Hours)	>	<	75	>	<	75	>	<	75	>	<	75	>	<	75
MTTR (NMC Repairs) (Hours)	>	<	7.5	>	<	7.5	>	<	7.5	>	<	7.5	>	<	7.5
Total Repair Time (PMC Repairs) (Hours)	>	<	25	>	<	25	>	<	25	>	<	25	>	<	25
MTTR (PMC Repairs) (Hours)	>	<	2.5	>	<	2.5	>	<	2.5	>	<	2.5	>	<	2.5

Example Maintenance Task

Task Info		
MPD #		
Description		
Task Type		
FEC		
WUC (Assigned)		
WUC (Associated)		
Interval Type(s)		
Interval Periodicity		
Performance Parameters	Generic or Customized?	
Task Performance Summary		
Compliant?	Yes or No	Trend improving or declining
Effective?	Yes or No	Trend improving or declining
Optimized?	Yes or No	Trend improving or declining
Compliance Check (Details in Rows 35-99)		
Date of Check		
Pass or Fail		
Effectivness Summary (Details in Rows 101-156)		
Date Range	Start	End
Date of Evaluation		
Number of Unscheduled Defects	**High or Low**	**Reason**
Impact on Operations	**High or Low**	**Reason**
Effectiveness Pass or Fail	Effective, Ineffective, or TBD	
Optimality Summary (Details in Rows 159-210)		
Date Range	Start	End
Date of Evaluation		
Number of Scheduled Defects	**High or Low**	**Reason**
Optimality Pass or Fail	Optimizied, Not Optimized, or TBD	

Customized Parameter Selection Table

Effectiveness Parameter Selection (i.e., number of unscheduled defects and operational impact)

	FEC # (Description)		
Unscheduled Defects Parameter	High	Low	Threshold
Reliability Metrics			
Count of Defects	>	<	#
Mean Time Between Failure (MTBF) (calendar	<	>	#
Mean Time Between Failure (MTBF) (flight hours)	<	>	#
Mean Time Between Failure (MTBF) (flight cycles)	<	>	#
Ratio to Scheduled Defects (count of unscheduled defects per scheduled defect)	>	<	#
Maintainability Metrics			
Total Repair Time (All Repairs)	>	<	#
Mean Time To Repair (MTTR) (All Repairs) (Hours)	>	<	#
Total Repair Time (NMC Repairs) (Hours)	>	<	#
MTTR (NMC Repairs) (Hours)	>	<	#
Total Repair Time (PMC Repairs) (Hours)	>	<	#
MTTR (PMC Repairs) (Hours)	>	<	#
Operational Impact Parameter			
Operational Availability			
Mean annual NMC hours per aircraft	>	<	#
Mean annual NMC % decrease per aircraft	>	<	#
Mean annual PMC hours per aircraft	>	<	#
Mean annual PMC % decrease per aircraft	>	<	#
Operational Reliability Metrics			
Count of annual ground aborts per aircraft	>	<	#
Count of annual in-flight aborts per aircraft	>	<	#

Optimality Parameter Selection (i.e., number of scheduled defects)

Scheduled Defects Parameter	High	Low	Threshold
Reliability Metrics			
Count of Defects	>	<	#
Mean Time Between Failure (MTBF) (calendar	<	>	#
Mean Time Between Failure (MTBF) (flight hours)	<	>	#
Mean Time Between Failure (MTBF) (flight cycles)	<	>	#
Ratio to Scheduled Defects (count of unscheduled defects per scheduled defect)	>	<	#
Maintainability Metrics			
Total Repair Time (All Repairs)	>	<	#
Mean Time To Repair (MTTR) (All Repairs) (Hours)	>	<	#
Total Repair Time (NMC Repairs) (Hours)	>	<	#
MTTR (NMC Repairs) (Hours)	>	<	#
Total Repair Time (PMC Repairs) (Hours)	>	<	#
MTTR (PMC Repairs) (Hours)	>	<	#

Compliance Details

Summary

Error Type	Count
Missing MPD Item Number	
Incorrect Interval	
Insuffiicent Removal	
Extra MPD Item Number	
Mispelled MPD Item Number	

Detailed List

Base	Error Type	Discrepancy
AMC	Missing MPD Item Number	
	Incorrect Interval	
	Insuffiicent Removal	
	Extra MPD Item Number	
	Mispelled MPD Item Number	
Altus	Missing MPD Item Number	
	Incorrect Interval	
	Insuffiicent Removal	
	Extra MPD Item Number	
	Mispelled MPD Item Number	
McConnell	Missing MPD Item Number	
	Incorrect Interval	
	Insuffiicent Removal	
	Extra MPD Item Number	
	Mispelled MPD Item Number	
McGuire	Missing MPD Item Number	
	Incorrect Interval	
	Insuffiicent Removal	
	Extra MPD Item Number	
	Mispelled MPD Item Number	
Seymour Johnson	Missing MPD Item Number	
	Incorrect Interval	
	Insuffiicent Removal	
	Extra MPD Item Number	
	Mispelled MPD Item Number	
Pease	Missing MPD Item Number	
	Incorrect Interval	
	Insuffiicent Removal	
	Extra MPD Item Number	
	Mispelled MPD Item Number	

Compliance Trend

Effectivness Details

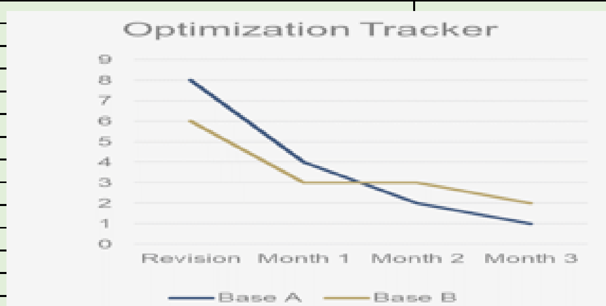
Unscheduled Defects Details

Reliability Metrics	**Value**	**Threshold**	**High or Low**
Count of Defects			
Mean Time Between Failure (MTBF) (calendar days)			
Mean Time Between Failure (MTBF) (flight hours)			
Mean Time Between Failure (MTBF) (flight cycles)			
Ratio to Scheduled Defects (count of unscheduled defects per scheduled defect)			
Maintainability Metrics	**Value**	**Threshold**	**High or Low**
Total Repair Time (All Repairs)			
Mean Time To Repair (MTTR) (All Repairs) (Hours)			
Total Repair Time (NMC Repairs) (Hours)			
MTTR (NMC Repairs) (Hours)			
Total Repair Time (PMC Repairs) (Hours)			
MTTR (PMC Repairs) (Hours)			
Operational Availability	**Value**	**Threshold**	**High or Low**
Mean annual NMC hours per aircraft			
Mean annual NMC % decrease per aircraft			
Mean annual PMC hours per aircraft			
Mean annual PMC % decrease per aircraft			
Operational Reliability Metrics	**Value**	**Threshold**	**High or Low**
Count of annual ground aborts per aircraft			
Count of annual in-flight aborts per aircraft			
Repeat/recur discrepancy rate			

Data Quality Metrics (Before Conditioning/Adjudication)	
% of repair JCNs with WDC not "3" or "M"	
% of repair JCNs with Type Maint Designator "B"	
% of task JCNs with HMC Type 1/2	
Effectiveness Trend	

Defects list	
Row Headers	
Defect 1	
Defect 2	
....	

Optimality Details			
Scheduled Defects Details			
Reliability Metrics	**Value**	**Threshold**	**High or Low**
Count of Defects			
Mean Time Between Failure (MTBF) (calendar days)			
Mean Time Between Failure (MTBF) (flight hours)			
Mean Time Between Failure (MTBF) (flight cycles)			
Ratio to Scheduled Defects (count of unscheduled defects per scheduled defect)			
Maintainability Metrics	**Value**	**Threshold**	**High or Low**
Total Repair Time (All Repairs)			
Mean Time To Repair (MTTR) (All Repairs) (Hours)			
Total Repair Time (NMC Repairs) (Hours)			
MTTR (NMC Repairs) (Hours)			
Total Repair Time (PMC Repairs) (Hours)			
MTTR (PMC Repairs) (Hours)			
Other Parameters of Interest			
Comercial Interval (Full Utilization)			
Comercial Interval (Half Utilization)			
B767 Commercial Leader Interval			
Mean Man Hours to Repair Defect (Cost Metric)			
Total Man Hours to Repair Defect (Cost Metric)			
Data Quality Metrics (Before Conditioning/Adjudication)			
% of repair JCNs with letter in sixth position			
% of repair JCNs with WDC "3" or "M"			
% of task JCNs with HMC Type 1/2			
% of repair JCNs with Type Maint Designator "E" or "P"			
Optimality Trend			

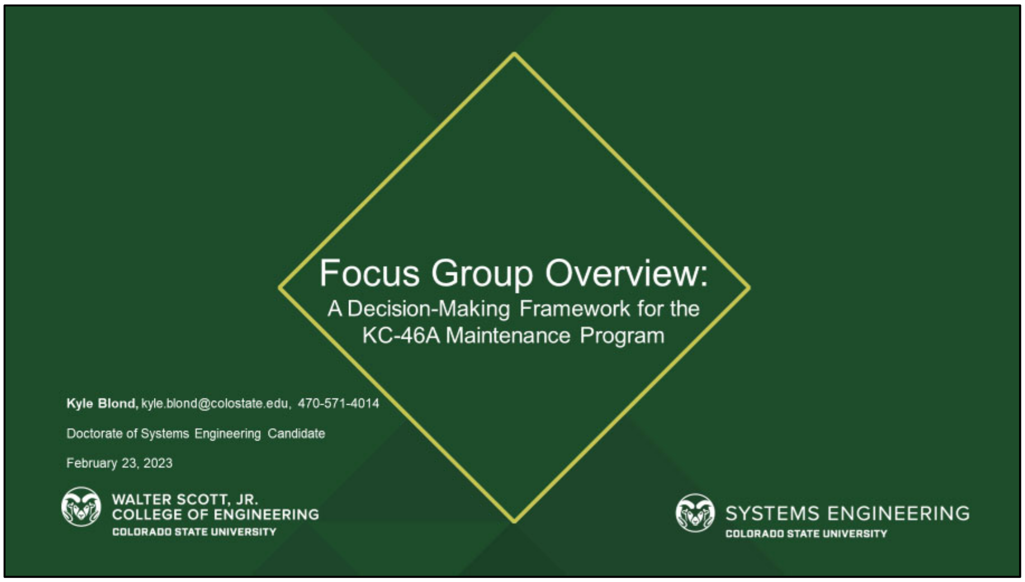


Defects list	
Row Headers	
Defect 1	
Defect 2	
....	

APPENDIX E: FOCUS GROUP OVERVIEW AND RESULTS

Below is an overview and the results of the focus group to evaluate the proposed KC-46A decision-making framework.

Focus Group Overview



Why a Focus Group?

- **Purpose:** To evaluate the proposed decision-making framework compared to the state of the art
- **Method:**
  - Historical and notional use cases of KC-46A maintenance program decisions will be discussed
  - An in-person small group discussion is intended to facilitate conversation/interaction among participants
    - The moderator (Kyle Blond) facilitates discussion vs directing it [1]
- **Result:** An objective assessment of the proposed framework by KC-46A maintenance program SMEs is achieved to inform a business case analysis of its potential applications
- **Other:** This focus group is the future work of the related conference proceedings published in the 69th Reliability and Maintainability Symposium in January 2023
  - Publication Link: https://s3.amazonaws.com/amz.xcdsystem.com/A464CF98-BDF7-92CE-64F634C79E2DA53D_abstract_File22782/C03-3-RM-009.pdf

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[1] Focus group methodology: introduction and history. In P. Liamputtong Focus group methodology: Introduction and history (pp. 1-14). SAGE Publications Ltd, https://dx.doi.org/10.4135/9781473957657)

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Focus Group Structure

- **Medium:**
  - In-person with four to eight KC-46A maintenance program SME's
  - Audio-tape recorded for follow on analysis
- **Date:**
  - Thursday, February 23, 2023
- **Duration:**
  - 1300 -1500 ET

Image Source: https://www.jpost.com/breaking-news/article-690271

- **Notes:**
  - Institutional Review Board (IRB) determined this is not human subjects research
  - Participant inputs are anonymous and non-attribution
  - Published results will not include ITAR/export controlled info (e.g., CUI) and will be approved for public release by USAF

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Agenda

- 1300 – 1315: Welcome, Overview, and Instructions
- 1315 - 1345: Proposed Decision-Making Framework Tutorial
  - See separate Excel spreadsheet attachment for proposed framework
- 1345 - 1400: Break (if desired)
- 1400 – 1445: Focus group discussion
- 1445 – 1500: Focus group conclusion*

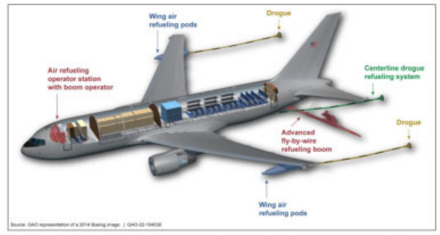

Image Source: https://www.jpost.com/breaking-news/article-690271

*Focus group results will be disseminated to the group via email by March 31, 2023.

Focus Group Question Guide [1]

Participants will be asked to answer and discuss the following:

1. Are there current shortfalls in making reliability and maintainability (R&M) decisions for KC-46 maintenance tasks?
2. How would the proposed KC-46A maintenance program decision-making framework be used in R&M management decisions?
3. Is this an improvement to current state?
4. What barriers (i.e., technical, regulatory, financial, policy) do you expect the proposed framework face if implemented?
5. What is the cost / benefit of the framework?

Adapted from Box 5.1 Example of a Focus Group Question Guide in [1] Focus group methodology: introduction and history. In P. Liamputtong Focus group methodology: Introduction and history (pp. 1-14). SAGE Publications Ltd. https://dx.doi.org/10.4135/9781473957657)

Group Interaction Analysis Approach [1]

The following questions will be answered to produce the results of the focus group.

Group Component	Aspect of Interaction for Analysis
What?	What topics/opinions produced agreement?
	What statements seemed to evoke conflict?
	What were the contradictions in the discussion?
	What common experiences were expressed?
	Did the collective interaction generate new insights or precipitate an exchange of information among participants?
Who?	Whose interests were being represented in the group?
	Were alliances formed among group members?
	Was a particular member or viewpoint silenced?
How?	How closely did the group adhere to the issues presented for discussion?
	How did group members respond to the ideas of others?
	How did the group resolve disagreements?
	How were non-verbal signs and behaviors used to contribute to the discussion?

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Adapted from Table 10.2 Analyzing Group Interaction in [1] Focus group methodology: introduction and history. In P. Liamputtong Focus group methodology: Introduction and history (pp. 1-14). SAGE Publications Ltd, https://dx.doi.org/10.4135/9781473957657)

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Thank you

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Focus Group Results

KC-46A Decision Making Framework Focus Group Interaction Analysis		
Group component	**Aspect of interaction for analysis**	**Analysis Results**
What?	What topics/opinions produced agreement?	The group agreed that a standardized framework is needed to identify the R&M performance of individual maintenance tasks as well as the maintenance program as a whole. Additionally, automating and reporting the framework's KPIs is needed to prescribe and support decision-making in the KC-46A maintenance program.
	What statements seemed to evoke conflict?	Disagreement occurred in how to implement such framework and who is responsible for its implementation. Organizational responsibilities/conflicts we're discussed among the KC-46A SPO, AFLCMC/EZP, and Booze Allen Hamilton as the PFMT provider. Additionally, how to condition the data and measure a maintenance tasks' R&M performance produced disagreement.
	What were the contradictions in the discussion?	Contradictions existed in that a need for the framework was agreed upon but the need to identify how/who should execute and implement it was not agreed upon. Additionally, the KC-46A CASS TO states the existing PFMT infrastructure shall implement the framework but the requirement is not formalized elsewhere to resource it properly.
	What common experiences were expressed?	Common experiences included ad hoc and manual execution of the framework's functions, reactive management to maintenance task performance, and lack of enterprise consensus on how to perform R&M analysis on maintenance programs.
	Did the collective interaction generate new insights or precipitate an exchange of information among participants?	Yes. The participants better understood the proposed framework and began to discuss how the KC-46A SPO, AFLCMC/EZP, Booze Allen Hamilton, and GTRI would implement it.
Who?	Whose interests were being represented in the group?	Due to limited attendance, only AFLCMC/EZP and Booze Allen Hamilton interests we're being represented. Given the close working relationship with the KC-46A SPO, the participants voiced the SPO's interests as well.
	Were alliances formed among group members?	Yes. Alliances between AFLCMC/EZP and Booze Allen Hamilton formed in agreeing that the KC-46A SPO needed to lead the implementation of this framework for the KC-46A.
	Was a particular member or viewpoint silenced?	The KC-46A SPO CASS office was not present and did not challenge AFLCMC/EZP on the framework being specific to the KC-46A. In a follow-on conversation with the KC-46A SPO, the representative indicated that this type of framework should be standardized across R&M management for every weapon system AFLCMC/EZP supports and is thus their responsibility to implement it.
How?	How closely did the group adhere to the issues presented for discussion?	The group moderately adhered to the issues for discussion and was able to discuss each issue at varying lengths.
	How did group members respond to the ideas of others?	Participants positively responded to each other to constructively build the conversation.
	How did the group resolve disagreements?	Disagreements we resolved by identifying follow-on actions to answer questions and determine next steps.
	How were non-verbal signs and behaviors used to contribute to the discussion?	Body language was used to facilitate transitions between discussion issues and indicate consensus/disagreement with other's statements.

LIST OF ABBREVIATIONS

AC	Advisory Circular
AFB	Air Force Base
AFI	Air Force Instruction
AFLCMC	Air Force Life Cycle Management Center
AFMC	Air Force Material Command
AFSC	Air Force Sustainment Center
AMC	Air Mobility Command
ASAF	Assistant Secretary of the Air Force
ASAF/AQ	Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics
ATC	Airworthiness Type Certification
ATO	Authority to Operate
AWS	Amazon Web Services
CAMP	Continued Airworthiness Maintenance Program
CASS	Continuing Analysis and Surveillance System
CAT	Compliance Assurance Tool
CBM	Condition Based Maintenance
CDA	Commercial Derivative Aircraft
CMPD	Customized Maintenance Planning Document
CRB	Continuing Analysis and Surveillance System Review Board
CSAF	Chief of Staff of the Air Force
DIV	Data and Information View
DLA	Defense Logistics Agency
DSS	Decision Support System
ER	Extended Range
ESE	Enterprise Systems Engineering
ETIMS	Enhanced Technical Management Information Management System
EZP	Product Support Engineering Division
FAA	Federal Aviation Administration
FEC	Failure Effects Category
FMC	Full Mission Capable
GAO	Government Accountability Office
GTRI	Georgia Tech Research Institute
HAF	Headquarters Air Force
HM	How Malfunction
HOF	Health of the Fleet
IEEE	Institute of Electrical and Electronics Engineers
IOC	Initial Operational Capability
ISC	Industry Steering Committee
JCN	Job Control Number
JCS	Joint Chiefs of Staff
K-MEDE	KC-46A Maintenance Effectiveness Decision Engine

MBSE	Model Based Systems Engineering
MC	Mission Capable
MIS	Maintenance Information System
MPD	Maintenance Planning Document
MRB	Maintenance Review Board
MSG-3	Maintenance Steering Group Third Edition
MTC	Military Type Certification
NDS	National Defense Strategy
NMC	Non-mission Capable
OEM	Original Equipment Manufacturer
OO	Object-Oriented
OV	Operational View
PACAF	Pacific Air Forces
PFMT	Pegasus Fleet Management Tool
PMP	Project Management Plan
RAM-C	Reliability, Availability, Maintainability, and Cost
RAMS	Reliability and Maintainability Symposium
ROI	Return on Investment
SASMO	Statistical Analysis for Maintenance Optimization
SEMP	Systems Engineering Master Plan
SME	Subject Matter Expert
SPO	System Program Office
STC	Supplemental Type Certification
TO	Technical Order
USAF	United States Air Force
USAFE	United States Air Forces in Europe – Air Forces Africa
WUC	Work Unit Code